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| **Project title:** | Improving integrated pest management in soft fruit crops. |
| **Project number:** | SF 174 |
| **Project leader:** | Michelle Fountain, NIAB EMR |
| **Report:** | Annual report, March 2022 |
| **Previous report:** | NA |
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| **Location of project:** | NIAB EMR, growers' holdings |
| **Industry Representative:** | **Chairman:** Stephen McGuffie<br>**Industry representatives:** Andrey Ivanov, Steve Greenaway, Cristian Marmandiu, Richard Harnden |
| **Date project commenced:** | 01 April 2020 |

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## GROWER SUMMARY

The UK soft fruit industry is experiencing a period of change which offers opportunities for new and novel pest control options. Brexit, coupled with uncertain pesticide approvals, losses of actives (and associated insecticide resistance), emerging and invasive pests, and climate change offer the industry an opportunity to explore and exploit non-pesticide control methods. These will span cultural to bio-control products for integration into pest management strategies for long lasting control, building up resilience through conservation biology and augmented applications of natural enemies.

Our project covers a range of strategies targeted at key pests identified by AHDB soft fruit panel including capsids, thrips, early-season aphids and midges. We offer testing and integrating of solutions that are often applicable across the range of soft fruit crops, including cane fruits, strawberries and blueberries and consider control measures being applied for spotted wing drosophila (SWD).

In the first three years of this project we will: 1) research and report new and emerging pests which pose a future threat to UK soft fruit production informing the industry ahead of potential pest outbreaks, allowing better preparation for prevention and control options; 2) test the efficacy of the repellent successfully used in strawberry to control capsid in cane fruit and optimise the dispensing method for the repellent compound; 3) investigate the ability of Orius to predate the capsid juvenile stages for use under warmer, summer, temperatures; 4) determine whether early season aphids can be kept in check with a novel biocontrol strategy utilising mass releases of hoverflies with semiochemical attractants for retention in the crop; 5) determine winter survival of parasitoids in aphids in strawberry crops and how insecticide use in the autumn and spring can be adjusted to protect these key natural enemies; 6) gain scientific data on efficacy of floral margins on soft fruit crop protection and potential to harbour pest species to inform growers on sowings; 7) pilot test a ‘push-pull’ method to prevent non-western flower thrips entering strawberry crops and causing fruit damage; 8) develop a culturing method for thrips so that cost effective experiments can be done to understand the biology, damage and control strategies for future use and, finally; 9) field test a semiochemical push pull strategy of control of midges in cane fruit.

## WP1. Identify and report new and emerging pests which pose a future threat to UK soft fruit production (Year 1-2, Lead; NIAB EMR, Contributors; ADAS, JHI, NRI)

### Headline

- A range of future potential pest threats to the soft fruit industry have been identified.

### Background

Whilst there continues to be successes in pest control strategies, changing climate (Sharma 2016; Taylor et al. 2018), the introduction of invasive pests into new territories (Early et al. 2016) and resistance to a declining selection of Plant Protection Products (PPPs) (Lamichhane et al. 2016) raises new challenges for food production. It is estimated that arthropod pests destroy up to 20% of annual crop production worldwide, at a value of more than US$470 billion (Fried et al. 2017; Sharma et al. 2017). In the last decade, in the UK, growers of soft fruit crops have been required to shift from the use of broad-spectrum PPPs to fewer selective PPPs combined with biopesticides, augmented and conservation biocontrol, cultural practices and novel semiochemical manipulation of insect pest populations to reduce the incidence and damage caused by pests. However, the removal of some broad-spectrum PPPs in combination with a warmer and more unpredictable climate can result in higher populations and unpredictable outbreaks of familiar and native, and non-native species (Hulme 2016). Increased movement of plant material around the globe (Chapman et al. 2017) also leaves UK fruit production vulnerable to new pests, which often thrive in the extended season and warmer temperatures created by protected cropping. Hence, new monitoring tools for both arthropod pests and their natural enemies are needed in combination with new, less environmentally damaging approaches that can be integrated, but not at the detriment of other pest outbreaks. The reduced range of PPPs inevitably results in the same products being applied to crops sequentially, hence other control measures are needed which can be interspersed with remaining conventional PPPs, but which have different modes of action to reduce the occurrence of resistance to remaining products.

In 2020 the SF 174 team attended national and international meetings to report back potential new and invasive pests of soft fruit crops. This has been summarised in the tables, and selected references and web links). There has been liaison with AHDB, Fera, Animal and Plant Health Agency, RHS, and EPPO and CABI databases have been searched to identify and alert growers and agronomists to potential new pest problems.

Future potential pest threats to the UK soft fruit industry are summarised in tables in the report, including their, Species / Common name, Geographic distribution, Hosts / Crops, Symptoms, Description, Control used in other parts of world, Monitoring, and potential Risk for soft fruit.

Threats include two species of thrips; Japanese flower thrips, and flower thrips, a true bug; Brown Marmorated Stink Bug, a whitefly; honeysuckle whitefly, a scale insect; white peach scale, two beetles; Japanese flower beetle, whitefringed weevil and several tortix moths; strawberry tortrix, Blastobasis, lesser apple leaf-folder, *Acleris nishidai*, *Acleris fimbriana*, yellow tortrix moth and snowy-shouldered acleris moth. In addition, a spider mite threatens to cause damage in glasshouse crops; *Tetranychus mexicanus*. Details of useful literature including links to keys are also included. Another beetle species has been raised as a potential concern, but little information has been found on this to date (*Anthonomus bisnignifer*).

## Summary

In 2021 we also met with Wageningen scientists to discuss progress with Brown Marmorated Stink Bug and attended various on-line conferences where we were made aware of additional potential future pest threats to the soft fruit industry. Summary tables in the main report (see page 23 onwards) were updated with the latest scientific information and another beetle species has been raised as a potential concern, but little information has been found on this to date (*Anthonomus bisnignifer*).

Concern was raised on pests of hedgerows/ windbreaks in the UK. Alder leaf beetle which causes defoliation of *Alnus incana* & *A. glutinosa* windbreaks and has also been seen on *Populus* TX 32 windbreaks surrounding soft fruit & vegetable crops at site near Worthing. Other hedgerow pests of note include woolly beech aphid (*Phyllaphis fagi*), scale insects such as Euonymus scale (*Unaspis euonymi*), beech scale or felted beech coccus (*Cryptococcus fagi*), vine weevil (*Otiorhynchus sulcatus*), winter moth caterpillars and beech red spider mite (*Eotetranychus fagi*).

## Financial Benefits

Native and non-native pests are increasing due to increased transport of goods globally and fewer approved broad spectrum products. These are likely to have financial impact on fruit growers.

## Action Points

- Growers and their agronomists should be vigilant to new pests in the UK
- All imported plant material should be isolated and rigorously checked before planting

- Non-native species should be reported to plant health https://www.gov.uk/government/organisations/animal-and-plant-health-agency/about/access-and-opening
- Note that information in this report was correct at the time of writing (May 2022). All control options should be checked with a BASIS qualified adviser.

 

## Task 2.2. Dose and method of deployment of capsid repellent in strawberry and cane fruit (Year 1-2, Lead; NIAB EMR, Contributors; NRI, Russell IPM)

### Headline

A product developed in this project has been commercialised by Russell IPM to repel capsids from crops.

### Background

In previous work under SF156, successful control of European tarnished plant bug, *Lygus rugulipennis,* was achieved in strawberry in two years of replicated field trials using a push-pull approach based on synthetic semiochemicals (Fountain et al. 2021).

The repellent “push” component, hexyl butyrate (HB), is a component of the sex pheromone of several *Lygus* species. To date, monitoring crops containing the HB repellent has not revealed any adverse effects on natural enemies.

Various blends of hexyl butyrate were formulated in blister packs by Russell IPM and their release rates and longevity evaluated in the laboratory at NRI. A blister-pack formulation of hexyl butyrate was selected having similar release rate to the NRI polyethylene sachets used in all previous trials. However, the lifetime of these formulations was less than two weeks at 27°C and 8 km/h windspeed. Russell IPM polyethylene sachet formulations based on their commercial “Dismate” formulations were evaluated, and a thick-wall formulation was developed with satisfactory release rate and lifetime of over five weeks under laboratory conditions. Formulations of HB were optimised through laboratory release rate measurements with the aim of developing a suitable formulation(s) for evaluation in field trials during 2021. Results produced two HB dispensers both providing a convenient formulation of HB; 1) a blister pack (Russell IPM) and 2) a “thick-wall” polyethylene sachet (Russell IPM).

The aim of the field trial in 2021 was to test increasing the spacing of the HB dispensers in the crop from the standard 2 m spacing, to further reduce cost whilst maintaining control of capsids by deterring them from crops.

### Summary

The trial was carried out by NIAB East Malling on commercial strawberry crops at five locations in Kent. Previous HB dispenser spacings (2 m) were compared to lower densities

(5 m and 20 m). Russell IPM blister packs were used during the first two weeks and the polyethylene sachets during the next four weeks.

Numbers of both capsid nymphs and adults were lower in the treatment plots overall compared to numbers in untreated plots. However, capsids were less abundant than in previous years and there were no significant treatment effects. Damage was also low with no significant treatment effects. There were no detectable effects of the treatments on numbers of beneficials in the plots and the formulations showed no phytotoxic effects, so this approach is compatible with IPM strategies.

## Financial Benefits

A commercial formulation of the capsid repellent has been developed that lasts for at least five weeks compared with the two weeks of previous formulations. Increasing the spacing of the dispensers from 2m to 5m or 20m would decrease cost by 6-fold and 100-fold respectively.

## Action Points

- Growers are encouraged to trial the commercial product on crops where capsids are known to cause damage.

## Task 2.3. Ability of *Orius* to predate the capsid, *Lygus rugulipennis* juvenile stages (Year 1, Lead; NIAB EMR)

### Headline

- Growers have reported fewer *Lygus rugulipennis* where *Orius laevigatus* have been introduced to control other pests.
- Laboratory based experiments were established to investigate *Orius* predation on *L. rugulipennis* juvenile stages.
- EthoVision tracking software was also used to monitor *Orius* behaviour in the presence of *L. rugulipennis* eggs.
- Significantly fewer *Lygus* nymphs emerged from eggs when *Orius* was present.
- Significantly higher probability of death occurred in *Lygus* nymphs when *Orius* was present.

### Background and expected deliverables

Capsids, such as the European Tarnished Plant Bug (*Lygus rugulipennis* Poppius), cause direct crop damage by feeding on developing fruits (Easterbrook, 2000). This results in deformation known as 'cat-facing', making the fruit unmarketable. Chemical Plant Protection Products (cPPP) are typically relied on to supress capsid populations. However, conventional use of broad-spectrum insecticides for capsid control may disrupt biological-based Integrated Pest Management strategies used for other major soft fruit pests, such as Western Flower Thrips (WFT - *Frankliniella occidentalis*) (Powell, 2019).

Anecdotal information from growers indicates that the presence of *Orius laevigatus* (Say), used to control WFT in the summer months, may also reduce capsid numbers. This was supported by data collected in project SF 174 in which fewer *L. rugulipennis* were found in tap samples where *Orius* were also collected.

The purpose of this trial was to investigate the possible role of *Orius* in *Lygus* predation in soft fruit crops, and specifically to determine the ability of *Orius* to predate the juvenile stages of *Lygus* in the laboratory.

### Summary of the project and main conclusions

Laboratory based bioassays were performed to assess the impact *Orius* adults and nymphs had on juvenile *Lygus* stages. Wild caught *Lygus* adults were used to establish breeding cultures for use in the experiments. Green beans containing *Lygus* eggs were offered to *Orius* for several days and the number of nymphs that emerged were counted. *Orius* behaviour was

also observed using an insect-tracking software in the presence of *Lygus* exposed green beans (containing *Lygus* eggs) compared to untreated green beans. The amount of time spent in the vicinity of the 2 bean treatments was recorded. Nymph predation assessments were conducted over 24- and 72-hours in which different *Lygus* nymph instars were exposed to *Orius* and mortality was compared to untreated controls.

There was a reduction in emergence of *Lygus* nymphs from eggs that had been exposed to *Orius* although this was not significant. From the EthoVision insect-tracking software, *Orius* spent more time in the vicinity of green beans that contained *Lygus* eggs than those that did not. There was a significantly higher probability of *Lygus* nymph death at both 24- and 72-hours of exposure to *Orius* regardless of *Lygus* instar in comparison to the control. For both 24- and 72-hour exposures there was a 17 and 18% probability of death in the *Orius* treatments (regardless of *Lygus* instar and *Orius* stage) compared to <0.01 and 0.02% in the controls respectively.

## Action points for growers

- *Orius* may be contributing to *Lygus* control in the field.
- Predation is low, resulting in ~17 probability of death within 24- and 72-hours of exposure.
- *Orius* predation may contribute to *Lygus* control but will not solely supress *Lygus* populations.

## Task 3.1. Promoting the control of early aphid in strawberry by augmenting and retaining aphidophagous hoverflies in the crop (Year 1/2, Lead; NIAB EMR, Contributors; NRI, Russell IPM, Koppert UK

### Headline

Results of this trial were inconclusive and methods for assessing the impact of hoverflies on aphids in commercial strawberry have been revised

### Background

Early season control of aphids in strawberry (particularly potato aphid, *Macrosiphum euphorbiae*) has become difficult to achieve in recent years partly due to a reduction in conventional options and a need for suitable alternatives.

Hoverflies (Family: Syrphidae) are important predators of aphids. Adults have a high fecundity and larvae are voracious predators. However, naturally occurring hoverflies often only migrate into crops as pest populations increase, and thus too late in the season to prevent damaging populations of the pest from occurring.

Herbivore-induced plant volatiles (HIPVs), such as methyl salicylate can be formulated into commercially available lures and have been shown to attract beneficial insects, including hoverflies, into crops. Moreover, the addition of other HIPV's, has been shown to increase hoverfly numbers, demonstrating there is considerable potential to improve the attractiveness of commercially available lures using readily available chemicals, with the added benefit that such lures do not require regulatory approval. Added to this, at least three companies have been successful in mass producing hoverflies for release in commercial crops.

During 2021, a field trial was done in polytunnel grown June bearer strawberry, to test whether deployments of aphidophagous hoverflies could reduce populations of aphids (*M. euphorbiae*) early in the spring and whether this interaction could be enhanced using 2 types of hoverfly attractant to retain aphidophagous hoverflies in the crops.

### Summary

The trial was set up mid-April 2021 (after the aphid clean-up spray) in 4 replicate strawberry crops in Kent and ended early-June. Strawberries were June bearer varieties grown conventionally on tabletops in polytunnels. Each replicate crop was divided into 4 plots; 1) control (untreated), 2) hoverfly release only, 3) hoverfly release plus MagiPal™ lure, 4) hoverfly release plus NRI modified lure. Plots were mostly in the centre of separate strawberry fields to avoid hoverfly migration out of plots.

Seven days after hoverflies (*Epiphyas balteatus*), in kind contribution of Jasper Hubert at Koppert UK Ltd) were deployed in treated plots, sentinel strawberry plants infested with equal numbers of *M. euphorbiae* aphids*,* were deployed in all plots to attract hoverfly egg laying and compare subsequent aphidophagy between treatments. After a sufficient time in the field these plants were returned to NIAB EMR and aphid and hoverfly life stages counted during 3 weeks incubation.

Trial findings were inconclusive as to whether releases of aphidophagous hoverfly can reduce *M. euphorbiae* early in the season. Therefore, we also cannot conclude whether the 2 types of hoverfly lure tested enhance aphidophagy in strawberry early in the season. Numbers of hoverfly and aphid counted on sentinel plants after field deployment were highly variable. This is possibly because plants were positioned on the ground (to be away from the crop), where other predators (e.g. Carabidae) may have reduced aphid numbers on plants.

However, there was some evidence to suggest that hoverfly activity was positively correlated to aphid abundance, as described by Hodgkiss et al. (2019). This was observed within the plot where highest numbers of *M. euphorbiae* were observed in the crop.

Most other arthropods recorded on sentinel plants were parasitoids (indicated by mummified aphid and adult parasitoids), but we found no clear treatment effect, due to numbers being low and variable between plots.

In year 2, two field trials are planned for spring; 1) Trial 1 will investigate which attractant blends are most attractive to natural aphidophagous hoverflies and other natural enemies in strawberry crops, 2) Trial 2 will investigate if a commercially available attractant (MagiPal™) can retain commercially produced hoverflies and attract natural aphidophagous hoverflies and other natural enemies into strawberry crops.

## Financial Benefits

None currently

## Action Points

None currently.

 

## Tasks 3.4. Parasitoids for aphid control in overwintered protected strawberry

### Headline

A trial has begun to examine the overwintering ability of parasitoids in aphid in commercial strawberry crops

### Background

Early season control of aphids in strawberry (particularly potato aphid, *Macrosiphum euphorbiae*) has become difficult to achieve in recent years. Unfortunately, potato aphid populations can persist in over-wintered crops, surviving at temperatures below freezing and continuing to grow and develop very slowly when the temperature exceeds just 1°C. With the first warmer days of spring, the aphids start to grow and reproduce much more rapidly, leading to early outbreaks and damage. The withdrawal of chlorpyrifos and thiacloprid leaves soft fruit growers with fewer conventional options for early season aphid control, especially when temperatures are too low for biopesticide efficacy. In addition, aphid colonies can be difficult to target with contact-acting PPPs in strawberry, early in the season, because they are often out of spray range in the crown of strawberry plants.

With limited insecticide options now available, growers are increasingly relying on releases of parasitoid wasps in early spring for aphid biocontrol. Two parasitoid species (*Aphidius ervi* and *Praon volucre*) can be particularly effective at parasitizing potato aphid. Both species are present in the mixed parasitoid products available to growers for aphid control on soft fruit (e.g., FresaProtect from Viridaxis, Aphiline Berry from Bioline), and *A. ervi* is also available separately from some biocontrol companies. However, there are three main possible areas of risk and uncertainty associated with release of parasitoids for early-season aphid control:

- Failure of parasitism due to low temperature
- Impact of insecticide residues on parasitism
- Failure of parasitism due to resistance

We aim to address some of these potential risks, so that growers can be better informed in releasing parasitoids appropriately (in terms of species and timing) for effective early season biocontrol of aphids. In addition, it was observed from work in SF 156 that some parasitoids may be surviving in aphids over the winter and ready to emerge the following spring giving a head-start to biological aphid control. However, it is difficult for growers to observe this hidden

biocontrol and PPP harmful to emerging parasitoids maybe applied risking early season aphid control.

## Summary

Three grower's sites in Kent and Scotland are being used. Strawberry tunnels have already been surveyed for aphid and parasitoid species. A total 80 leaf samples were taken per site. Aphids were brought back to the laboratory and incubated at 20-23°C for 3 weeks. The size of the colony, parasitoids and aphid predators were recorded for each sample. Assessment of parasitoid emergence from aphids was done at 7, 14 and 21 days of incubation. On each assessment, and for each sample, the following was recorded: i) vegetative material sampled; ii) number of parasitoids emerged; iii) number of mummies present; iv) number of other aphid predators.

In addition, aphids from sites 1, 2 and 3 were sampled and DNA extracted. Sequences from individuals collected at sites 1 and 2 matched sequences from *Aphis fabae* (black bean aphid). The sequence generated from site 3 aphid material matched *Chaetosiphon fragaefolli* (strawberry-aphid).

In 2022, there will be 2 sampling occasions between February and March before any parasitoid release. After these samplings at each farm a first release of a parasitoid mix product will be made at a rate of 0.25 parasitoids per plant, and aphids sampled on a number of occasions after for the prevenance of parasitoids.

In 2021, levels of parasitism were higher in August than September and were highest at Sites 1 and 3. Numbers of parasitoid emerging between sites were variable, probably due to management practices and number of aphids present. For example, discussion with the manager of site one at the beginning of sampling revealed no insecticides had been used up to the point of first sampling.

Work on this task continues in 2022.

## Financial Benefits

None currently

## Action Points

None currently.

 

## Task 3.5. Ability of floral margins to support natural enemies and pests in proximity to soft fruit crops (Year 1-2, Lead; NIAB EMR)

### Headline

Wildflower margins could be source of natural enemies and pollinators, however impacts into the crop are minimal and sowing wildflowers inside polytunnel crops should be the focus of future research.
Numbers of thrips in wildflowers in the margins were not significant and did not appear to migrate in significant numbers into the crop.

### Background and expected deliverables

Two literature reviews have been published, partly funded by the AHDB, on the impact of organic treatments and floral margins for pest and disease control in orchards (Shaw et al. 2021; Fountain 2022).

Several research studies have implemented floral margins which are thought to benefit strawberry crops, but with very little evidence of the species or phenology of natural enemies in the crop or which flora might be attractive to crop pests. The wildflower margins, that are part of the other projects, offer an ideal opportunity to monitor margins for beneficial and pest species of soft fruit crops including ladybirds, lacewings, and hoverflies, but also capsids, and thrips.

With a growing need for alternatives to plant protection products, the implementation of wildflower margins that support natural enemies is a potential contributing solution. Floral resources implemented near crops have been shown to be effective in increasing the abundance of pollinators and natural enemies (Fountain 2022). Crops themselves do not provide the diversity that most natural enemies need to establish a stable and growing population throughout the year (Ramsden et al. 2017). A properly managed floral resource could provide a food source for natural enemies in the form of alternative prey, pollen, and nectar, and as a shelter and overwintering habitat.

In 2019, a replicated experiment of floral margins was sown around the WET Centre at NIAB EMR to reduce runoff from polytunnel structures but provide secondary benefits of boosting natural enemies and pollinators in the vicinity of the tunnel (Holistic Water for Horticulture,

 

HWH). The data from the first year will be collated and funding from and Interreg-NSR, BEESPOKE project facilitated surveys of pollinating insects.

In this study, we aimed to;

1. Compare 3 floral treatments to an unsown control
2. Monitor the establishment and floral resource in the margins
3. Identify key natural enemies utilising floral margins
4. Identify pest species inhabiting specific flora
5. Monitor floral margins in commercial farms in the vicinity of soft fruit crops (2021) only

## Summary

*NIAB EMR WET Centre*

In the first year the replicated plots (unsown, sainfoin, chicory, perennial meadow mix (EM1)) established around the WET Centre (strawberry crop) at NIAB EMR in 2019 were surveyed for soft fruit natural enemies and pest species in May, June, July, and August. Records of vegetation cover were also made in July. Floral units were identified, and invertebrates extracted using the extraction device, developed in SF 156, and ethanol extraction to monitor for thrips species that may be attracted to floral margins. Thrips adults, relevant to strawberry production, were identified to species.

Floral margins

All sown plots established successfully. Single species plots had more than 90% coverage of the sown species, sainfoin and chicory. The EM1 meadow seed mix covered 72% of the plots with wild carrot and common knapweed being the better-established flowering species. Single species plots like sainfoin and chicory had shorter flowering periods than unsown and EM1 plots. Longer flowering periods provided a better food and habitat resource for natural enemies and pollinators. In 2021, single species plots had > 70% coverage of the sown species, sainfoin and chicory. EM1 seed mix species covered 99% of the plots with oxeye daisy and common knapweed dominating.

Arthropods in floral margins

There was a higher abundance of beneficial arthropods in the margins of the strawberry crop in May and June. Floral resources were also adequate in July, but some arthropod groups like beetles, ladybirds, and moths declined. This may be related to life cycle and/or dispersal away from the plots. The meadow mixture (EM1) had a higher floral resource in June. Arthropod group diversity was highest with approximately 1 specimen of each group recorded

 

per 1.5 $m^2$. Chicory plots had fewer arthropods when compared with all other treatments. In August unsown and EM1 plots were dominated by predatory spiders, and groundbugs thought to be from genus *Nysius* (not a soft fruit pest).

Herbivores in floral margins

Most arthropod herbivores or potential soft fruit pests found during this trial were capsids and aphids. No strawberry pest aphids were found in the floral resources. Aphids were only present in May and June and were particularly widespread in sainfoin plots. Capsid were thought to be breeding in sainfoin as higher numbers of nymphs were recorded in sainfoin in June. Most of the nymphs were common green capsid. Numbers of herbivores declined in July. No aphids or capsid nymphs were found in July and August. Three capsid species were identified using the floral margins: Common green capsid, European tarnished plant bug, and potato capsid. Common green capsid was found in high numbers in all treatments except in chicory. The meadow mix (EM1) was less attractive to capsids than the unsown treatment.

Thrips on flower heads

Unsown species like dandelion, bindweed, hawkbit, white clover, and yarrow had, on-average, greater numbers of thrips (2 per flower head) than sown species (Park et al. 2007). In June, yarrow contained on average 5.2 ±1.0 *Thrips tabaci* per flower, known to affect soft fruit crops. White clover had 5.1 ±4.1 *Frankliniella intonsa* per flower also found on strawberry crops. Other unsown plant species had fewer than 2 thrips per flower or had thrips species not found on soft fruit.

In sown plots chicory, sainfoin, oxeye daisy, common knapweed and wild carrot were the flowering species with more than 2 thrips per flower (Park et al. 2007) on at least at one sampling occasion. Wild carrot had higher numbers of *Thrips tabaci* per flower head in June and July (respectively, 6.7 ±2.3 and 4.4 ±1.4). Common knapweed attracted (2.0 ±0.3) *Frankliniella occidentalis* (WFT) a known pest of strawberry crops and 2.2 ±0.6 'other' thrips not found in soft fruit crops. Overall thrips numbers declined in August.

The extraction device from project SF 156 gave very good recovery of adult thrips (at least 90%) but was less efficient at extracting larval thrips (around 50%) from flower heads.

Beneficials on flower heads

Predatory thrips (*Aeolothrips*), parasitoids, ground beetles and *Orius* nymphs and adults were present in flower heads. No significant numbers were recorded on any plant species. There was a more diverse and abundant community of pollinators in May than September, probably a reflection of floral resource. Bumblebees were frequent visitors to sainfoin flowers, including

many wild species, but more research is needed to see if commercial bumblebees are distracted by wildflower margins. Some bumblebee species with long-tongues prefer flowers with longer corolla flowers (Plowright et al. 1997) than those typical of strawberry flowers.

*Commercial Farms*

In 2021, floral margins adjacent to 2 strawberry and 2 raspberry crops were monitored. Most herbivores or potential soft fruit pests were capsids and aphids. No strawberry pest aphids were found in the floral resources. Aphids were only present in the crop from July to September and in low numbers (average of < 0.2 aphids per plant). Capsid (mirids) were recorded in low numbers in the floral margins and were not analysed. No capsids of soft pests were identified.

Although the number of flowering species varied between sampling dates, thrips numbers and species in each flower type (species) were consistent. Overall numbers of adult thrips in the crop were low (< 1 thrips per 4 flowers). The flower margin species, with the highest numbers of WFT, was common knapweed, in August (16 thrips per 4 flowers). Numbers of onion thrips were higher in dandelion (16 per 4 flowers), in June and in yarrow (12.1 thrips per 4 flowers), in August. Rose thrips were more abundant in strawberry in June (23.9 per 4 flowers), and in sainfoin (17.3 per 4 flowers) in July. Thrips in floral margins did not appear to enter crops in significant numbers at up to 50 m into the crop.

Parasitoids, spiders and anthocorids were the most abundant beneficials in the floral margins and crops.

No significant differences in numbers of pollinator species were observed between the floral margins and distances up to 50 m into the crop. Bumblebees and honeybees were the most common pollinators recorded. However, numbers of bumblebees were higher in the floral margin, while honeybees are more abundant in the crop.

## Financial Benefits

None currently

## Action points

- Growers might consider implementing wildflower strips in and around soft fruit crops as part of their on-farm biodiversity deliverables.
- Supporting natural enemies and pollinators on farms will provide pollination and pest control resilience to crops.

 

- Once established wildflower margins may be able to help outcompete less desirable weeds and require minimum maintenance after the second year.

## WP 4 Control thrips species other than western flower thrips damaging to strawberry crops

### Headline

- Blue sticky traps baited with the thrips lures Lurem-TR or Thripnok placed just above the plants caught significantly more thrips than unbaited traps (2.8x and 1.3x respectively). Higher numbers of thrips were caught on the Lurem-TR traps than on the Thripnok traps (2.1x more).
- Blue sticky traps baited with the natural enemy attractant Magipal (also considered to be a pest repellent) did not catch fewer thrips than unbaited traps.
- Thrips species identified on the traps were a mix of *Thrips fuscipennis* (rose thrips), *Thrips major* (rubus thrips), *Thrips tabaci* (onion thrips) and *Frankliniella intonsa* (flower thrips).
- In two push-pull trials using Lurem-TR, on blue roller traps as the 'pull' and Magipal as the 'push', thrips numbers in flowers were too low to demonstrate a reduction in thrips numbers in flowers or thrips damage to fruit. Thrips adults in flowers were predominantly rose thrips, rubus thrips and onion thrips although numbers of flower thrips increased at one site at the final assessment.
- Very low numbers of thrips larvae were found in the flowers in both push-pull trials and were identified as *T. major* and *T. tabaci*.
- The proportion of *Thrips* species to *Frankliniella* species caught on the roller traps baited with Lurem-TR in both push-pull trials did not mirror that recorded in the flowers. Proportionally more *Frankliniella* species were caught on the roller traps than found in the flowers.

### Background and expected deliverables

Highly successful IPM programmes for management of western flower thrips (WFT*), Frankliniella occidentalis* on strawberry have been developed using knowledge of its biology

 

and behaviour. These programmes are based on the use of the predatory mites, *Neoseiulus cucumeris*, predatory bugs, *Orius laevigatus* and 'mass monitoring' with blue roller traps on some farms - with or without the WFT aggregation pheromone lure which can increase numbers of WFT caught. Strategies for controlling WFT on strawberry are not effective against several other species of thrips which fly in as adults and can damage fruit. The biology and behaviour of these species is not well understood. However increasing evidence is emerging to suggest that these other species now dominate in commercial strawberry crops where WFT are controlled using IPM.

In this study two trials were done. In the first trial, a push-pull strategy was evaluated for thrips control at two sites This strategy used Magipal as the 'push' and blue roller traps with Lurem-TR as the 'pull'. Magipal is currently marketed as an attractant for natural enemies but has also been found to be a general pest repellent. Lurem-TR is a non-pheromone lure containing methyl isonicotinate (MI), which has been found to increase catches of 12 different species of thrips, including WFT, the rubus thrips (*Thrips major*) and the onion thrips (*Thrips tabaci*). However, to date there is no published evidence demonstrating that Lurem-TR attracts two other species that infest strawberry: the rose thrips, *Thrips fuscipennis* and the flower thrips, *Frankliniella intonsa*.

In the second trial, the effect of both Magipal and Lurem-TR on catches of thrips and beneficials on blue sticky traps was evaluated. A third semiochemical, Thripnok which is reported by the supplier to be an effective lure for WFT and onion thrips, was also evaluated in this trial.

The objectives of these trials were to test whether:

1. Thrips numbers per flower and fruit damage are reduced by using MagiPal (push) combined with Lurem-TR and blue roller traps (pull) compared to in control plots.
2. The roller traps used in the push-pull strategy have a negative impact on beneficials in the crop.
3. The addition of Lurem-TR, Magipal or a new kairomone lure (Thripnok) to blue monitoring traps has a significant impact on the catches of thrips and beneficials.

## Summary of project and main conclusions

*Push-pull trial*

As in previous work in this project and in SF 156, several species of thrips adults invaded everbearer strawberry crops. Species composition is likely to vary with site, season and weather but unless WFT is present, there seems to be very little breeding in the flowers.

 

Thrips adult and larvae numbers per flower across both sites was low, with fewer than a mean of one thrips adult per flower across all assessments. At both sites, push-pull treatment did not result in any significant differences in the mean number of either *Thrips* spp. or *Frankliniella* spp. per flower. At both sites, *Thrips fuscipennis* and *Thrips major* were the most prevalent species in flowers. *Thrips minutissimus* was dominant on the first assessment date at site 1 but owing to the small sample size this result might be spurious. This species was found only on the first assessment date at site 1 and not at site 2.

At the final assessment, at Site 2, a markedly different thrips species mix was seen in the flowers, with *Thrips tabaci* and *Frankliniella intonsa* dominating. Only a single individual of *Frankliniella occidentalis* (WFT) was identified across both sites throughout the trials, demonstrating the continuing efficacy of WFT control within IPM. Very low numbers of larvae were recorded in the flowers, and were more numerous at site 2, where they were identified as *Thrips major* and *Thrips tabaci.*

At Site 1, fruit bronzing incidence and percentage area was minimal, with well below a mean of 1% fruit area damaged. At Site 2, fruit bronzing incidence and percentage area was notably higher, significantly increasing on the last two assessments relative to earlier assessments, reaching almost a mean of 5% fruit area damaged. No significant differences were seen in fruit bronzing incidence or percentage damage between untreated and push-pull treated blocks at either site.

The proportion of *Thrips* spp. to *Frankliniella* spp. was 3:2 on roller traps at site 1 and approximately 1:1 at site 2 on all assessment dates. However, this was not reflected in the proportions of thrips species found in the flowers. At site 1, *Frankliniella* species were absent in flowers except for very low numbers on the first assessment date. At site 2, most thrips found in flowers were *Thrips* species until the final assessment date when the proportion of *Thrips* spp. to *Frankliniella* spp. was approximately 1:1, with all the *Frankliniella* spp. identified being *F. intonsa*. These results indicated that the proportions of thrips species on roller traps baited with Lurem-TR under the table tops are not necessarily the same as those in the flowers; the roller traps may catch relatively more *Frankliniella* spp.

Numbers of bees and other beneficials on the roller traps were very low.

*Semiochemical trial*

Traps with either a Lurem-TR or Thripnok lure caught significantly more (2.8x and 1.3x respectively) adult pest thrips (*Thrips* spp. females, *Frankliniella* spp. females and males) than untreated traps. Traps with a Lurem-TR lure caught significantly more (2.1x) adult pest thrips (*Thrips* spp. females, *Frankliniella* spp. females and males) than traps with a Thripnok

 

lure. Lurem-TR significantly increased trap catch of both *Thrips* spp. and *Frankliniella* spp. relative to untreated traps and traps combined with a Thripnok or Magipal lure. Thripnok increased mean numbers of *Frankliniella* spp. adults per trap compared to untreated traps, but was significantly outperformed by Lurem-TR. Thripnok did not increase mean numbers of *Thrips* spp. per trap. Magipal did not affect mean numbers of thrips adults per trap compared with those on the untreated control traps.

Of the thrips females identified to species, all the *Frankliniella* spp. on the traps in the semiochemical trial were *F. intonsa* (flower thrips) and the *Thrips* spp. were a mix of *T. fuscipennis* (rose thrips), *T. major* (rubus thrips), and *T. tabaci* (onion thrips).

Thripnok resulted in a significantly increased catch of bees (4x as many as on untreated traps), however 'dry glue' traps were used in the semiochemical trial which are known to catch more bees than the 'wet glue' used on roller traps. Lurem-TR and Magipal also increased mean numbers of bees caught on traps (2x as many as on untreated traps) however significantly less so than Thripnok.

None of the semiochemicals affected the number of predatory thrips, *Aeolothrips* spp. on the traps.

## Action points

- Be aware that several species of thrips adults can invade everbearer strawberry crops. Species composition is likely to vary with site, season and weather but unless WFT is present, there are few species breeding in strawberry flowers.
- Make regular preventive releases of *Neoseiulus cucumeris* and supplement these with releases of *Orius laevigatus* when temperatures are high enough. *Neoseiulus cucumeris* can give good control of young WFT larvae and is also known to feed on *T. tabaci* larvae. *Orius laevigatus* is likely to feed on both adults and larvae of all pest thrips species.
- Consider using Lurem-TR together with blue sticky traps for monitoring thrips as this may improve detection of both *Thrips* spp. and *Frankliniella* spp.
- Continue to monitor thrips numbers in flowers as well as on traps.
- Most thrips species found in strawberry flowers (except for predatory thrips) can cause fruit damage. However, if species identification is needed e.g. to assist choice of plant protection product if required, contact an entomologist.

## Objective 6. To investigate the efficacy of a pheromone-based push-pull strategy for control of first-generation raspberry cane midge and blackberry leaf midge in raspberry. (ADAS and NIAB EMR)

### Headline

Trials in Kent and Norfolk did not demonstrate a significant impact of pheromone push-pull strategies on raspberry cane midge.

However, there was a significant reduction in blackberry leaf midge damage to raspberry leaves and shoots in in the Kent trial and this warrants further investigation.

### Background and expected deliverables

The raspberry cane midge *Resseliella theobaldi* (RCM) and blackberry leaf midge D*asineura plicatrix* (BLM) are major pests in UK raspberry production. With the loss of thiacloprid and the importance of biological control for mites in raspberry production, novel IPM strategies are required for control of these pests. Semiochemicals have been successfully used in IPM programmes to improve control of other pest species in other crops. MagiPal™ sachets containing methyl salicylate, a signal molecule for systemic acquired resistance (SAR) in plants, have been used in combination with pheromone lures imbedded in roller traps. In an initial push-pull trial against the blueberry gall midge *Dasineura oxycoccana* in blueberry promising results have been obtained. This objective aims to test the efficacy of this push-pull strategy against RCM and BLM in commercial raspberry which would be compatible with IPM for other pests.

### Summary

Two trial sites were established one in Kent and one in Norfolk in early spring 2021. The push (MagiPal sachets) and pull (white roller sticky traps) were deployed prior to midge detection in commercial raspberry crops. Monitoring traps were deployed to evaluate the variation in trap catches between untreated control and push-pull treated plots. Midge damage was assessed on leaves and shoots from BLM and the number of eggs and larvae of RCM present in artificially made cane splits. In Kent, significantly higher numbers of midges were caught in the control plots compared with the push-pull treated plots for both BLM and RCM. There was a significant reduction in BLM damage to leaves and shoots in two of the three assessments

 

in the push-pull treated plots. There were significantly more RCM eggs found in green spawn growth than in woody growth in push-pull treated plots for the first assessment. There was no overall difference in the numbers of RCM eggs and larvae between push-pull treated and control plots within artificial cane splits.

In Norfolk there was no significant difference in the monitoring trap catches of BLM, however significantly more RCM midges caught in the monitoring traps in the control plots compared with the push-pull treated plots on 24 May 2021. There was no significant difference in BLM damage to shoots or leaves between the control and treated plots. This could be because the BLM population was too low to be significantly affected. There were significantly more RCM larvae found in push-pull treated plots compared with control plots on the second assessment (24 May 2021), however larval numbers were very low. No RCM larvae were found on the first and third assessments and there was no significant difference between treatments on the fourth assessment.

## Action points for growers

- Growers should continue to remove green spawn from the crop to reduce availability of preferred egg laying sites for RCM.
- Growers should continue to monitor midge emergence with pheromone lures and monitoring traps. Traps should be checked at least twice a week so that control measures can be applied at the correct time.
- Growers may want to trial the push-pull technique against BLM on their local populations.

# SCIENCE SECTION

## WP1. Identify and report new and emerging pests which pose a future threat to UK soft fruit production (Year 1-2, Lead; NIAB EMR, Contributors; ADAS, JHI, NRI)

### Introduction

Whilst there continues to be successes in pest control strategies, changing climate (Sharma 2016; Taylor et al. 2018), the introduction of invasive pests into new territories (Early et al. 2016) and resistance to a declining selection of Plant Protection Products (PPPs) (Lamichhane et al. 2016) raises new challenges for food production. It is estimated that arthropod pests destroy up to 20% of annual crop production worldwide, at a value of more than US$470 billion (Fried et al. 2017; Sharma et al. 2017). In the last decade, in the UK, growers of soft fruit crops have been required to shift from the use of broad-spectrum PPPs to fewer selective PPPs combined with biopesticides, augmented and conservation biocontrol, cultural practices and novel semiochemical manipulation of insect pest populations to reduce the incidence and damage caused by pests. However, the removal of some broad-spectrum PPPs in combination with a warmer and more unpredictable climate can result in higher populations and unpredictable outbreaks of familiar and native, and non-native species (Hulme 2016). Increased movement of plant material around the globe (Chapman et al. 2017) also leaves UK fruit production vulnerable to new pests, which often thrive in the extended season and warmer temperatures created by protected cropping. Hence, new monitoring tools for both arthropod pests and their natural enemies are needed in combination with new, less environmentally damaging approaches that can be integrated, but not at the detriment of other pest outbreaks. The reduced range of PPPs inevitably results in the same products being applied to crops sequentially, hence other control measures are needed which can be interspersed with remaining conventional PPPs, but which have different modes of action to reduce the occurrence of resistance to remaining products.

### Materials and methods

The SF 174 team attended national and international meetings to report back potential new and invasive pests of soft fruit crops. This has been summarised in the tables below with selected references and web links). There has been liaison with AHDB, Fera, Animal and Plant Health Agency (APHA, Rachel Barker; Plant Health Risk Register (PHRR) status of pests in new UK legislation: https://www.legislation.gov.uk/uksi/2020/1527/made/data.pdf) (including a meeting with Rachel Yale), RHS (Andrew Salisbury), and EPPO and CABI databases have been searched to identify and alert growers and agronomists to potential

new pest problems. In 2021 we also met with Wageningen scientists to discuss progress with Brown Marmorated Stink Bug.

## Results

Future potential pest threats to the UK soft fruit industry are summarised in the tables below, including their, Species / Common name, Geographic distribution, Hosts / Crops, Symptoms, Description, Control used in other parts of world, Monitoring, and potential Risk for soft fruit.

Species included in the 2020 report were;

1. two species of thrips; Japanese flower thrips, and flower thrips,
2. a true bug; Brown Marmorated Stink Bug,
3. a whitefly; honeysuckle whitefly,
4. three scale insects; white peach scale, Indian wax scale, and tortoise wax scale,
5. five beetles; Japanese flower beetle, whitefringed weevil, citrus longhorn beetle, tortoise beetle, peach red necked longhorn,
6. several tortix moths; strawberry tortrix, *Blastobasis*, lesser apple leaf-folder, *Acleris nishidai, Acleris fimbriana,* yellow tortrix moth and snowy-shouldered acleris moth, and
7. a spider mite

The spider mite threatens to cause damage in glasshouse crops; *Tetranychus mexicanus*. Details of useful literature including links to keys are also included.

In 2022, another beetle species has been raised as a potential concern, but little information has been found on this to date (*Anthonomus bisnignifer*).

Concern was raised on pests of hedgerows/ windbreaks in the UK. Alder leaf beetle which causes defoliation of *Alnus incana* & *A. glutinosa* windbreaks and has also been seen on *Populus* TX 32 windbreaks surrounding soft fruit & vegetable crops at site near Worthing. Other hedgerow pests of note include woolly beech aphid (*Phyllaphis fagi*), scale insects such as Euonymus scale (*Unaspis euonymi*), beech scale or felted beech coccus (*Cryptococcus fagi*), vine weevil (*Otiorhynchus sulcatus*), winter moth caterpillars and beech red spider mite (*Eotetranychus fagi*).

Note that information in this report was correct at the time of writing.

All control options should be checked with a BASIS qualified adviser.

 

## Thysanoptera – thrips

| Species / Common name | Geographic distribution | Hosts / Crops | Symptoms | Description | Control used in other parts of world | Monitoring | Risk for soft fruit |
|---|---|---|---|---|---|---|---|
| *Thrips setosus* / Japanese flower thrips | Native to eastern Asia, has recently been introduced into UK (2016, West Sussex), France (2014), Germany, and the Netherlands. In 2016, it was found at a single nursery in Michigan.<br><br>Presence in UK: present (limited) – PHRR, few occurrences (EPPO GD)<br><br>Spread through cut flower imports. | 14 plant families. Inc. vegetable and ornamental crops: tomato (transmits TSWV), pepper, eggplant, chrysanthemum, cucumber, hellebore, hosta, hydrangea, impatiens, petunia, poinsettia, soybean.<br><br>Currently causing issues in ornamentals on south coast of England (Bennison Pers. Comm) | Polyphagous thrips which can cause direct feeding damage to protected, ornamental and field crops, as well as vectoring Tomato spotted wilt virus.<br><br>Will feed on all above ground parts of plants.<br><br>Typical thrips damage: silvery streaks and spots.<br><br>Does not feed on pollen.<br><br>RR review concluded that damage is "not thought to be any more significant than those of other thrip species" | Adults: 1.3mm long<br><br>Females: basal quarter of wing pale otherwise dark brown body, obvious with a hand lens.<br><br>Males: yellow and must be identified by an expert. | Broad spectrum insecticides including chlorpyrifos.<br><br>May not respond well to biocontrol practices and be more abundant where biocontrol agents are the primary control method.<br><br>*N. cucumeris* does not seem to be effective in control (Bennison Pers. Comm)<br><br>Current thrips control measures should also be effective against this species. | Monitor for presence, particularly following findings in the Netherlands and elsewhere, including the UK's first finding in 2016.<br><br>Larvae and frass on underside of leaves.<br><br>Use of HortiPro - PheroThrip 2.0 pheromone attractant. | MEDIUM (14/08/2020)<br><br>Added to the EPPO Alert List in 2014 – Deleted in 2018<br><br>In UK, not yet reported on fruit crops.<br><br>Legislative status: not in GB legislation<br><br>PHRR information: Action: No statutory action against findings. |

IDENTIFICATION: https://keys.lucidcentral.org/keys/v3/british_thrips/the_key/key/britishthysanoptera_2017/Media/Html/thrips_setosus.htm

https://gd.eppo.int/taxon/THRISE

https://www.cabi.org/ISC/abstract/20183082689

https://www.oregon.gov/ODA/shared/Documents/Publications/IPPM/JapaneseFlowerThripsPestAlert.pdf

https://www.aphis.usda.gov/publications/plant_health/card-japanese-flower.pdf

https://secure.fera.defra.gov.uk/phiw/riskRegister/viewPestRisks.cfm?cslref=22136

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Improved signalling and monitoring of thrips with PheroThrip 2.0 https://www.hortidaily.com/article/9305732/improved-signaling-and-monitoring-of-thrips-with-pherothrip-2-0/

| Species / Common name | Geographic distribution | Hosts / Crops | Symptoms | Description | Control used in other parts of world | Monitoring | Risk for soft fruit |
|---|---|---|---|---|---|---|---|
| *Frankliniella intonsa* / Flower thrips or Taiwan flower thrips | Mostly a pest in China and Japan, much more than in the UK. Worldwide including UK. | Wide range of unrelated plant species, with little evidence of any specificity, including fruit | Leaves and flowers<br><br>Fruit/Inflorescence skin discoloration/ distortion. External feeding. Vector of TSWV, TCSV, GRSV | Body and legs variable, mainly brown with head and pronotum often paler than abdomen, tibiae, and tarsi largely | Natural enemies: Ceranisus menes (parasite), Misumenops tricuspidatus, Orius sauteri (predators) | | MEDIUM<br><br>In UK, not yet reported causing significant damage. Risk |

 

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|---|---|---|---|---|---|---|---|
| | Europe, Palearctic Asia (spreading to Taiwan, Northern Thailand, Bangladesch, Northern India and Pakistan)<br><br>Presence in UK: present (CABI) | trees and vegetable crops<br>Denmark: The most abundant thrips species found on commercial strawberry farms. | | yellow; antennal segments III–IV yellow with apices shaded; fore wing pale with setae dark. Very similar to WFT, but intonsa has considerably shorter postocular setae than WFT and lacks campaniform sensilla on the metanotum | *Rosmarinus officinialis* L. (Lamiaceae) is a promising repellent.<br>Elevated CO2 amplifies the efficacy of spinetoram. | | with warmer summers.<br><br>Not on PHRR.<br><br>Legislative status: not in GB legislation |

IDENTIFICATION: https://keys.lucidcentral.org/keys/v3/nz_thrips/the_key/key/New_Zealand_Thysanoptera/Media/Html/frankliniella_intonsa.htm

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## Hemiptera

| Species / Common name | Geographic distribution | Hosts / Crops | Symptoms | Description | Control used in other parts of world | Monitoring | Risk for soft fruit |
|---|---|---|---|---|---|---|---|
| *Halyomorpha halys / Brown marmorated stink bug* | Native to eastern Asia, including China, Taiwan, Korea, and Japan.<br><br>Expanding range in North America (first detected in 1996), in Europe (first detected 2004), UK in pheromone traps in 2020.<br><br>Brown marmorated stinkbug is a pest which is spreading in many parts of the world.<br><br>Rhodes, Greece (also includes parasitoids),<br><br>Croatia<br><br>Algeria, North Africa<br><br>Aegean Region of Turkey<br><br>Azov Sea coast of Russia | More than 100 plant species, primarily fruit trees, nuts, and woody ornamentals, but also field crops. Citrus, apple, mulberries, blueberry, apricot, sweet cherry, plum, pear, raspberry, grapevine.<br><br>Also, field crops and woodland trees.<br><br>Peach, Almond, Cranberry, Satsuma, okra, tangerine, Kiwifruit, Sweet corn, Field maple (Acer campestre L.), Green ash (Fraxinus pennsylvanica Marshall), London plane (Platanus × hispanica | Adults feed on fruit, nymphs feed on leaves, stems, and fruit.<br><br>Leaf feeding characterized by small lesions (3 mm diameter) which become necrotic and coalesce.<br><br>Fruit: small necrotic spots (corky spots) or blotches, grooves, and brownish discolorations to severely disfigured ('cat-facing') and unmarketable.<br><br>Nuisance to humans because of aggregation in buildings.<br><br>Induces a strong phenolic response in the injured area of the apple.<br><br>Increases capsaicinoid content | Eggs: elliptical (1.6 x 1.3 mm) light green-blue, in groups of 20-30.<br><br>Five nymphal inasterisks, 2.4-12 mm length, deep-red eyes, abdomen is red/orange with black markings in first instar with later stages mottled with dark brown and pale areas, pronotum and head armoured with spines.<br><br>Adults: 12-17 mm long, brown with lighter bands on antennae and darker bands on membranous, overlapping part at the rear of wings, patches of coppery or bluish | **Chemical control:** Triflumuron caused significantly higher mortality on BMSB nymphs.<br><br>Essential oils or their individual terpenic compounds.<br><br>Essential oils of Turmeric and clove.<br><br>Pyrethroid insecticides (e.g. deltamethrin and lambda-cyhalothrin).<br><br>Insect exclusion mesh.<br><br>Ghost nets – attract and kill.<br><br>Irradiation supports the potential for the use of SIT.<br><br>Plant Growth-Promoting Rhizobacteria induce systemic resistance in plants. | Hitchhiker on packing material or via plant imports or passenger luggage.<br><br>Eggs: underside of leaves.<br><br>Aggregation pheromone traps and tap sampling. Pyramid traps attracted significantly more BMSB than sticky panel traps.<br><br>Modelling by a zero-inflated negative binomial regression (ZINB) model<br><br>**France:** Citizen | MEDIUM<br><br>Detected active in UK in 2020 and 2021, not yet at high numbers.<br><br>Females detected in 2021 in UK.<br><br>PHRR information: No statutory action against findings. Management by industry.<br><br>Legislative status: not in GB legislation |

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| | | Münchhausen), Persian walnut (Juglans regia L.), Oregon grape (Berberis aquifolium Pursh),<br><br>**Insect culture:** A rearing system for BMSB on live cowpea plants, Vigna unguiculata | in the infested peppers which implies that capsaicincoid could have defence properties.<br><br>*Wine*: Molecules responsible for the off-flavours in contaminated musts volatilise during the fermentation process. Though contamination has potential to alter the quality of grape juices and musts, there is little risk for influencing the taste of processed wines. | metallic-coloured punctures on the head and pronotum, head more rectangular than likely confusion species.<br><br>In the forward flip BMSB creates a tripod of support using the hindlegs and the tip of the abdomen to elevate the anterior portion of the body<br><br>**Insect physiology:** low humidity decreasing first-instar survival high temperatures decreased BMSB reproduction.<br><br>Increasing photoperiods increased probability of higher rates of fecundity. | Native egg parasitoids and predators not very effective.<br><br>Samurai wasp, *Trissolcus japonicus,* and *T. mitsukurii* have potential as classical biological control agents; adventive populations of both species recently reported in Europe.<br><br>Slovienia: parasitoids-native species *Anastatus bifasciatus* and non-native *Trissolcus mitsukurii*.<br><br>**New Zealand:** Modelling the climatic niche of parasitoid T. mitsukurii to estimate its global potential distribution.<br><br>**Japan:** Japanese acrobat ants *Crematogaster matsumurai* and *C. osakensis* reduced the survival of early instar BMSB.<br><br>**France, Italy**: parasitoid *Trissolcus* | science to track BMSB expansion in France.<br><br>**New Zealand:** A ddRAD sequencing approach to track origins.<br><br>New Zealand: Genetic diversity using two mitochondrial genes, COI and COII<br><br>High-throughput sequencing of gut contents has potential for exploring the dietary histories.<br><br>Parasitoid monitoring and detection using COI. | |

 

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| | | | | Mutualism: BMSB facilitates feeding of European wasps and ants Hymenoptera: Vespidae, Formicidae) on plant exudates | *mitsukurii, Trissolcus japonicus.*<br><br>**Bulgaria:** Trapping in heated shelters.<br><br>**Georgia:** Parasitoids- five species of *Trissolcus* Ashmead | | |


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| Species / Common name | Geographic distribution | Hosts / Crops | Symptoms | Description | Control | Monitoring | Risk for soft fruit |
|---|---|---|---|---|---|---|---|
| *Aleyrodes lonicera*/ honeysuckle whitefly | Native and widespread species in the U.K.<br>Found throughout Europe and east into Russia; Israel, Turkey, Iran, and Korea. | *Lonicera periclymenum* and *Rubus fruticosus.*<br>Cultivated strawberry *Fragaria x ananassa*<br>Violets<br>From Evans (2008): Balsainaceae—*Impatiens noli-tangere*<br>Campanulaceae—*Platycodon grandiflorum*<br>Caprifoliaceae—*Lonicera* spp.<br>Ericaceae—*Vaccinium myrtillus*<br>Fabaceae—*Robinia viscosa*<br>Oxalidaceae—*Oxalis* spp.<br>Papaveraceae—*Chelidonium* | Overwintered as adults on *R. fruticosus* on the woodland floor, spreading onto spring growth of *L. periclymenum, Geum urbanum* and other minor hosts to reproduce, before retreating to *R. fruticosus* in the autumn. | PUPA: 1 mm long, light yellow in color, oval and dorsally ADULTT: 1 mm long light yellow body and white wings with a faint grey curved line in the lower portion of the forewing.<br>LARVA: larvae do produce a fringe of wax around the circumference but are devoid of wax dorsally.<br>All post-egg stages are an opaque light yellowish-green dorsally. The lingula, which is barely visible under a hand lens, is bluntly triangular and brown. An oval ring of wax | parasitoids *Euderomphale chelidonii* and *Encarsia tricolor* and the specialist whitefly predators *Clitostethus arcuatus* and *Acletoxenus formosus* are natural enemies.<br>11 parasitoid wasp species associated with *A. lonicerae*– eight in the family Aphelinidae (*Cales noaki, Encarsia spp., Eretmocerus mundus*), and three in Eulophidae (*Ceranisus pacuvius, Euderomphale sp1, Euderomphale sp2*). *Encarsia inaron, E. lutea, E. meritoria, E. pergandiella* and *Eretmocerus mundus* are recorded from Florida. | | LOW |

 

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|---|---|---|---|---|---|---|---|
| | | *majus, Dicentra spectabilis*<br><br>Rosaceae—*Crategus microphylla, Filipendula ulmaria, Fragaria* spp.; *Geum rivale, Prunus dulcis, Rubus chamaemorus*<br><br>Urticaceae—*Urtica* spp.<br><br>Violaceae—*Viola* spp.<br><br>Wood avens-*Geum urbanum* | | residue can be seen on the leaf surface after the pupal exuviae are removed | | | |

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https://www.cabi.org/isc/datasheet/119630

https://www.gbif.org/species/4484307 - geographic distribution

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| Species / Common name | Geographic distribution | Hosts / Crops | Symptoms | Description | Control | Monitoring | Risk for soft fruit |
|---|---|---|---|---|---|---|---|
| *Pseudaulacaspis pentagona*/ White peach scale | Since 2006 several outbreaks (Cornwall, Devon, Gloucestershire, Kent and Oxfordshire)<br><br>Kenya- first report 2021 | 100 plant genera<br><br>Inc. peach (*Prunus persica*) trees grown under protection, *Malus, Prunus, Pyrus, Ribes, Rubus, Sorbus,* and *Vitis*<br><br>*Catalpa bignonioides*<br><br>Kiwi fruit<br><br>lilac (*Syringa*)<br><br>dogwood (*Cornus*) | Foliage of infested trees may become sparse and yellow. Fruit size may be reduced, and premature fruit drop is likely to occur, especially if scale feeding is accompanied by other stresses. Heavy infestations can result in the drying out and death of twigs, branches, and even large mature trees if left unattended. Young plants can die very quickly after infestation. | Adult female scale covers are convex, circular to oval, dull white with a subcentral yellow spot (shed skins), 2.0 – 2.5 mm in length. The body of the adult female is yellow.<br><br>The male cover (test) is smaller, felted, white, elongate, often ridged with a terminal yellow spot (shed skin), 1.5 mm in length. The male tests often occur in conspicuous masses occasionally smothering the bark and turning it white.<br><br>The adult males are winged and | Infested hosts can be trimmed/pruned to remove infested parts, which can then be burned. Chemical options are available, but the waxy covering of the organism affords it some protection. Repeated application of chemical insecticides over more than one season may be required to control the pest.<br><br>acetamiprid, deltamethrin or petroleum oil<br><br>South Korea: Parasitoids, Biological Control, Four aphelinid and one encyrtid parasitoid species (Hymenoptera: Chalcidoidea) were collected from Pseudaulacaspis pentagona were | Visual inspection.<br><br>Sticky tape erected with its stickiness facing outwards on the trunk and branches can help to optimise spray of young larvae ('crawlers') timings. In the spring. | MEDIUM<br><br>Easily spread from imported material. Lack of good controls.<br><br>Wide host range. |

 

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| | | | | mobile in order to locate a mate.<br>Temperature affects spawning and egg stages to the emerging adult stage on the induction of reproductive diapause in females. | identified as Aphytis proclia (Walker), Encarsia berlesei (Howard), Marietta carnesi (Howard), Pteroptrix orientalis (Silvestri) (Aphelinidae) and Arrhenophagus chionaspidis Aurivillius (Encyrtidae). | | |


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| Species / Common name | Geographic distribution | Hosts / Crops | Symptoms | Description | Control used in other parts of world | Monitoring | Risk for soft fruit |
|---|---|---|---|---|---|---|---|
| *Ceroplastes ceriferus/ Indian wax scale* | Near global distribution.<br><br>Native to Southern Asia, Switzerland, Italy, Turkey, Bulgaria, Hungary, parts of East and South Africa, Australia, US, Brazil, Chile. | Wide host range including trees but notably Prunus, Salix (willows), Citrus, Tea, Coffee etc. (see Plantwise website). | Infestations on the foliage, stems and branches.<br><br>Reduced vigour and general debility.<br><br>Heavy infestations may cause chlorotic spotting on the leaves, dieback of stems and wilting.<br><br>Honeydew leads to growth of black sooty moulds. | The body hidden under a roughly convex, circular or oval covering of wax.<br><br>Wax is white in nymphs and young adults and becomes pinkish in older individuals.<br><br>Adults have a forward-pointing waxy horn and there are waxy filaments projecting from the margin of the scale, giving the insect a daisy-flower-like appearance.<br><br>Most populations are and reproduce parthenogenically. | **Chemical control:** Acetamiprid, Buprofezin, Malathion<br><br>**Cultural controls:** Maintain overall plant health and reduce plant stress. Avoid overfertilization.<br><br>Adult wax scales are protected against insecticide treatments by their thick waxy coating.<br><br>When adults are present, best to physically remove them by handpicking or pruning. | DNA barcoding | Not yet identified in UK. |
| Good Resource: https://www.plantwise.org/knowledgebank/datasheet/12342<br><br>Description: http://scalenet.info/catalogue/Ceroplastes%20ceriferus/ | | | | | | | |

Chemical control: https://vtechworks.lib.vt.edu/bitstream/handle/10919/84256/ENTO-238.pdf?sequence=1&isAllowed=y

and https://mgnv.org/wp-content/uploads/2021/03/2021PestManagementGuideHomeGroundsandAnimals.pdf

First records of Ceroplastes ceriferus (Fabricius) (Hemiptera: Coccidae) and Ceroplastes japonicus (Gray) in Switzerland identified by DNA barcoding

https://onlinelibrary.wiley.com/doi/full/10.1111/epp.12805?campaign=wolearlyview

| Species / Common name | Geographic distribution | Hosts / Crops | Symptoms | Description | Control used in other parts of world | Monitoring | Risk for soft fruit |
|---|---|---|---|---|---|---|---|
| *Ceroplastes japonicus*<br>*Tortoise wax scale* | France, Germany, Switzerland, Italy. Slovakia, Turkey, Greece, Croatia, Russia, China. | Wide host range and an important pest of many ornamentals, forest trees and shrubs but also Citrus, Prunus (stone fruit). | Infestations on the foliage, stems and branches.<br>Reduced vigour and general debility.<br>Heavy infestations may cause chlorotic spotting on the leaves, dieback of stems and wilting.<br>Honeydew leads to growth of black sooty moulds. | Body oval or rectangular; convex in lateral view in old females, nearly flat in young females. Body reddish brown; with a thick wax covering.<br>Eggs laid in chamber under body of adult. Eggs less than 0,5 mm long.<br>One female may lay till 2500 eggs. Small females lay 400 – 500 eggs.<br>No pupa stage. | Chemical control not effective due to protective wax covering.<br>The coccinelid, Chilocorus kuwanae, & parasitoid, Microterys clauseni.<br>Longer list of natural enemies provided in the CABI website and EU factsheet. | DNA barcoding | Not yet identified in the UK |

Resource: https://www.cabi.org/isc/datasheet/12349

Description: http://idtools.org/id/scales/factsheet.php?name=6877

Description: http://scalenet.info/catalogue/Ceroplastes%20japonicus/

Natural enemies/ control: https://www.cabi.org/isc/datasheet/12349#tonaturalEnemies and https://gd.eppo.int/download/doc/1318_ds_CERPJA_en.pdf

First records of Ceroplastes ceriferus (Fabricius) (Hemiptera: Coccidae) and Ceroplastes japonicus (Gray) in Switzerland identified by DNA barcoding

https://onlinelibrary.wiley.com/doi/full/10.1111/epp.12805?campaign=wolearlyview

 

## Coleoptera - beetles

| Species / Common name | Geographic distribution | Hosts / Crops | Symptoms | Description | Control used in other parts of world | Monitoring | Risk for soft fruit |
|---|---|---|---|---|---|---|---|
| *Popillia japonica / Japanese beetle* | Native to Northern Japan and far east Russia.<br><br>North America (1911), Canada, Azores (1970s), mainland Europe (2014).<br><br>No UK records to date.<br><br>Extensive damage in US, with a significant outbreak confirmed in northern Italy in 2014.<br><br>Presence in UK: no (EPPO GD) | Wide host range, over 300 hosts in 79 plant families, including crops and woody plants.<br><br>Fruit trees, turf, ornamentals.<br><br>Blueberry, apple, grapevine, cherry, plum, peach, raspberries, strawberry.<br><br>Adult beetles eat inside blueberries.<br><br>Seasonal abundance, defoliation, and parasitism dependent on the apple cultivar.<br><br>3 Carpinus taxa, Carpinus caucasica Grossh., Carpinus tschonoskii Maxim., and the hybrid Carpinus | Adults: skeletisation of foliage, which may turn brown and fall.<br><br>Can cause significant defoliation and may damage flowers.<br><br>Larvae: feed on roots, symptom not specific, e.g. strawberry.<br><br>Dug up by badgers and foxes in turf. | Chafer beetle<br><br>Adults: 8 to 13 mm long, metallic green thorax and head and coppery bronze wing cases with distinct white setal tufts/spots on margins.<br><br>Eggs: round, elliptical or nearly cylindrical, 1.5 mm long.<br><br>Larvae: typical chafer, C-shape form, well developed legs and head capsule. | Plant Protection Products, broad spectrum including pyrethroids.<br><br>Chemical control outperforms organic methods.<br><br>Insect excluding mesh.<br><br>Mulching of container-grown nursery stock.<br><br>Native generalist predators and birds.<br><br>Entomopathogenic nematodes; *Steinernema* and *Heterorhabditis*.<br><br>*Metarrhizium anisopliae.* | Regulated in EU (Annex IAII of the EC Plant Health directive).<br><br>Adults hitchhike on non-host commodities or vehicles. Larvae highly cryptic and easily moved with rooted plants.<br><br>Traps: part food-type lure (phenethyl propionate + eugenol + geraniol) and sex attractant (Japonilure)<br><br>Modelling: Model outputs can support the best timing for implementation | LOW<br><br>(long lifecycle in UK – 2 years)<br><br>PHRR information:<br><br>Action: Statutory action against findings. Awareness raising.<br><br>Already listed in legislation, but stakeholders may wish to monitor for possible presence. EPPO protocol has been developed which sets out measures needed in the event of an outbreak. |

 

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| | | caroliniana x C. coreana. | | | | of monitoring and control activities.<br>Immunomarking method to investigate the flight distance.<br>Stable isotopes provide a method to determine where and what insects are feeding on. | Legislative status: GB QP |


IDENTIFICATION: https://idtools.org/id/beetles/scarab/factsheet.php?name=15216 & https://planthealthportal.defra.gov.uk/assets/factsheets/popillia-japonica-factsheet.pdf

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| **Species / Common name** | **Geographic distribution** | **Hosts / Crops** | **Symptoms** | **Description** | **Control used in other parts of world** | **Monitoring** | **Risk for soft fruit** |
|---|---|---|---|---|---|---|---|
| *Naupactus leucoloma* / white fringed weevil | South Africa, Europe (not UK), North America, Oceania, South America | *Brassica*<br>*Daucus carota subsp. sativus*<br>Fabaceae<br>*Fragaria x ananassa*<br>*Pisum sativum*<br>*Rubus*<br>*Solanum tuberosum*<br>*Trifolium*<br>vegetable plants | Eggs, larvae, pupae (on roots, stems and lower leaves and in growing media) Adults (on foliage).<br>**Physiology:** Modulating gene expression may be an important mechanism of successful colonization. | Eggs: Oval approximately 0.9 mm long and 0.6 mm wide, laid in clusters of approximately 10–60. Milky-white when first laid, changing to dull light-yellow.<br>Larvae: Legless, slightly curved, yellowish-white grub with a light brown head up to | Natural enemies: *Conoderus exsul*<br>*Heterorhabditis Hexamermis*<br>*Paecilomyces farinosus*<br>*Passer domesticus*<br>*Rhabditis hambletoni Steinernema feltiae*<br>Phytosanitary measures<br>Soil fumigation<br>Crop rotation | Phytosanitary inspections<br>Pest survey cards | LOW<br>Not yet identified in UK. |

 

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| | | *Vigna unguiculata*<br><br>*Zea mays* | | 13 mm long, 6 mm wide.<br><br>Pupa: Creamy white, 10–12 mm long occurring in chambers in soil. Two or three days before adult emergence, the pupa turns brown.<br><br>Adult: Approximately 10–13 mm long, 4 mm wide across the abdomen with a short snout, greyish, with a broad longitudinal white stripe along each side of the elytra. The body is densely covered with short pale hairs which are longer on the elytra. | Nematodes and EPFs | | |


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| Species / Common name | Geographic distribution | Hosts / Crops | Symptoms | Description | Control used in other parts of world | Monitoring | Risk for soft fruit |
|---|---|---|---|---|---|---|---|
| *Anoplophora chinensis*- *Citrus longhorn beetle* | Asia (China, Korea, and Japan, with occasional records from Indonesia, Malaysia, Philippines, Taiwan, and Vietnam)<br><br>Europe, Turkey | Highly polyphagous.<br><br>Deciduous trees and shrubs, for example: Acer spp., Betula spp. and Prunus spp. | Adult beetles make a distinctive circular hole in the bark when they emerge from their larval and pupation stages. Typically, 6-11mm wide (0.25 – 0.4in).<br><br>Holes mostly found towards the base of trunks and exposed roots.<br><br>On smooth-barked trees they resemble drilled holes.<br><br>Scars or slits on the bark at sites where eggs have been laid, frass at the base of an attacked tree. | Adults species are glossy black with 10–20 distinct irregular shaped patches on the elytra, although in rare instances the number of patches ranges from 0 to over 60.<br><br>Patch colour is usually white and at times pale yellow.<br><br>Body length between 17 and 40 mm.<br><br>Presence of 20–40 small projections (tubercles) on the basal quarter of each elytron. | Fell and chip, burn or deeply bury infested trees.<br><br>Foliar insecticide sprays can be effective against adults.<br><br>*Aprostocetus fukutai*, an Egg Parasitoid | Test trapping protocols.<br><br>Molecular diagnostics from whole body insects (adults and larvae) and frass samples. | Not yet in the UK<br><br>Notifiable |


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| Species / Common name | Geographic distribution | Hosts / Crops | Symptoms | Description | Control used in other parts of world | Monitoring | Risk for soft fruit |
|---|---|---|---|---|---|---|---|
| *Anthonomus rubi/ Strawberry blossom weevil* | Europe, North America (Canada) | Strawberry<br>Raspberry (increasing importance) | Severed buds<br>Non-severed buds containing an egg develop through to open flowers with a dark spot near the base of the receptacle, resulting in malformed berries. | Adults: black in colour and 2– 4 mm in length, with scattered greyish pubescence and a long snout about 40% of the length of the body.<br>Eggs: 0.5 x 0.4 mm in size, oval, white and translucent. They are found inside flower buds.<br>Larvae: 3.5 mm long, dirty creamish-white, legless, with a brown head. The body has a | Insecticides<br>Mass trapping<br>Attractive tapes<br>Pheromone lures (Russell IPM) | Baited yellow sticky traps | LOW<br>Effective control options are available |

 

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|---|---|---|---|---|---|---|---|
| | | | | noticeable C shape and is wrinkled. It is found inside severed, withered flower buds. | | | |

Zanettin TL et al. 2021 Anthonomus rubi on Strawberry Fruit: Its Biology, Ecology, Damage, and Control from an IPM Perspective. Insects, 12, 701. https://doi.org/10.3390/insects12080701

| Species / Common name | Geographic distribution | Hosts / Crops | Symptoms | Description | Control used in other parts of world | Monitoring | Risk for soft fruit |
|---|---|---|---|---|---|---|---|
| *Charidotella sexpunctata - Tortoise beetle* | North America, Central America,<br>Caribbean, South America | Cabbage<br>Strawberries<br>Raspberries<br>Corn<br>Milkweed<br>Eggplant<br>Sweet potato (most damage) | Both larvae and adults feed on foliage.<br>The typical form of injury is the creation of numerous small to medium-sized irregular holes.<br>Both stages usually inhabit the lower surface but eat entirely through the foliage. | Adult; Length: 5 to 8 mm.<br>Variable in colour from reddish-brown with black spots to brilliant, mirror-like gold, earning it the nickname "goldbug".<br>Elytral margins are expanded and nearly transparent. | Parasitoids of this species include the eulophid wasp *Tetrastichus cassidus* and the tachinid fly *Eucelatoriopsis dimmocki*. | | LOW<br>Not yet in the UK |

Identification: https://www.insectidentification.org/insect-description.php?identification=Golden-Tortoise-Beetle

https://entnemdept.ufl.edu/creatures/veg/potato/golden_tortoise_beetle.htm

Taxonomy: https://www.itis.gov/servlet/SingleRpt/SingleRpt?search_topic=TSN&search_value=720028#null

 

| Species / Common name | Geographic distribution | Hosts / Crops | Symptoms | Description | Control used in other parts of world | Monitoring | Risk for soft fruit |
|---|---|---|---|---|---|---|---|
| *Aromia bungii – Peach red-necked longhorn/ plum and peach longhorn/ red-necked longhorn* | China, North Korea, South Korea, Mongolia, Japan and Vietnam.<br><br>Germany, Italy, (possibly) Spain.<br><br>Intercepted in the UK and US | Prunus species, in particular stone fruit trees, such as peach,<br><br>Apricot, plum, cherry and almond.<br><br>Other species such as pomegranate, kaki and olive trees are potential hosts. | Detection of reddish coloured frass at the base of the trunk, bark or near the crown in upper branches.<br><br>Removal of the bark reveals larval galleries and holes.<br><br>Adults observed in field conditions because of their diurnal activity. | Adult brightly black elytra and the red dorsal region of the prothorax, hence, red neck longhorn beetle (23– 37 mm).<br><br>A. bungii ssp. cyanicornis is black<br><br>Eggs: elongated, subcylindrical approx. 2 mm long.<br><br>Larvae: hatched larvae are 2-2.5 mm long; mature larvae are 42- 52 mm.<br><br>Pupae: pupae light yellow and are 22-38 mm long showing clearly defined legs, and long coiled antennae.<br><br>Larvae may overwinter two or three times | Pheromone traps<br><br>Male sex aggregation pheromone<br><br>Parasitoid: *Sclerodermus guani* | Genetic information-mito-genome<br><br>Pest survey card | LOW<br><br>Not yet established in the UK |

 

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | and usually mature after 21–36 months. | | | |

**Good resource:**

Pest survey card on Aromia bungii. European Food Safety Authority (EFSA), https://efsa.onlinelibrary.wiley.com/doi/pdf/10.2903/sp.efsa.2019.EN-1731

Aromia bungii Pest Report to support ranking of EU candidate priority pests. EFSA (European Food Safety Authority), https://.doi.org/10.5281/zenodo.2786515

Germinara GS et al. 2019 Electroantennographic Responses of Aromia bungii (Faldermann, 1835) (Coleoptera, Cerambycidae) to a Range of Volatile Compounds. Insects, 10(9), 274; https://doi.org/10.3390/insects10090274

Men J et al. 2019 Evaluating host location in three native Sclerodermus species and their ability to cause mortality in the wood borer Aromia bungii (Coleoptera: Cerambycidae) in laboratory https://doi.org/10.1016/j.biocontrol.2019.04.007

Russo E, Francesco Nugnes, Francesco Vicinanza, Antonio P. Garonna & Umberto Bernardo 2020 Biological and molecular characterization of Aromia bungii (Faldermann, 1835) (Coleoptera: Cerambycidae), an emerging pest of stone fruits in Europe. Scientific Reports, 10, 7112 https://www.nature.com/articles/s41598-020-63959-9

Song RLZ & Yimin Du 2021 Mitochondrial genome of Aromia bungii (Coleoptera: Chrysomeloidea: Cerambycidae) and phylogenetic analysis. https://doi.org/10.1080/23802359.2020.1846475

Yasui H, et al 2019 Electroantennographic responses and field attraction of an emerging invader, the red-necked longicorn beetle Aromia bungii (Coleoptera: Cerambycidae), to the chiral and racemic forms of its male-produced aggregation-sex pheromone. Applied Entomology and Zoology, 54, 109–114 https://link.springer.com/article/10.1007/s13355-018-0600-x

Yasui H, Nao Fujiwara-Tsujii, Soichi Kugimiya & Naoto Haruyama 2021 Extension of sustained pheromone release for monitoring an emerging invader, red-necked longicorn beetle Aromia bungii (Coleoptera: Cerambycidae). Applied Entomology and Zoology, 56,291–297 https://link.springer.com/article/10.1007/s13355-021-00726-w

Zou Y, Laura Hansen, Tian Xu, Stephen A. Teale, Dejun Hao & Jocelyn G. Millar 2019 Optimizing pheromone-based lures for the invasive red-necked longhorn beetle, Aromia bungii. Journal of Pest Science, 92, 1217–1225 https://link.springer.com/article/10.1007/s10340-019-01108-6

 

## Lepidoptera – moths

| Species / Common name | Geographic distribution | Hosts / Crops | Symptoms | Description | Control used in other parts of world | Monitoring | Risk for soft fruit |
|---|---|---|---|---|---|---|---|
| *Acleris comariana / strawberry tortrix* | Widely distributed in Europe, inc. Denmark, North America, China, and Japan<br><br>Presence in UK: present (CABI) | strawberry, Fragaria x ananassa | Spun or rolled leaf, causing sufficient damage to be a serious pest in some areas | Wingspan 13-18 mm with costal blotches. Closely resemble forms of A. laterana, from which reliably separated by dissection of the genitalia.<br><br>This is a highly variable species, having several known forms in Britain | Other torticid moth controls are likely to be affective.<br><br>common egg-larval parasitoid Copidosoma aretas found in the UK | Pheromone identified E11,13-14Ald<br><br>Eggs on lower surface of leaves on the proximal half of the leaflets. Eggs most frequently occurred on older plants and on inedium-sized leaves. | MEDIUM<br><br>In UK, reducing options for control of caterpillars.<br><br>Not on PHRR.<br><br>Legislative status:<br>not in GB<br>legislation |

IDENTIFICATION: https://britishlepidoptera.weebly.com/065-acleris-comariana-strawberry-tortrix.html

http://idtools.org/id/leps/tortai/Acleris_comariana.htm

https://www.cabi.org/isc/datasheet/2713


Fryer, J. C. F. 1928. Polymorphism in the moth Acalla comariana Zeller. J. Genet. 20: 157-178.

Petherbridge, F. P. 1920. The life history of the strawberry tortrix, Oxygrapha comariana (Zeller). Ann. App. Bio!. 7: 6-10.

Svensson, G.P., Tönnberg, T., and Sigsgaard, L. 2019. Identification and field evaluation of (E)-11,13-tetradecadienal as sex pheromone of the strawberry tortrix (Acleris comariana). J. Appl. Entomol. 143:535-541.

Turner, J. R. G. 1968. The ecological genetics of Acleris comariana (Zeller) (Lepidoptera: Tortricidae), a pest of strawberry. Journal of Animal Ecology. 37: 489-520.

Vernon, J. D. R. 1971. Observations on the biology and control of tortricid larvae on strawberries. Plant Path. 20: 73-80.


 

| Species / Common name | Geographic distribution | Hosts / Crops | Symptoms | Description | Control used on apple | Monitoring | Risk for soft fruit |
|---|---|---|---|---|---|---|---|
| *Blastobasis lacticolella/ decolorella* | Introduced into western Europe.<br>Now reported in Netherlands, Sweden, Denmark, and UK (1946) from Madeira. Belgium (2017).<br><br>Established and expanding its range.<br><br>Presence in UK:<br>present (CABI) | Wide host range including leaf-litter, vegetation, and stored products.<br><br>Strawberry, apple, pear. | Scalloping of epidermis of fruit, weep and are sometimes covered by a sticky mass of black frass.<br><br>Webbing and tenting of foliage, with foliar damage and frass.<br><br>In strawberry under calyx and feed superficially on berries. | Wingspan 18-21 mm.<br><br>Adults: quite variable some being very plain, others quite well-marked. Broad forward pointing 'V' mark at one third, dots or patch at two thirds and a sub-terminal fasci. Closely related species only discriminated by genitalia.<br><br>Larvae: purplish-brown. | 1-2 sprays of methoxyfenozide - protective deposit.<br>Chlorantraniliprole applied during egg-laying, before egg-hatch.<br><br>Pyriproxyfen (Harpun) inhibits egg hatch, metamorphosis of nymphs to adults and reduces the fecundity of adult females.<br><br>Indoxacarb may be effective.<br><br>*Bacillus thuringiensis* has little activity against Blastobasis.<br>Synthetic pyrethroids<br>highly effective. | Tap sampling | LOW<br><br>In UK, sporadic occurrence in crops. Causes significant damage when it occurs, reducing control options available.<br><br>Not on PHRR.<br>Legislative status:<br>not in GB<br>legislation |
| IDENTIFICATION: https://britishlepidoptera.weebly.com/blacticolella-vs-badustella.html | | | | | | | |

https://ukmoths.org.uk/species/blastobasis-lacticolella

https://apples.ahdb.org.uk/blastobasis.asp

| Species / Common name | Geographic distribution | Hosts / Crops | Symptoms | Description | Control used in other parts of world | Monitoring | Risk for soft fruit |
|---|---|---|---|---|---|---|---|
| *Acleris minuta / lesser apple leaf-folder*<br><br>*yellow-headed fireworm* | North America: USA, Canada, Europe (possibly).<br><br>Presence in UK: absent (PHRR) | apples, plums and cranberries, blueberry, peach, also pear. | Larval feeding on underside of leaves and superficially on berries. | Tortricid moth: Adult: 6.5-9.5 mm, forewing uniform, colour; summer form yellow or orange, winter form grey.<br><br>Larvae: last instar greenish yellow ~ 12 mm. | Other torticid moth controls are likely to be affective and should be timed with sex pheromone traps.<br><br>Cranberry management guide | Regulated quarantine pest.<br><br>Sex pheromone identified. | LOW<br><br>Not yet identified in UK.<br><br>PHRR information:<br><br>Action: Statutory action against findings.<br><br>Planting material of several hosts are mitigated by current regulations prohibiting imports.<br><br>Legislative status: GB QP |

https://secure.fera.defra.gov.uk/phiw/riskRegister/viewPestRisks.cfm?cslref=1406

http://idtools.org/id/leps/tortai/Acleris_minuta.htm

https://pherobase.org/database/species/species-Acleris-minuta.php

https://gd.eppo.int/download/doc/1145_minids_ACLRMI.pdf

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Chapman, P. J. and S. E. Lienk. 1971. Tortricid fauna of apple in New York (Lepidoptera: Tortricidae); including an account of apple's occurrence in the state, especially as a naturalized plant. Spec. Publ. Geneva, NY: New York State Agricultural Experiment Station. 122 pp.

de Jong Y et al. 2014. Fauna Europaea - all European animal species on the web. Biodiversity Data Journal 2: e4034. doi: 10.3897/BDJ.2.e4034.

Gilligan TM, Epstein M. 2014. Tortricids of Agricultural Importance. Interactive Keys developed in Lucid 3.5. Last updated August 2014. http://idtools.org/id/leps/tortai/index.html

OSU. No date. Codling Moth Information Support System (CMISS). Natural Enemies of Codling Moth and Leafrollers of Pome and Stone Fruits. Integrated Plant Protection Center, Oregon State University. http://www.ipmnet.org/codlingmoth/biocontrol/natural/ (accessed August 2015).

Schwarz, M., Klun, J.A., Hart, E.R., Leonhardt, B.A., and Weatherby, J.C. 1983a. Female sex pheromone of the yellowheaded fireworm, Acleris minuta (Lepidoptera: Tortricidae). Environ. Entomol. 12:1253-1256

Weatherby, Julie C., "The life system of the yellow-headed fireworm, Acleris minuta (Robinson) (Lepidoptera: Tortricidae) " (1982). Retrospective Theses and Dissertations. 8396.

Weatherby J C., E. R. Hart, Seasonal Development and Color Morph Determination of the Yellowheaded Fireworm (Lepidoptera: Tortricidae), Environmental Entomology, Volume 13, Issue 3, 1 June 1984, Pages 818–821, https://doi.org/10.1093/ee/13.3.818

2021-2023 Cranberry Chart Book Book revised September 2021 https://scholarworks.umass.edu/cgi/viewcontent.cgi?article=1274&context=cranchart

| Species / Common name | Geographic distribution | Hosts / Crops | Symptoms | Description | Control used in other parts of world | Monitoring | Risk for soft fruit |
|---|---|---|---|---|---|---|---|
| *Acleris nishidai* | Known only from mountains of central Costa Rica<br><br>Presence in UK: absent (PHRR). | Rubus, cultivated blackberry | Larvae fold, roll, and tie young leaves of the host,<br>feeding on them and surrounding leaves; the larvae reside within or adjacent to the folded or rolled<br>leaves. | Typical Tortricidae<br><br>Taxonomic identification in Brown and Nishida (2008)<br><br>Larva: last instar 7–8 mm, head pale caramel, thorax, and abdomen green. | Other torticid moth controls are likely to be affective. | Pheromone not listed on Pherobase. | LOW<br><br>Not yet identified in UK.<br><br>PHRR information:<br>Action: Statutory action against findings.<br>Legislative status: GB QP |

https://secure.fera.defra.gov.uk/phiw/riskRegister/viewPestRisks.cfm?cslref=29502

Brown JW and Nishida K, 2008. A new species of Acleris Hübner, [1825] from high elevations of Costa Rica (Lepidoptera: Tortricidae, Tortricini). SHILAP Revista de Lepidopterología, 36, 341–348.

 

| Species / Common name | Geographic distribution | Hosts / Crops | Symptoms | Description | Control used in other parts of world | Monitoring | Risk for soft fruit |
|---|---|---|---|---|---|---|---|
| *Acleris nivisellana / snowy-shouldered acleris moth* | North America, and southern Canada<br><br>Presence in UK: absent (PHRR) | hawthorn<br>apple<br>paradise apple<br>mallow ninebark<br>pin cherry<br>mountain ash<br>feeds on the leaves of various plants in the family Rosaceae | Larval feeding occurs in a silken chamber on the lower surface of leaves along the midrib. Larvae skeletonize the leaves and may partly sever the midrib, causing injured leaves to have a characteristic twisted appearance. Larvae have not been recorded feeding on fruit or other parts of the plant. | Adults: 15–17 mm.<br><br>Forewings white with large blackish semicircular patch along the costa and irregular patches of light grey mixed with brown in the median area and along the inner margin.<br>Dark spot near the inner margin in antemedial area and subterminal area is dark grey. Hindwings are brownish grey.<br><br>Larvae: Mid- to late instar ~ 9-16 mm long. | Other torticid moth controls are likely to be affective. | Pheromone not listed on Pherobase. | LOW<br><br>Not yet identified in UK.<br>PHRR information:<br>Action: Statutory action against findings.<br>Likelihood of entry on the main pathways is mitigated by current regulations prohibiting imports of the host.<br>Legislative status: GB QP |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | Abdominal color varies. Head is brown to dark brown posteriorly and dark brown to black anteriorly. | | | |

IDENTIFICATION: https://bugguide.net/node/view/58615/bgimage

Chapman, P. J. and S. E. Lienk. 1971. Tortricid fauna of apple in New York (Lepidoptera: Tortricidae); including an account of apple's occurrence in the state, especially as a naturalized plant. Spec. Publ. Geneva, NY: New York State Agricultural Experiment Station. 122 pp.

Powell, J. A. 1964. Biological and taxonomic studies on tortricine moths, with reference to the species in California. University of California Publications in Entomology. Vol. 32. 317 pp.

| **Species / Common name** | **Geographic distribution** | **Hosts / Crops** | **Symptoms** | **Description** | **Control used in other parts of world** | **Monitoring** | **Risk for soft fruit** |
|---|---|---|---|---|---|---|---|
| *Acleris fimbriana*/ Yellow tortrix moth | pest of fruit trees in Northern China, found in mainland Europe but not the UK<br>France, Germany, Denmark, Italy, Slovakia, Hungary, Romania, Poland, Norway, Sweden, Finland, the Baltic region, Ukraine and Russia.<br>South Korea | Malus and Prunus<br>In Germany mainly on sloes<br>*Prunus spinosa, Vaccinium uliginosum, Betula nana, Malus domestica* and *Spiraea* species | | wingspan is 18–20 mm | | Pheromone discovered | LOW<br>Not yet identified in UK. |

IDENTIFICATION:

https://lepidoptera.eu/species/2770

https://www.cabi.org/isc/datasheet/2714

 

Yuxiu Liu and Xianzuo Meng Trapping Effect of Synthetic Sex Pheromone of Acleris fimbriana (Lepidoptera: Tortricidae) in Chinese Northern Orchard. Verlag der Zeitschrift für Naturforschung | 2015 DOI: https://doi.org/10.1515/znc-2003-5-622

https://www.pherobase.net/database/species/species-Acleris-fimbriana.php

Gustafsson, B. (Lep) (2003) Catalogus Lepidopterorum Sueciae. Naturhistoriska riksmuseet, Stockholm, Excelfil hämtad från http://www.nrm.se/en/catalogus.html.se. - via Dyntaxa. Svensk taxonomisk databas

Gärdenfors (ed.) (2010) Rödlistade arter i Sverige 2010 - via Dyntaxa. Svensk taxonomisk databas

Jin-Liang Zhao,Yu-Peng Wu,Tian-Juan Su,Guo-Fang Jiang,Chun-Sheng Wu &Chao-Dong Zhu 2014 The complete mitochondrial genome of Acleris fimbriana (Lepidoptera: Tortricidae). 2200-2202

## Phytophagous mites

| Species / Common name | Geographic distribution | Hosts / Crops | Symptoms | Description | Control used in other parts of world | Monitoring | Risk for soft fruit |
|---|---|---|---|---|---|---|---|
| *Tetranychus mexicanus / Polyphagous spider mite* | China, Netherlands, North America, South America<br><br>Presence in UK: no records (EPPO GD) | Glasshouse crops.<br><br>100 hosts (in 44 plant families), including Citrus spp., Malus domestica, Vitis vinifera, papaya, and many ornamentals | Like other spider mites. Feeding punctures lead to whitening or yellowing of leaves, followed by desiccation, and eventually defoliation. | Identify using Gutierrez (1968) and Jepson et al. (1975) | Natural enemies; Phytoseiulus macropilis | Pathways for entry are Plants for planting, cut foliage fruits with green parts. | MEDIUM<br><br>Already detected in glasshouse crops in Netherlands. Growers need to be aware of this if control measures break down. |

https://www.rhs.org.uk/science/pdf/plant-health/Biosecurity-2019-Pest-Alerts.pdf

https://platform.cabi.org/isc/datasheet/53354

Netherlands took statutory action in 2018: https://www.eppo.int/ACTIVITIES/plant_quarantine/alert_list_insects/tetranychus_mexicanus

Aguilar H, Murillo P, 2012. New hosts and records of plant feeding mites for Costa Rica: interval 2008-2012. (Nuevos hospederos y registros de ácaros fitófagos para Costa Rica: período 2008-2012.) Agronomía Costarricense, 36(2):11-28. http://www.mag.go.cr/rev_agr/index.html

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EPPO, 2020. EPPO Global database. In: EPPO Global database, Paris, France: EPPO.

Gutierrez, J., 1968. Tetranychidae nouveaux de Madagascar (Quatrième note). Acarologia, 10(1), 13-28.

Jepson, L.R., Keifer, H.H., Baker, E.W., 1975. Mites injurious to economic plants. Berkeley, University of California Press.

Santos R S, Ferla N J, Ferla J J, Silva W da, 2018. Record of Tetranychus mexicanus (McGregor) (Acari: Tetranychidae) in papaya plant (Carica papaya L.) in the Acre State, Brazil. (Registro de Tetranychus mexicanus (McGregor) (Acari: Tetranychidae) em mamoeiro (Carica papaya L.) no estado do Acre, Brasil.). EntomoBrasilis. 11 (2), 147-150. https://www.periodico.ebras.bio.br/ojs/index.php/ebras/article/view/ebrasilis.v11i2.764/486

## Task 2.2. Dose, blend and method of deployment of capsid repellent in strawberry and cane fruit (Year 1-2, Lead; NRI, Contributors; NIAB EMR, Russell IPM)

### Introduction

Two years of replicated field trials demonstrated successful control of the European tarnished plant bug, *Lygus rugulipennis,* in strawberry, using a synthetic semiochemical push-pull approach. A hexyl butyrate (HB) 'push' was deployed in the crop in combination with a 'pull', consisting of *Lygus* sex pheromone and phenylacetaldehyde in green cross vane funnel traps, spaced at regular intervals around the crop perimeter (SF 156). The approach significantly reduced numbers of *L. rugulipennis* (adults and nymphs) in the crop and reduced fruit damage by up to 90% in organic strawberry. Following this success, a trial was set up in a commercial raspberry crop to assess whether the synthetic semiochemical push can reduce capsids and capsid damage in cane fruit (Task 2.1, SF 174). Standard HB as a push significantly reduced numbers of common green capsid *Lygocoris pabulinus* nymphs in treated crops and capsid damage to fruit and leaves.

The objective of this study was to develop commercial formulations of the capsid repellent (Year 1), then to evaluate them and a suitable method of deployment in the field (Year 2) for commercial application. During Year 1 (2020), Russell IPM and NRI focussed on optimising the HB repellent sachet (push) through laboratory release rate measurements. Results produced two HB dispensers both providing a convenient formulation of hexyl butyrate for use to control capsids by deterring them in crops. The standard blister pack formulation by Russell IPM, containing 1 g hexyl butyrate in 4 g paraffin oil, released hexyl butyrate at a rate comparable to that from the standard NRI polyethylene sachets used in all previous push-pull field trials (18 mg per day). The "thick-wall" (300 µm) polyethylene sachet containing 1 ml hexyl butyrate, released hexyl butyrate at a rate of 31.6 mg per day, considered enough to last a month. In this study we aimed to test both types of HB dispenser produced by Russell IPM, at the standard 2 m and more distanced spacings to determine whether:

1. Capsid numbers and strawberry damage were reduced using the Russell IPM HB dispensers (push) in conjunction with a perimeter pheromone trapping system (pull)
2. Increasing HB dispenser spacing provided comparable capsid control and reduction in capsid damaged fruit
3. The HB dispensers impacted numbers of natural enemies
4. The HB dispensers caused phytotoxic effects.

## Materials and methods

Trial sites: The trial was set up in 5 commercial strawberry crops (blocks) in Kent. Strawberries were polytunnel grown, everbearer varieties; Murano (block 1), Favori (blocks 2, 3 and 4) and Majestic (block 5) (Fig. 2.2.1). At least one of the polytunnel ends at all blocks was open for the duration of the trial. Strawberries were planted in grow bags and raised on tabletops. Weeds noted adjacent to crops, at all blocks, that could host pest capsids were docks (*Rumex* spp.) and nettle (*Urtica dioica* L, Urticaceae) (Fig. 2.2.2). Others may have been present, but a full habitat assessment was not made.

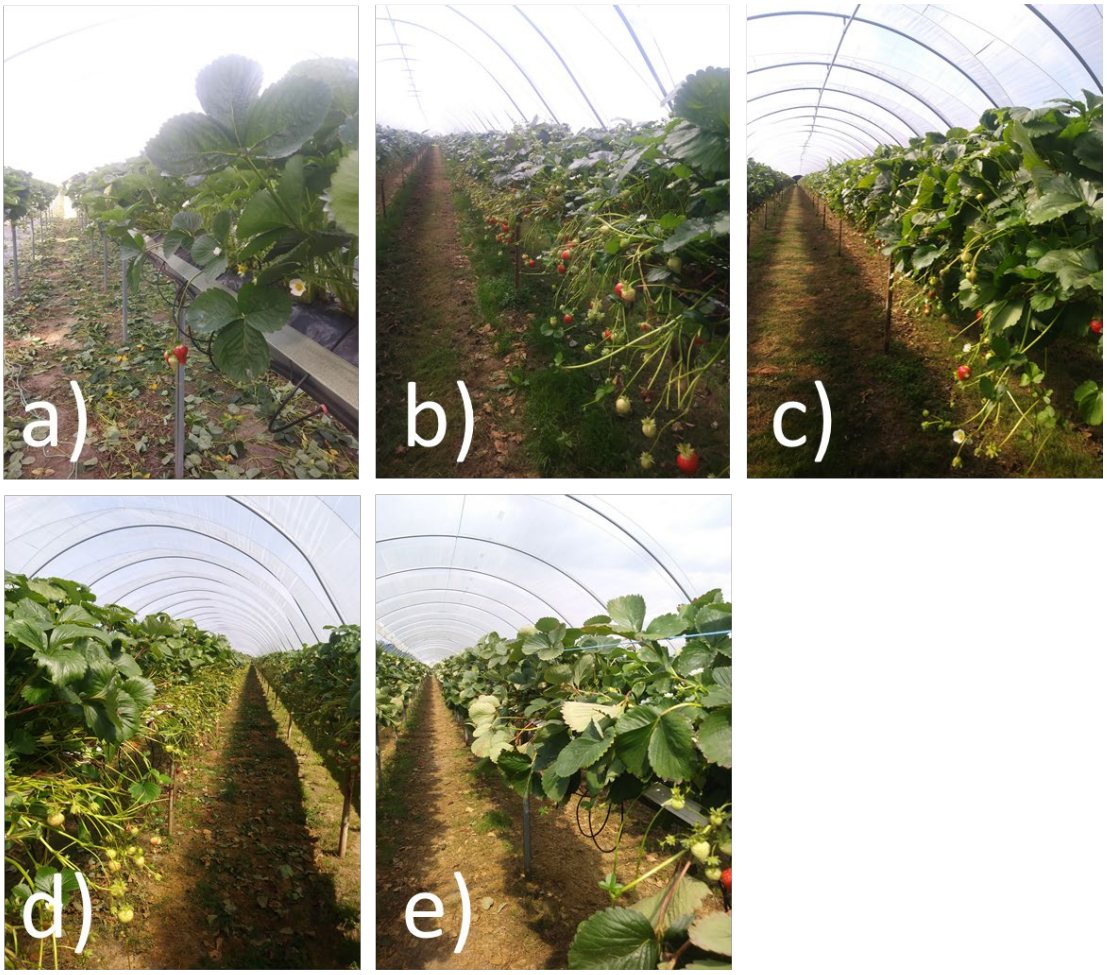



**Figure 2.2.1**. Photographs of capsid push-pull trial blocks 2021; a) Block 1; b) Block 2; c) Block 3; d) Block 4; e) Block 5.

**Figure 2.2.2.** Example of weeds adjacent to crops at all blocks that could host pest capsids, including docks (*Rumex* spp.) and nettle (*Urtica dioica* L, Urticaceae).

Block layout: A randomised block design was used. Each block was sub-divided into 4 plots (Fig. 2.2.3). Control and 2 m HB spacing plots were the standard 25 m x 25 m, 5 m and 20 m HB spacing plots were 40 m x 40 m and 50 m x 50 m, respectively (Fig. 2.2.3) and set up at the corners of the crop. Polytunnels at all blocks were ~8 m wide. Plots were ordered randomly to avoid position affect bias and spaced at least 30 m apart to avoid interaction between treatments.

Treatments. There were 4 treatments:

1. Untreated control: No semiochemicals or traps deployed
2. 2 m HB spacing (standard push-pull configuration); A central push with 8 rows of 8 (64 total) HB repellent sachets (14 x 14 m grid), 1 every 2 m, combined with a perimeter pull of 12 traps
3. 5 m HB spacing; A central push with 7 rows of 7 (49 total) HB repellent sachets (30 x 30 m grid), 1 every 5 m, combined with a perimeter pull of 20 traps
4. 20 m HB spacing; A central push with 3 rows of 3 (9 total) HB repellent sachets (40 x 40 m grid), 1 every 20 m, combined with a perimeter pull of 25 traps

At the trial start, HB repellent sachets were Russell IPM HB blister packs, which were renewed after two weeks. Four weeks after the trial start (halfway), Russell IPM HB blister packs were replaced with Russell IPM HB “thick-wall” (300 µm) polyethylene sachets, which retained a liquid until the end of the trial (~4 weeks later). HB sachets were wedged between the tabletop

and grow bags by the collar, leaving sachet walls exposed to release HB. This positioning also ensured sachets were not in contact with developing fruit or dislodged by farm activity (Fig. 2.2.4).

The pull consisted of green cross vane “bucket traps” (Agralan UK, *Lygus rugulipennis* trap system) with *Lygus* female sex pheromone, female *Lygus* attractant phenylacetaldehyde (PAA) (both formulated at NRI) and a drowning solution of water with a drop of liquid detergent. Traps were positioned around the border of the push, ~5.5 m away to prevent interference between HB and *Lygus* sex pheromone, as HB is a component of the *Lygus* sex pheromone. Traps were spaced at 8 m intervals and secured between the truss support tape and grow bags (Fig. 2.2.5).

*Lygus* sex pheromone and PAA sachets were renewed after 4 weeks.

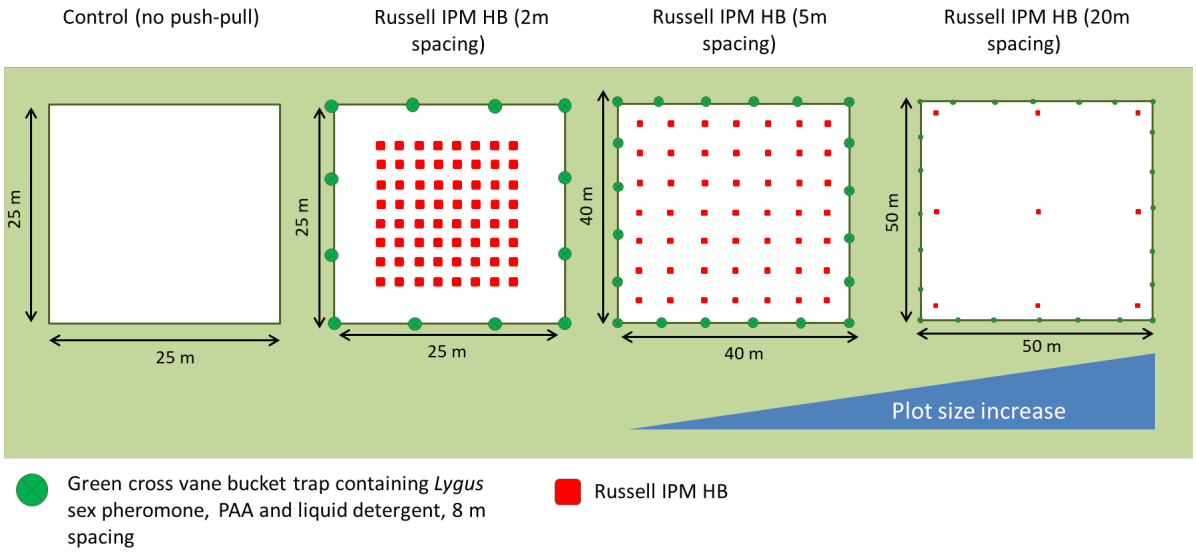



**Figure 2.2.3**. Diagrammatic representation of an experimental block of the capsid push-pull trial 2021, showing the control and 3 push-pull plots with positions of HB repellent sachets and green cross vane traps containing *Lygus* attractants.

a) 

b) 


**Figure 2.2.4**. HB repellent sachets wedged between tabletop and strawberry grow bag; a) Russell IPM HB blister pack, b) Russell IPM HB "thick-wall" (300 µm) polyethylene sachet.

a) 
b) 


**Figure 2.2.5**. a) Typical position of a green cross vane trap in the plot perimeter and b) location of *Lygus* sex pheromone (pipette tip) and phenylacetaldehyde (sachet) in the trap.

Semiochemical formulations were: 1) Russell IPM HB proprietary blister packs and 2) Russell IPM HB "thick-wall" (300 µm) polyethylene sachets formulated in polyethylene sachets (1 piece of dental roll with 1 ml HB, sealed in a polyethylene sachet 100 mm x 50 mm x 300 µm thick).

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

Crop husbandry involved the standard grower practices, including the growers' standard spray programme (Appendix 2.2.1). Growers were advised that insecticide sprays should be avoided to prevent target pests being killed. Data loggers recorded temperature and humidity throughout the experimental period in each block (Appendix 2.2.2).

Assessments: Assessments were done late June to beginning of September and included a pre-assessment, before push-pull treatments were deployed and 4 post treatment application assessments, when push-pull treatments were deployed. See Table 2.2.1 for HB deployment and renewal dates.

*Tap sampling*

To compare numbers of capsids and beneficials in control and treatment plots, 100 plants were tap sampled fortnightly in the central 14 x 14 m of each plot within a block and invertebrate numbers counted. See Table 2.2.1 for tap assessment dates.

*Trap counts*

To compare numbers of capsid adults and beneficials caught in perimeter traps of the 3 push-pull plots, all perimeter traps per plot within a block were emptied fortnightly and invertebrate numbers counted. See Table 2.2.1 for trap assessment dates.

*Fruit assessment*

Flowers were tagged at each visit to relate numbers of pests to subsequent fruit damage. The timing of the first assessment was determined by following tagged flowers to fruit. All fruit at the same development stage on a plant were assessed to prevent bias. Assessments were conducted in the central 14 x 14 m of each plot within a block. Approximately 100 fruits were assessed per plot and categorised according to capsid damage: 0 (zero), 1 (slight), 2 (moderate) and 3 (severe) (Fig. 2.2.6). See Table 2.2.1 for fruit assessment dates.

*Phytotoxicity*

To determine if the 2 types of Russell IPM HB sachets caused leaf phytotoxicity, at block 1, 12 July 2021; 10 Russell IPM HB blister packs (release rate 18 mg/d at 22°C), 10 Russell IPM HB double concentration HB sachets (release rate 31.6 mg/day at 22°C) and 10 sachets containing dental roll soaked in 1 ml water, were attached to young leaves close to the crown on separate strawberry plants. A further 10 plants were tagged with no sachets attached. On 31 August 2021, the 4 groups of 10 plants were assessed according to the phytotoxicity key (Appendix 2.2.3) (onlinelibrary.wiley.com. 2006).

The water sachet was formulated in polyethylene sachets (1 ml deionised water on a dental roll sealed in a polyethylene sachet 100 mm x 50 mm x 300 µm thick).

**Table 2.2.1**. Dates for capsid push-pull trial semiochemical deployment and renewal, tap, trap and fruit assessments at each block, 2021. Invertebrates were counted in traps assessments 1 to 4. *During assessment 4, no assessments were done at block 4 due to very few capsids recorded in the same block previous assessments.

| Location | Pre-treatment assessment, then semiochemical deployment | Assessment 1 & HB blister pack renewal | Assessment 2 & semiochemical renewal (incl. HB polythene sachets) | Assessment 3 | Assessment 4 |
|---|---|---|---|---|---|
| Block 1 | 28-Jun | 12-Jul | 27-Jul | 10-Aug | 31-Aug |
| Block 2 | 29-Jun | 13-Jul | 28-Jul | 11-Aug | 02-Sep |
| Block 3 | 29-Jun | 13-Jul | 28-Jul | 11-Aug | 02-Sep |
| Block 4 | 30-Jun | 14-Jul | 29-Jul | 12-Aug | N/A* |
| Block 5 | 01-Jul | 15-Jul | 03-Aug | 17-Aug | 01-Sep |

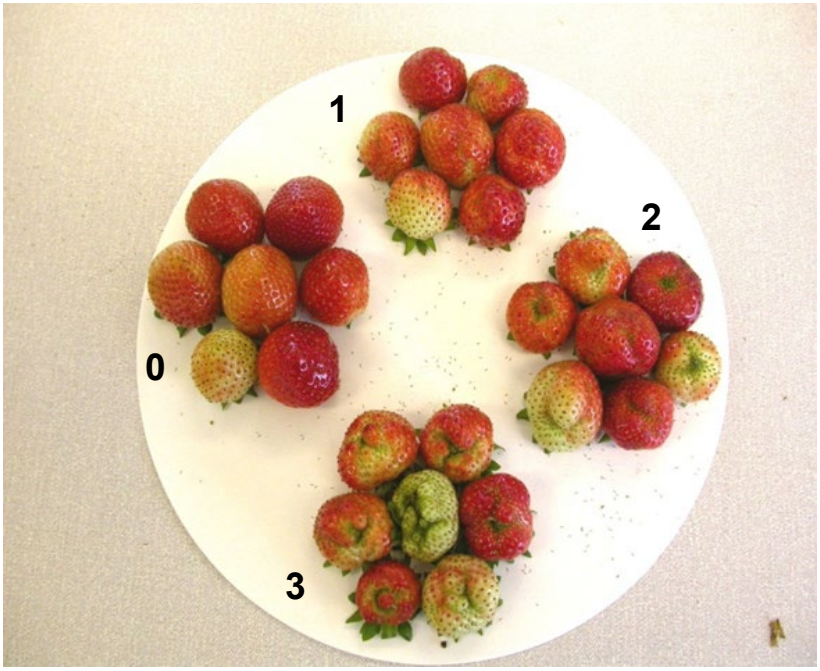



**Figure 2.2.6**. Capsid damage categories for strawberry fruits; from left working clockwise, 0 = no damage, 1 = slight damage, 2 = moderate damage, 3 = severe damage.

Statistical analyses: All statistical analyses were carried out in R.

*Tap and trap assessments*

The effect of treatment and assessment on capsid numbers in tap and trap samples was analysed using repeated measures ANOVA. Post-hoc marginal means and contrasts were calculated using the R emmeans package, with Tukey adjusted p-values to control false discovery rate.

*Fruit assessments*

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

## Results

*Tap sample assessments (per 100 plants)*

Statistical analysis of numbers of capsid nymphs recorded per plot during tap sampling, found no significant treatment effect, despite there being fewer in push-pull treatment plots overall compared to control (grand mean = 0.5 and 2.12 respectively). However, analysis of treatments by assessment, found a significant interaction assessment 3 (10 to 17 August), with significantly fewer capsid nymphs in 5 m and 20 m plots compared to control (mean = 0.57, 0.07 and 2.64 respectively, $P$ = <0.001). There were also fewer capsid nymphs in 2 m plots, but this was not significant (Fig. 2.2.7).

The main adult capsid species recorded during tap sampling was *L. pabulinus. L. rugulipennis* was also recorded, but in much lower numbers (grand mean = 0.3 and 0.04 respectively). Statistical analysis found a small overall treatment effect ($P$ = 0.09), with fewer adult *L. pabulinus* where there was a push-pull treatment compared to the control (Fig. 2.2.8). Numbers of adult *L. rugulipennis* were too low for statistical analysis.

*Fruit assessments*

Statistical analysis of mean fruit damage score found no significant treatment effect. Fruit damage score (recorded as 0 = none to 3 = severe) was low in all plots (grand mean = 0.23).

*Perimeter trap assessments*

The main adult capsid species recorded per push-pull plot in perimeter traps was *L. rugulipennis. L. pabulinus* was also caught, but in lower numbers (grand mean = 0.9 and 0.15 respectively). No other capsid species were captured. Statistical analysis of both species found no significant treatment effect.

*Beneficials*

Statistical analysis of numbers of beneficials recorded per plot during tap sampling, found no significant treatment effect. Beneficials counted in the crop with numbers suitable for statistical analysis were Aeolothripidae, Anthocoridae spp., Chrysopidae spp., Coccinellidae spp., Hemerobiidae spp. nymphs, parasitoid Hymenoptera spp. and Syrphidae spp. Analysis of numbers of beneficials recorded per plot in perimeter traps also found no significant treatment effect. Beneficials counted in traps with numbers suitable for statistical analysis were Araneae spp., Chrysopidae spp., Coccinellidae spp., Hymenoptera spp. and Syrphidae spp..

*Phytotoxicity*

After attachment close to the crown on separate strawberry plants between 12 July and the assessment; 31 August, the two types of HB sachets had no clear adverse effect on strawberry plant foliage compared to plants with water sachets or no sachets applied (Fig. 2.2.9). During the contact period, mean temperature in the polytunnel was 17.8°C, ranging from 10.5 to 35°C (Fig. 2.2.10) and mean humidity was 82%RH ranging from 41 to 100%RH (Fig 2.2.11).

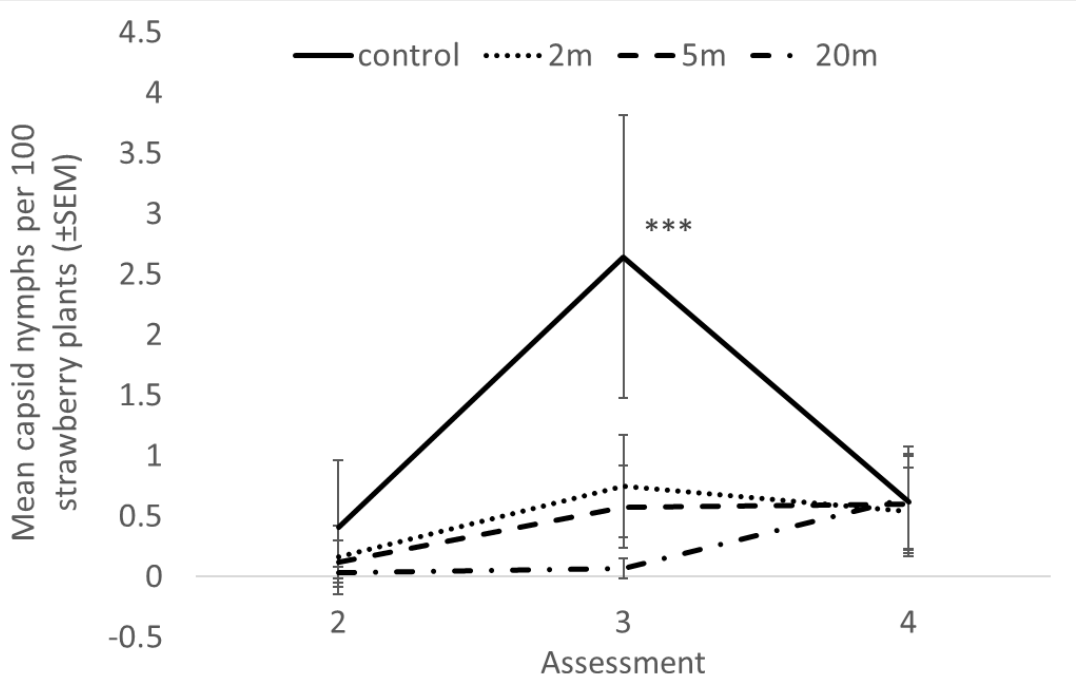



**Figure 2.2.7** Mean capsid nymphs recorded in the different treatment plots (per 100 strawberry plants), assessments 2 to 4 of the capsid push pull trial 2021; ***indicates a significant difference at *P* = 0.05.

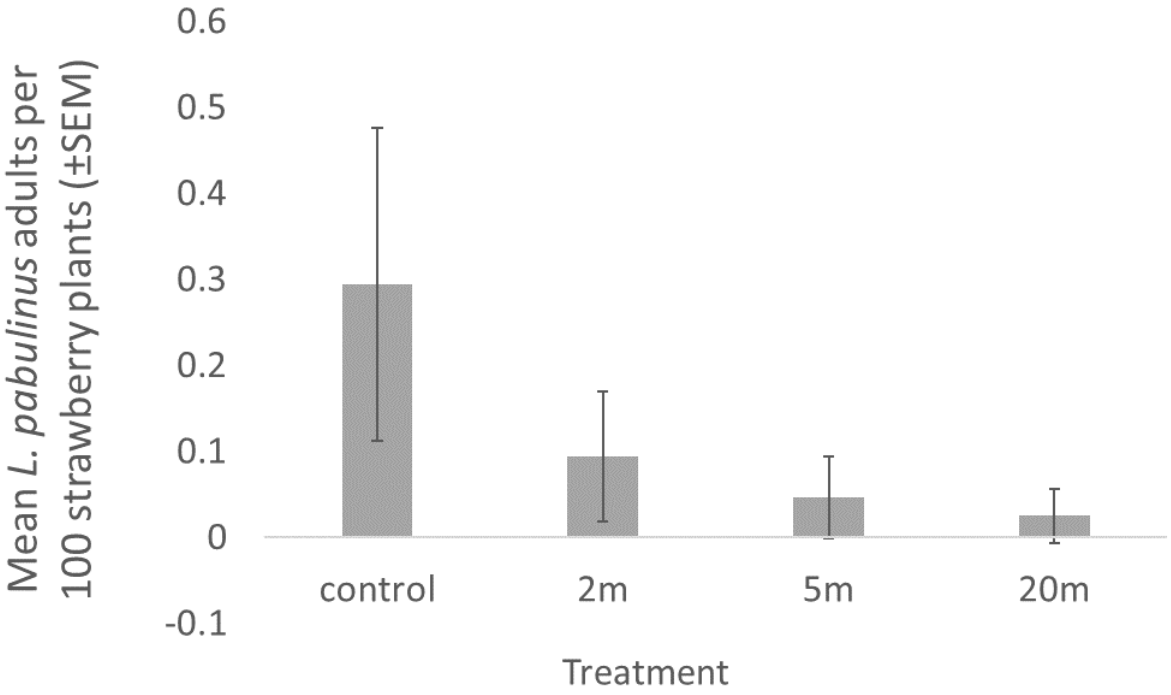



**Figure 2.2.8** Mean *L. pabulinus* adults recorded in the different treatment plots (per 100 strawberry plants) during the capsid push pull trial 2021. There was a small treatment effect at *P* = 0.1, but not at *P* = 0.05.

**Table 2.2.2**. Grand mean numbers of capsids (nymphs and adults) counted per 50 plants in experiment blocks, during 4 years of push-pull trials in commercially grown strawberry. LRN & LRA = *L. rugulipennis* nymphs & adults, LPN & LPA = *L. pabulinus* nymphs & adults, LTN & LTA = *Liocoris tripustulatus* nymphs & adults and capsid nymphs = a potential mix of these capsid species that could not be identified in the field.

| Year | County | LRN | LRA | LPN | LPA | LTN | LTA | Capsid nymphs |
|---|---|---|---|---|---|---|---|---|
| 2017 | Kent | 0.3594 | 0.2500 | 0.2500 | 0.4531 | NA | NA | 0.3047 |
| 2018 | Kent | 0.0097 | 0.0030 | 0.0219 | 0.0156 | NA | 0.0012 | 0.4844 |
| 2019 | Kent | 0.0004 | 0.0006 | 0.0009 | 0.0015 | NA | 0.0003 | 0.3000 |
| | Herefordshire | 0.2189 | 0.1125 | 0 | 0 | NA | 0.0236 | 34.2500 |
| 2021 | Kent | NA | 0.0208 | NA | 0.1719 | NA | NA | 0.4688 |

**Table 2.2.3**. Grand mean numbers of capsid adults counted per 12 green cross vane perimeter traps in treatment plots per experiment block, during 4 years of push-pull trials in commercially grown strawberry. LRA = *L. rugulipennis* adults, LPA = *L. pabulinus* adults and LTA = *L. tripustulatus* adults.

| Year | County | LRA | LPA | LTA |
|---|---|---|---|---|
| 2017 | Kent | 0.250 | 0.453 | 0.000 |
| 2018 | Kent | 0.391 | 0.035 | 0.005 |
| 2019 | Kent | 0.639 | 0.000 | 0.002 |
| | Herefordshire | 4.879 | 0.016 | 0.274 |
| 2021 | Kent | 0.588 | 0.072 | NA |

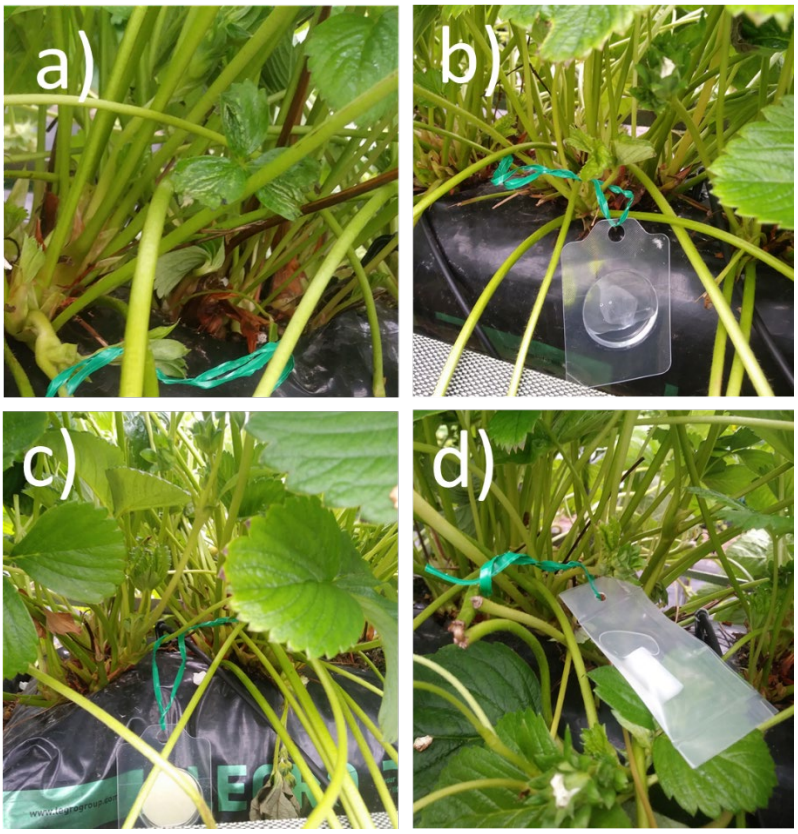



**Figure 2.2.9**. Sample photos from HB phytotoxicity assessment comparing plant foliage following ~1 month exposure to HB repellent sachets used in the push-pull trial 2021; a) control - no sachet; b) sachet containing dental roll soaked in 1 ml water; c) Russell IPM HB blister pack; d) Russell IPM 'thick wall' HB sachet.

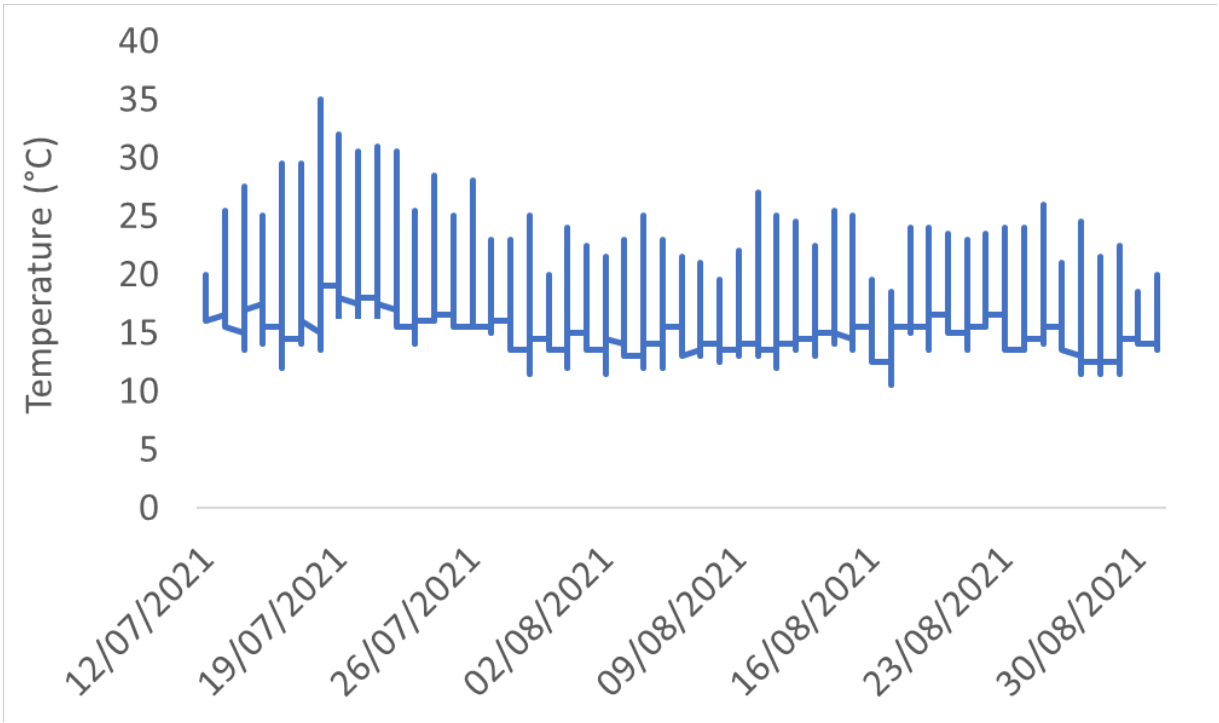


**Figure 2.2.10**. Temperature (°C) in the Polytunnel during the HB phytotoxicity experiment between 12 July (sachet attachment) and 31 August (phytotoxicity assessment).

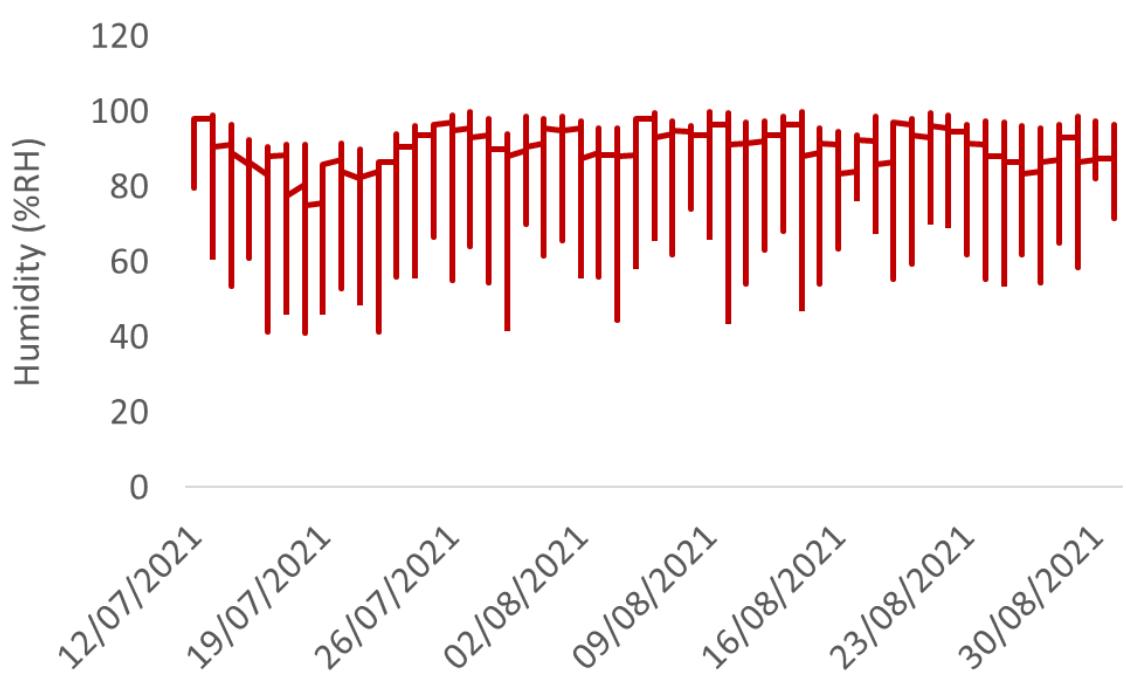



**Figure 2.2.11**. Humidity (%RH) in the Polytunnel during the HB phytotoxicity experiment between 12 July (sachet attachment) and 31 August (phytotoxicity assessment).

## Discussion

During the 2021 capsid push-pull trial in conventionally grown strawberry, we tested two potential commercial formulations of the HB dispenser in the push (both by Russell IPM) and whether increasing spacing of these HB dispensers in the crop, could reduce numbers of pest capsids and increase percent marketable fruit as effectively as the standard HB sachet (NRI) and 2 m spacing, previously demonstrated 2017 and 2019.

Both types of HB dispenser tested during this trial still contained HB after 6 weeks deployment in polytunnels. The amount of HB remaining in field sampled dispensers was determined by measuring weight loss (mg) daily for 7 days in the laboratory at constant 27°C, 8 km/h windspeed. Both types of HB dispenser released ~250 mg HB up to day 2. After day 2, blister packs stopped releasing HB, but “thick-wall” polyethylene sachets continued to release HB up to and including day 7. The average temperature was slightly higher during the 6 weeks period HB blister packs were deployed, compared to HB “thick-wall” polyethylene sachets (11.3ºC to 32.2 ºC, average 18.6 ºC and 8.9ºC to 28.9 ºC, average 17.5 ºC respectively) and humidity

slightly lower (44.1%RH to 97.1%RH, average 81.1%RH and 46.1%RH to 96.8%RH, average 81.6%RH).

Increasing spacing between HB dispensers may have been as effective at lowering numbers of capsids as the standard 2 m spacing, however, low numbers of capsids over the whole trial period meant that this could not be confirmed with any certainty. However, analysis of treatments by assessment, found at assessment 3 (10 to 17 August), there were significantly fewer capsid nymphs in 5 m and 20 m HB spacing plots compared to control (mean = 0.57, 0.07 and 2.64 respectively, $P = <0.001$).

Consequently, there was no significant impact of the treatments on fruit damage which was low in all plots. Low numbers of capsid nymphs were present in the 2021 trials (mostly *L. pabulinus*) and adult *L. rugulipennis* (mean = 0.5 and 0.02 respectively), compared to organic crops in Herefordshire in 2019, when push-pull treatments significantly reduced capsid damage to fruit by up to 80%. At the latter site there were considerably more capsid nymphs (mostly *L. rugulipennis*) and *L. rugulipennis* adults per 50 plants (mean = 34.3 and 0.1 respectively) (Table 2.2.2). Low numbers in 2021 might be attributed to the rather wet and cold summer which may not have been ideal for capsids.

More conclusive data is needed on the effectiveness of HB dispensers at increased spacing in the crop. *L. pabulinus* was the dominant species in strawberry in 2021 on our trial sites and is considered less damaging than *L. rugulipennis* (Alford 2007). A trial in crops with a history of high numbers of pest capsids (primarily *L. rugulipennis*) and fruit damage (as in 2019) is recommended.

Findings from this trial have promising implications for cane fruits. Numbers of *L. pabulinus* in the crop were reduced by all treatments compared to the control, and there was no significant difference in effectiveness with increases in HB spacing. *L. pabulinus* was the main pest capsid recorded during the capsid repellent trial in raspberry (Year 1 of this project), when HB was effective at reducing *L. pabulinus* numbers in the crop at 2 m spacing. This trial suggests, increasing HB spacing up to 20 m might be equally effective in cane fruits, but this would need to be tested due to the larger and more complex canopy.

In contrast to findings in the crop 2021, the main adult capsid species recorded in perimeter traps was *L. rugulipennis. L. pabulinus* was also caught, but in lower numbers (grand mean = 0.9 and 0.15 and respectively). Green cross vane traps are more effective at catching *L. rugulipennis,* whereas blue sticky traps are more effective for *L. pabulinus.* Perhaps encouragingly, statistical analysis found no significant difference between trap catches of both capsid species and push-pull treatments, suggesting increasing HB spacing does not affect the pull, but more conclusive data is advised.

Statistical analysis of numbers of beneficials recorded per plot during tap sampling, found no significant treatment effect. Beneficials counted in the crop with numbers suitable for statistical analysis were Aeolothripidae, Anthocoridae spp., Chrysopidae spp., Coccinellidae spp., Hemerobiidae spp. nymphs, parasitoid Hymenoptera spp. and Syrphidae spp.. Analysis of numbers of beneficials recorded per plot in perimeter traps also found no significant treatment effect. Beneficials counted in traps with numbers suitable for statistical analysis were Araneae spp., Chrysopidae spp., Coccinellidae spp., Hymenoptera spp., and Syrphidae spp. These findings are consistent with 2019 experiments, supporting the compatibility of push-pull with IPM in commercial strawberry.

Following 7 weeks attachment close to the crown of separate strawberry plants, no phytotoxic effects of the HB dispensers were observed.

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

## Conclusions

- Both types of HB dispenser tested during this trial still contained HB after 6 weeks deployment in polytunnels. HB “thick-wall” polyethylene sachets had at least 600 mg of HB left, whereas HB blister packs had up to 250 mg.
- More conclusive data is needed to confirm whether increasing HB dispenser spacing beyond 2 m in the crop, reduces pest capsids and respective fruit damage.
- Low numbers of capsids were found in the crop during the 2021 trial. Most were likely *L. pabulinus* (adults and nymphs). Although a damaging pest to strawberry, *L. pabulinus* has previously been considered less significant as a pest to strawberry (Alford 2007).
- A trial in crops with a history of high numbers of capsids (primarily *L. rugulipennis*) and fruit damage (as in 2019) is recommended.
- Findings from this trial suggest we might be able to increase HB spacing in cane fruit crops and maintain *L. pabulinus* control, but this would need to be tested.
- There were no noticeable adverse effects on numbers of beneficials in the crop (consistent with 2019 trial findings) therefore push-pull should be incorporated as part of an IPM approach.
- HB dispensers had no phytotoxic effects on strawberry plant foliage.

## Task 2.3. Ability of Orius to predate the capsid, Lygus rugulipennis juvenile stages (Year 1, Lead; NIAB EMR)

### Introduction

The AHDB Soft Fruit Panel identified capsids as a key pest of soft fruit crops in the UK. Capsids, such as the European Tarnished Plant Bug (*Lygus rugulipennis* Poppius), cause direct crop damage by feeding on developing fruits (Easterbrook, 2000). This results in deformation known as 'cat-facing', making the fruit unmarketable. Chemical Plant Protection Products (PPP) are typically relied on to supress capsid populations. However, conventional use of broad-spectrum insecticides for capsid control may disrupt biological-based Integrated Pest Management strategies used for other major pests, such as Western Flower Thrips *Frankliniella occidentalis* (Pergande) (WFT). SCEPTREplus Review SP 39 highlighted the sector's comments that capsid damage has become more frequent and of higher impact because of PPP withdrawals (e.g. chlorpyrifos, thiacloprid), increased reliance on biological controls for other pests, and increasing average UK temperatures.

These changes in the UK soft fruit industry, including uncertain pesticide approvals, a reduced range of active ingredients, and associated insecticide resistance, increase the need for effective, new and novel, non-pesticide control methods. Providing growers with a range of alternative control measures is essential to prevent reliance on a single strategy and to allow them to choose the most appropriate method to achieve robust and satisfactory capsid control in a variety of situations.

The enhanced use of commercially available biocontrols has been identified as one potential method. Anecdotal information from UK growers indicates that the presence of *Orius laevigatus* (Say), used to control WFT in the summer months, may also reduce capsid numbers. This was supported by data collected in project SF 174 where fewer *L. rugulipennis* were found in tap samples of crops in which *Orius* had been released.

The aim of this study was to investigate the possible role of *Orius* in capsid predation in soft fruit crops, and specifically to determine the ability of *O. laevigatus* to predate juvenile stages of *L. rugulipennis* in the laboratory.

## Methods

The trial was conducted in the laboratory at NIAB EMR, Kent, between July and November 2021. Environmental settings were controlled to represent summer field conditions; 16:8 hours light dark cycle, at 20°C.

*Culture Establishment: L. rugulipennis* were collected by sweep-netting areas of wild host plants (including *Chenopodium*), adjacent to cultivated strawberry, at the NIAB EMR site, Kent. Six sweep events were conducted between early July and early September.

Male and female *L. rugulipennis* adults were identified by visual assessment in the field and used to establish breeding cages. In the laboratory, *L. rugulipennis* were transferred into clear, ventilated, Perspex boxes (20 x 12 x 8 cm), housed within a medium Bugdorm (47.5 x 47.5 x 47.5 cm) (Figure 2.3.1). Each box contained damp paper to maintain humidity and prevent desiccation of the insects. Bee-collected pollen was offered as a protein source. Fine green beans (*Phaseolus vulgaris*) were provided both as a food source and as a medium for egg-laying *L. rugulipennis* females (Figure 2.3.2). Beans were removed and replaced in the breeding cages twice weekly and inspected for *L. rugulipennis* eggs under the microscope. For egg predation assessments, beans containing eggs were transferred directly into the bioassay set up.

Remaining *L. rugulipennis*-exposed beans were placed in clear, ventilated, Perspex emergence boxes with dry filter paper (Figure 2.3.3) and were monitored for hatching. Newly hatched juveniles (1$^{st}$ instar, Figure 2.3.4) were collected from emergence boxes and used to establish cultures in 9 cm Petri dishes, lined with filter paper dampened with distilled water, and containing a green bean as a food source (Figure 2.3.5). The bean and filter paper were replaced weekly, or as required. It was noted that in the small volume of a petri dish the bean provided enough humidity for instars 3-5. The filter paper was therefore left dry in the 3-5$^{th}$ instar petri dishes, helping to prevent mould growth.

*O. laevigatus* were supplied and purchased from Bioline (Oriline L 250 ml bottle containing 2000 nymphs) ahead of bioassays. Bottles were stored with a humidity box within a small Bugdorm (30 x 30 x 30 cm) (Figure 2.3.6). These consisted of Perspex boxes filled with blue roll, soaked in water with the Oriline bottle placed on top. The Bugdorm was covered with an additional layer of polythene to preserve humidity. The *Orius* were not starved prior to use in any of the bioassays based on advice from ADAS.

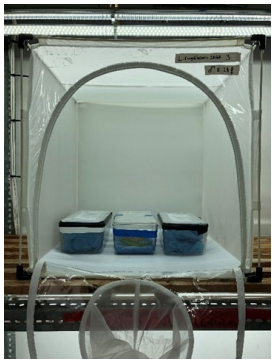


**Figure 2.3.1.** Medium Bugdorm, housing breeding cage (centre) and humidity boxes

**Figure 2.3.2.** Interior of prepared laboratory breeding cage showing damp paper, bee-collected pollen and green beans

**Figure 2.3.3.** Emergence box containing green beans with confirmed *L. rugulipennis* eggs

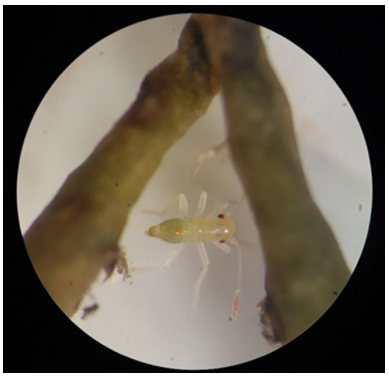


**Figure 2.3.4.** Newly hatched *L. rugulipennis* nymph with green bean, shown under microscope

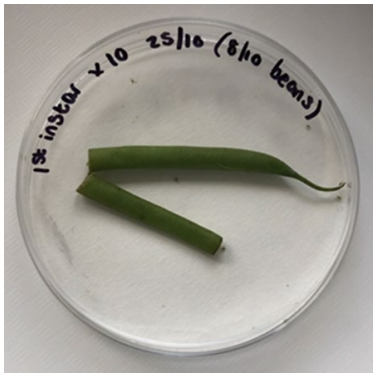



**Figure 2.3.5.** 1st Instar culture containing 10 individuals, collected from emergence boxes on 25/10/21, from beans collected from breeding cages 08/10/21

**Figure 2.3.6.** Oriline L 250ml bottle containing 2000 nymphs on top of humidity box within a small bugdorm. A sheet of polythene was placed over the bugdorm to preserve humidity

*Egg Predation Bioassays*

The number of eggs per bean were recorded by counting visible eggs under a microscope at x 24 magnification. An individual bean was placed in each filter paper-lined 9 cm Petri dish, and a single *Orius* (adult or 3rd stage nymph) introduced. *Orius* mortality was assessed at 24 and 72 hours, at which point all *Orius* were removed. Beans were kept in emergence boxes for three weeks post-*Orius* removal. *L. rugulipennis* nymph emergence was recorded and compared to the original egg count. The number of eggs and nymphs where *Orius* had been introduced, were compared to untreated controls in which no *Orius* was present.

*Nymph Predation Bioassays*

Nymphs were collected at the appropriate life stage (instar 1-5). Either a single, or five *L. rugulipennis* nymphs of the same stage were transferred to a filter paper-lined 9 cm Petri dish containing a green bean as a food and humidity source. A single *Orius* (adult or 3rd stage nymph) was introduced. The number of live/dead *L. rugulipennis* nymphs and *Orius* were assessed at 24 and 72 hours. This was compared to untreated controls in which no *Orius* were introduced; the natural mortality of *L. rugulipennis* nymphs was assessed at 24 and 72 hours. Survival of the *Orius* was also recorded.

*EthoVision Assessments*

EthoVision® XT is a video tracking system that automatically records animal activity and movement within a specified arena. This software was used to record the behaviour of *Orius* in relation to *L. rugulipennis*, particularly to assess whether *Orius* spent more time in the vicinity of the *L. rugulipennis* exposed beans than the area of the bean which had not been exposed to *L. rugulipennis* eggs.

The arena constituted an unvented 9 cm Petri dish, placed on a lightbox within an otherwise dark room, at an ambient temperature of 23°C. A camera on a stand was focused directly onto the Petri dish, at an angle of 90° to minimise distortion, and was connected to a computer (in another room) via ethernet cable. Resolution was set to 1280 x 1024, and frame rate 25 frames per second.

A length of bean containing *L. rugulipennis* eggs was placed on one side of the dish, and a similar length of unexposed bean was placed on the opposite side of the petri dish. The position of the beans was alternated between replications in case location had any impact on *Orius'* choice and to exclude directional bias.

A background image was taken and the area of the arena, and zones of the *L. rugulipennis* exposed bean and unexposed bean were specified in the EthoVision software (Figure 2.3.9). Calibration of the arena size allowed EthoVision to calculate measurements such as distance

travelled by the *Orius*. An individual *Orius* (adult or 3rd stage nymph) was introduced to the arena, the Petri dish closed, and detection settings used to identify the centre-point of the *Orius* (Figure 2.3.10) enabling the software to track the *Orius* through the duration of the trial. A period of 10 seconds was stipulated before video acquisition began to allow us time to leave the room. To prevent any disturbance that could impact the *Orius*'s behaviour, no personal re-entered the room until the trial had concluded. Video acquisition was visible on the computer monitor and was recorded for 24 hours (Figure 2.3.10).

In addition to a media file, EthoVision recorded numerical tracking data, including Mean Time Spent in Zone (seconds). This data was used for statistical analysis of the choice test.


**Figure 2.3.7.** Nymph Predation Treatment Bioassay – showing filter paper-lined, 9cm petri dish, halved green bean, instar 5 *L. rugulipennis* nymph (L) and *O. laevigatus* nymph (R)

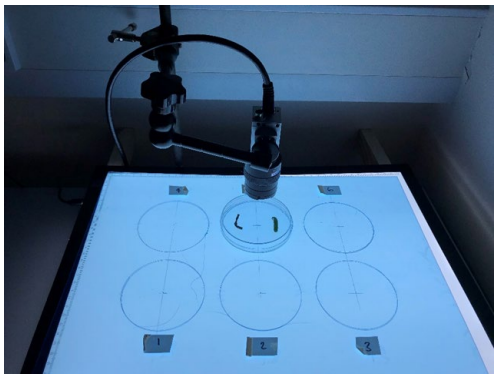


**Figure 2.3.8.** EthoVision set-up: camera on stand, at 90° to 9cm petri dish arena, containing lengths of green bean (*L. rugulipennis*-exposed and unexposed) and an *O. laevigatus* nymph, placed on a light box

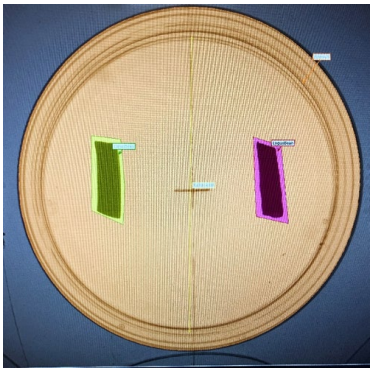


**Figure 2.3.9.** EthoVision software showing specified arena (orange circle), calibration (yellow line) and specified areas of *L. rugulipennis* exposed bean (purple) and unexposed bean (green)

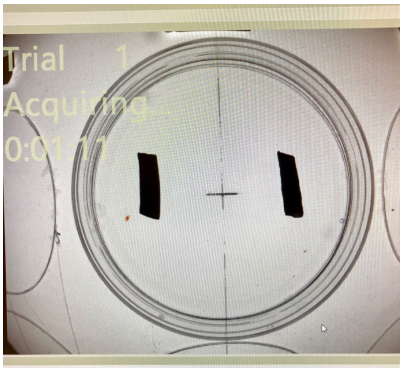



**Figure 2.3.10.** EthoVision acquiring trial video. The beans are visible and the *O. laevigatus* can be seen on the left of the dish (yellow with a red dot marking its centre-point)

## Statistical analysis

*Replication*

Table 2.3.1 displays the number of replicates collected over the course of the trial for each predation bioassay excluding the EthoVision analysis.

| *Lygus rugulipennis* Life Stage | Total Replicates Completed | Treatment Replicates Completed | Control Replicates Completed |
|---|---|---|---|
| Egg | 44 | 39 | 5 |
| Instar 1 | 86 | 43 | 43 |
| Instar 2 | 95 | 46 | 49 |
| Instar 3 | 50 | 23 | 27 |
| Instar 4 | 37 | 16 | 21 |
| Instar 5 | 35 | 17 | 18 |

*Egg predation*

The total amount of nymph emergence per 25 eggs was assessed using a quasipoisson model with a log link. Dunnettx post hoc test was performed to assess effect of *Orius* stage on egg predation.

*Nymph predation*

For the 24-hour exposure analysis, analysis of deviance was performed using a binomial model with logit link. For the 72-hour exposure analysis a 2x ANOVA was performed using a binomial model and logit link. Tukey method was used for comparing a family of 5 estimates for the 72-hour assessment comparing between *Lygus* instars. Test were performed on the log odds ratio scale.

## Results

*Egg predation*

Although there were fewer *Lygus* nymphs in *Orius* treated replicates there was no significant reduction in comparison to the control (Figure 2.3.11 left). There was a slight reduction in *Lygus* nymph emergence in the presence of *Orius* nymphs compared to *Orius* adults, but this was also not significant (Figure 2.3.11 right).

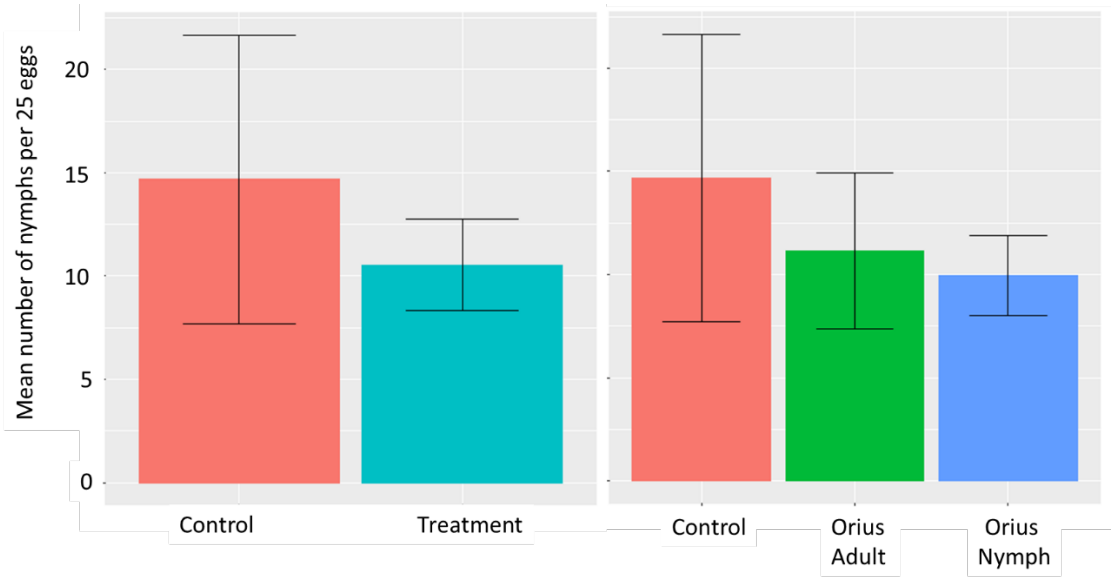



**Figure 2.3.11**. Mean number of *Lygus* nymphs to emerge from 25 eggs from green beans exposed to *Orius* (turquoise bar) and untreated (red bar) (left). Mean number of *Lygus* nymphs to emerge from 25 eggs from green beans exposed to *Orius* adults (green bar), *Orius* nymphs (blue bar) and untreated (red bar) (right)

*Nymph predation*

Overall, there was a significant difference in probability of death between treated and untreated trials regardless of *Orius* stage (adults or nymph) and *Lygus* instar stage at the 24-hour assessment ($\chi^2_{(1)}$ = 20.47, P=6.05 x $10^{-6}$) (Figure 2.3.12 left). For the 72-hour trial, there was also a significant effect of treatment on probability of death regardless of *Lygus* instar ($\chi^2_{(1)}$ = 28.94, P=7.45 x $10^{-8}$) (Figure 2.3.12 right). However, all treated replicates included *Orius* nymphs, and no adults were used in the 72-hour exposure. For both 24- and 72-hour exposures there was a 17 and 18% probability of death in the *Orius* treatments (regardless of *Lygus* instar and *Orius* stage) compared to <0.01 and 0.02% in the controls respectively.

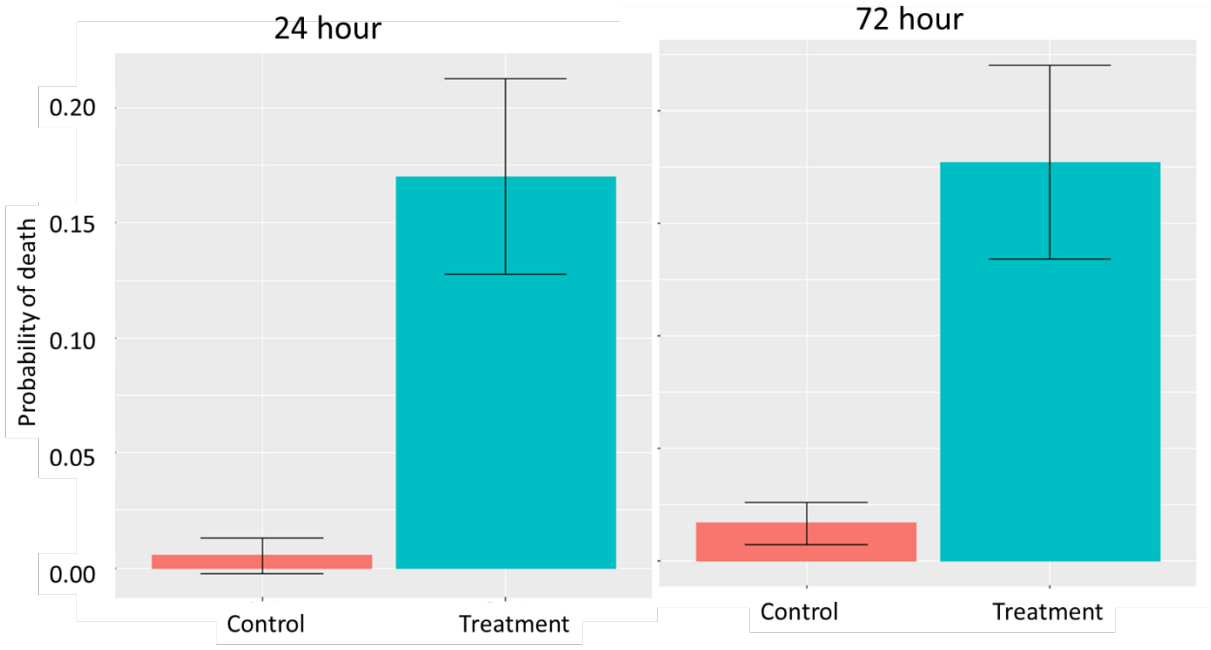



**Figure 2.3.12.** Overall probability of *Lygus* death in control (orange bar) and *Orius* treated (blue bar) trials, regardless of *Orius* and *Lygus* stage. Assessments taken at 24 hours (left) and 72 hours (right) of exposure. Please note the axis scale is as a probability of 1, with 1.00 as complete death and 0.00 as complete survival.

Within the 24- hour exposure assessments, 1st and 2nd instar *Lygus* had a significantly higher probability of death than the other *Lygus* stages. For the 1st instar *Lygus*, both stages of *Orius* resulted in significantly higher probability of death than the control (*Orius* adults to control P=0.03, *Orius* nymph to control P=0.04) (Figure 2.3.13 left). There was no significant difference in probability of death between *Orius* stage on 2nd instar *Lygus* although a higher probability of death occurred in the adults *Orius* treatment compared to the nymph *Orius* treatment (Figure 2.3.13 right).

Within the 72-hour exposure there was a significant difference between the *Lygus* stages ($\chi^2_{(4)}$ = 9.53, P=0.04) with 1st, 2nd and 4th instars having a higher probability of death than the 3rd and 5th (Figure 2.3.14).

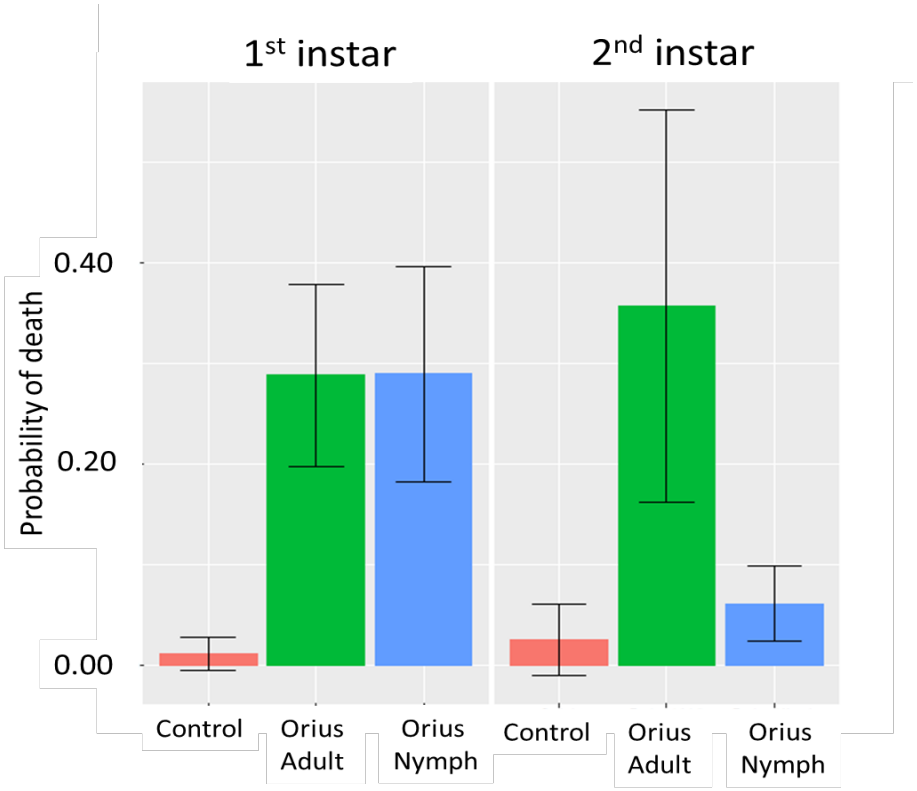



**Figure 2.3.13.** Probability of death in 1st (left) and 2nd (right) instar *Lygus* in untreated (red bars), *Orius* adult (green bars) and *Orius* nymph (blue bars) treatments after 24-hours of exposure. Please note the axis scale is as a probability of 1, with 1.00 as complete death and 0.00 as complete survival.

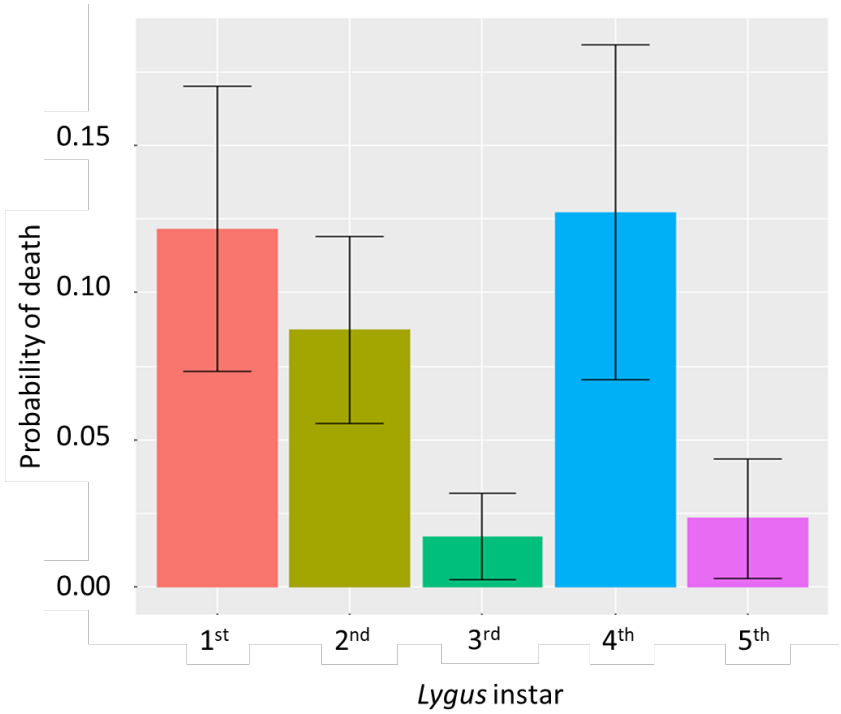


**Figure 2.3.14.** Probability of death of 1st (red bar), 2nd (yellow bar), 3rd (green bar), 4th (blue bar) and 5th (purple bar) *Lygus* instars in *Orius* treated replicates after 72-hours of exposure. Please note the axis scale is as a probability of 1, with 1.00 as complete death and 0.00 as complete survival.

*EthoVision*

Figures 2.3.15- 2.3.19 display the mean time (in seconds) that *Orius* spent in the vicinity of a clean (beans not previously exposed to *Lygus*) or *L. rugulipennis*- exposed green bean. This time is the mean from individual visits rather than overall time. From the five replicates of this experiment, *Orius* spent longer in the *L. rugulipennis*- exposed green bean area than the clean bean in three replicates. Due to technical issues, we have been unable to recover the raw data files from the EthoVision software and so have been unable to perform statistical analysis on this data.

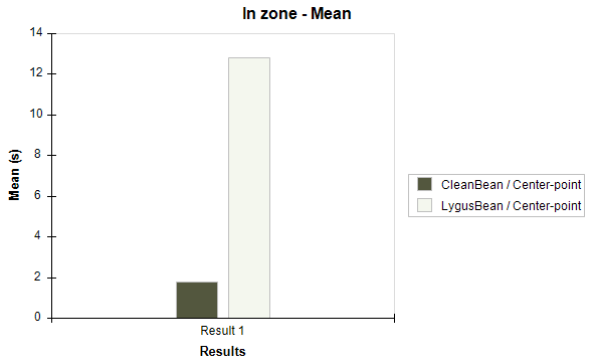



**Figure 2.3.15.** EthoVision 27/10/2021. Grey bar shows time on clean bean. White bar shows time on *L. rugulipennis* bean

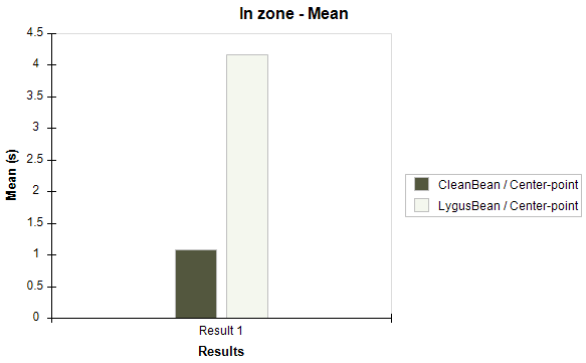



**Figure 2.3.16.** EthoVision 28/10/2021. Grey bar shows time on clean bean. White bar shows time on *L. rugulipennis* bean

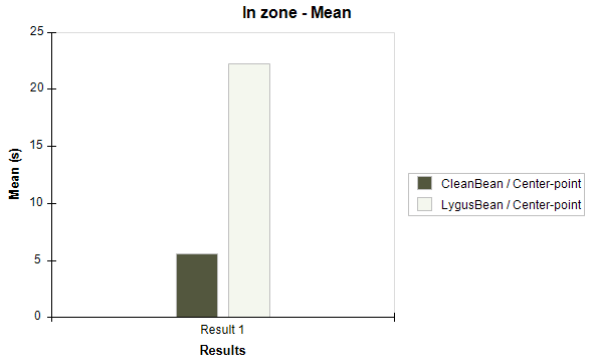



**Figure 2.3.17.** EthoVision 01/11/2021. Grey bar shows time on clean bean. White bar shows time on *L. rugulipennis* bean

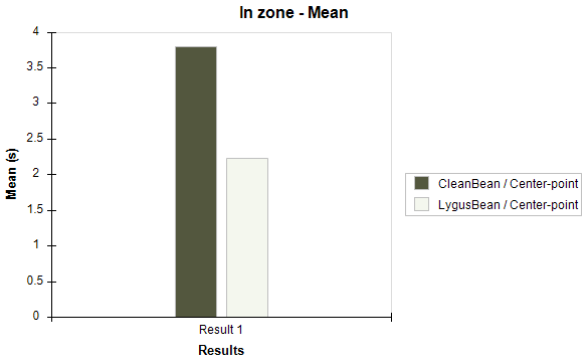



**Figure 2.3.18.** EthoVision 02/11/2021. Grey bar shows time on clean bean. White bar shows time on *L. rugulipennis* bean

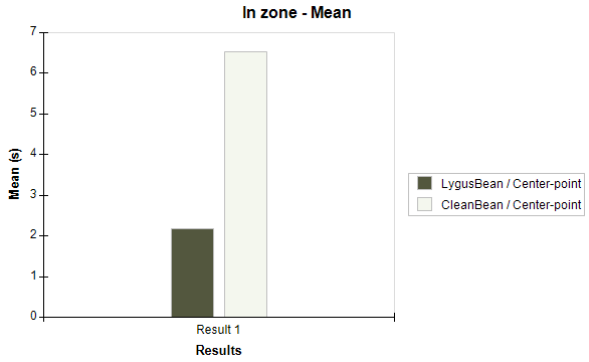



**Figure 2.3.19.** EthoVision 04/11/2021. Note legend opposite to other charts – Grey bar shows time on *L. rugulipennis*. White bar shows time on clean bean

## Discussion

Whilst not significant, there was a reduction in the number of *Lygus* nymphs that emerged from eggs in the presence of *Orius*. It appears that *Orius* nymph predation was higher than that of *Orius* adults, but again, this was not significant. The initial EthoVision data suggests that *Orius* spent more time in the vicinity of green beans which contained *Lygus* eggs over those that did not. This indicates there is some attraction to the eggs or where Lygus females have previously visited and there may be semiochemical signals to which the *Orius* is orientating. Counts of *Lygus* eggs prior to exposure to *Orius* were not reliable because some where missed. For example, sometimes more nymphs emerged from beans than the number of eggs that were counted, probably because the eggs were laid in areas not visible to the observer. Hence, unfortunately we are unable to calculate the percentage of predation.

Where *Orius* was introduced there was a significantly higher probability of *Lygus* death than in the untreated controls at both 24- and 72-hours of exposure. This was regardless of the stage of the *Orius* and regardless of the instar of *Lygus.* After 24-hours of exposure there was a significant difference in probability of death in *Orius* treated 1$^{st}$ and 2$^{nd}$ instar *Lygus*. For the 2$^{nd}$ instar, predation was higher from *Orius* adults compared to nymphs although this was not significant. Generally, *Orius* nymphs are thought to be the more voracious life stage however, this was not found to be the case as there was no significant differences between *Orius* adults and nymphs in any analysis.

After 72-hours exposure, 1$^{st}$, 2$^{nd}$ and 4$^{th}$ instar nymphs had a higher probability of death compared to 3$^{rd}$ and 5$^{th}$. However, even the highest probability was only 12.7% probability (4$^{th}$ instar) and so while it appears *Orius* presence does impact *Lygus* survival, it is minimal in its efficacy. It is likely that *Orius* will predate on both eggs and nymph stages of *Lygus,* but they would not solely control populations and should be used to contribute to other biological/organic control options. It is also not clear how the *Orius/Lygus* interaction results in predation in a strawberry crop and whether the main predation occurs during the Lygus moulting from one instar to the next or whilst they are feeding, as *Lygus* nymphs are very agile.

## Conclusions

- All experiments were completed under ideal conditions in the laboratory where *Lygus* nymphs were easily encountered by *Orius* resulting in optimum conditions for predation.

- Despite this, the mortality of *Lygus* by *Orius* was very low, although it was significantly higher than the controls in which no *Orius* was present.
- Generally, less than 20% mortality of *Lygus* occurred within 72 hours.
- It is not clear if predation happened when *Lygus* nymphs were moulting to the next stage – when at their most vulnerable, or when they were feeding and how this interaction would result in a strawberry crop.
- However, *Orius* do seem to orientate to beans with *Lygus* eggs.
- Although predation is low there could be disruption of *Lygus* in soft fruit crops by *Orius*, potentially by a semiochemical mechanism.
- The interaction of *Orius* and *Lygus* warrants further research.

# WP3. Enhance and augment biological control agents to target early aphid in protected crops

## Task 3.1. Promoting the control of early aphid in strawberry by augmenting and retaining aphidophagous hoverflies in the crop (Year 1/2, Lead; NIAB EMR, Contributors; NRI, Russell IPM, Koppert UK

### Introduction

Early season control of aphids in strawberry (particularly potato aphid, *Macrosiphum euphorbiae*) has become difficult to achieve in recent years. *M. euphorbiae* populations can persist in over-wintered crops, surviving at temperatures below freezing, continuing to grow and develop very slowly when the temperature exceeds just 1°C. Further, strawberry crops are typically forced to flower and crop early by the application of fleece and plastic covers from February. However, this can promote early development of aphid colonies that have overwintered in the crop, particularly *M. euphorbiae*. With the first warmer days of spring, the aphids start to grow and reproduce much more rapidly, leading to early outbreaks and damage. The loss of chlorpyrifos and thiacloprid leaves soft fruit growers with fewer conventional options for early season aphid control, especially when temperatures are too low for biopesticide efficacy. In addition, aphid colonies can be difficult to target with contact-acting PPPs in strawberry early in the season because they are often out of spray range in the crown of strawberry plants.

Hoverflies (Family: Syrphidae) are important predators of aphids early in the season. Adults have a high fecundity and larvae are voracious predators. A NIAB EMR PhD study demonstrated that the most common hoverfly species recorded visiting strawberry flowers were *Episyrphus balteatus, Eupeodes, Sphaerophoria, Eristalis* and *Platycheirus* (Hodgkiss et al. 2018). Of these, all except *Eristalis,* have larvae that feed on aphids (aphidophagous) (Ball and Morris 2015). However, hoverflies often only migrate into crops as pest populations increase, and thus too late in the season to prevent damaging populations of the pest from occurring.

Many plants respond to herbivore feeding by producing volatiles that act to reduce herbivore colonisation. These herbivore-induced plant volatiles (HIPVs) have been shown to be attractive to beneficial insects (Scutareanu et al. 1997; James 2005). One volatile, methyl salicylate, has been used to encourage beneficial insects including hoverflies, into a range of crops (James and Price 2004; James 2005, 2006; Mallinger et al. 2011; Zhu and Park 2005). In AHDB project TF218 (2015-2017) work by NIAB EMR and NRI confirmed the attractiveness

of methyl salicylate to hoverflies in apple orchards. Addition of other HIPV's, 2-phenylethanol and/or (E)-β-farnesene, gave increases in catches at certain times of the season and this was shown to be due to different effects on different species of hoverfly. 2-Phenylethanol is readily available and, since this research was completed, (E)-β-farnesene has also become a commodity chemical from Amyris (www.farnesene.net). More recently, NRI has worked with Olombria, a UK start-up company aiming to promote hoverflies as pollinators (www.flypollinator.com). Blends of HIPV's described in Nordstrom et al. 2017 were investigated in laboratory bioassays, and good electroantennogram (EAG) responses were obtained to a range of compounds that are candidate attractants (see also Primante and Dötterl 2010). Recently, at least three companies (e.g., http://polyfly.es/en/, https://www.flypollination.com/ (Olumbria), and www.bionostrum.com) have been successful in mass producing hoverflies for release in commercial crops.

These studies indicate there is considerable potential to improve the attractiveness of commercially available lures for beneficial insects, using readily available chemicals. Such lures do not require regulatory approval and we propose to optimise the lures and to use them in combination with augmentative releases of commercially available hoverflies in protected crops early in the season to attract and retain beneficial insects in the area where aphids are abundant in the crowns of the plants. The aims of this trial were to determine if:

1. Numbers of *M. euphorbiae* can be reduced in early spring, by releases of aphidophagous hoverfly
2. The MagiPal™ attractant retains aphidophagous hoverfly in the crop, further reducing numbers of *M. euphorbiae* on sentinel strawberry
3. The modified hoverfly lure enhances hoverfly retention and aphid predation
4. Treatments effect other beneficial arthropods

## Materials and methods

Trial sites: The trial was setup in 4 commercial strawberry crops (blocks) in Kent. Strawberries were polytunnel grown, June bearer varieties; Zara and Katrina (block 1), Murano (blocks 2 and 4) and Malling Centenary (block 3). Strawberries were grown conventionally in bags on tabletops (Fig. 3.1.1).

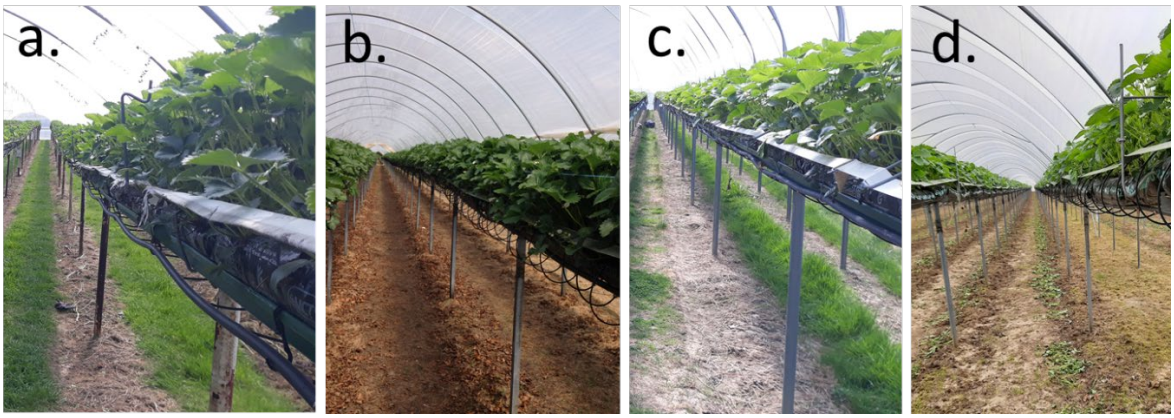



**Figure 3.1.1**. Photos of strawberry plantings in trial blocks during the aphidophagous hoverfly trial 2021; a) to d) Blocks 1 to 4 respectively.

Block layout: A randomised block design was used with four replicate blocks. Each block was sub-divided into four 30 x 30 m plots (Fig. 3.1.2) (4/5 polytunnels, depending on polytunnel width) comprising four treatments; 1) control, 2) hoverfly release only, 3) hoverfly release plus MagiPal™ lure, 4) hoverfly release plus NRI modified lure. Plots were mostly in the centre of separate strawberry fields, but if this was not possible, were >100 m apart and as far away from the edge as possible, to avoid hoverfly migration out of plots.

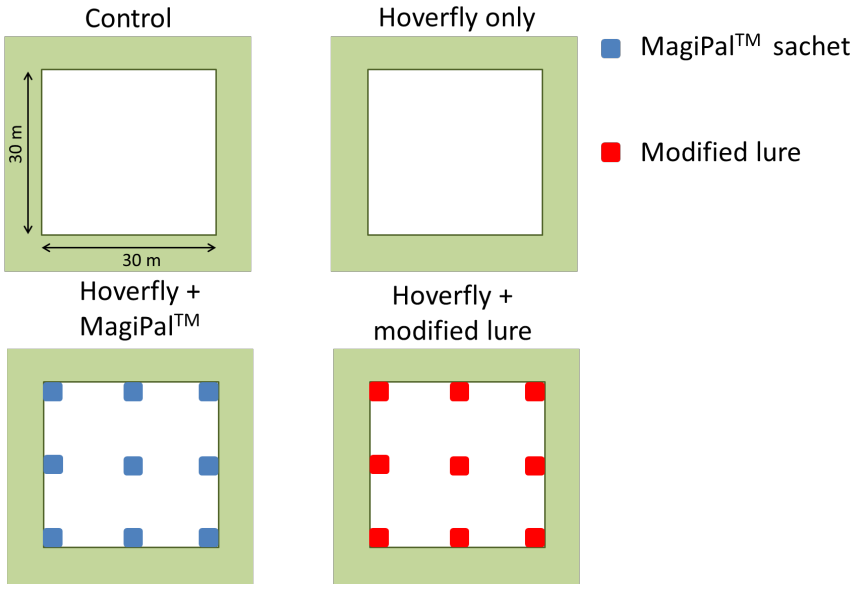



**Figure 3.1.2**. Diagrammatic representation of an experimental block of the aphidophagous hoverfly trial 2021. Each block consisted of four plots (>100 m apart, most in the centre of separate strawberry fields); 1) control, 2) hoverfly release only, 3) hoverfly plus MagiPal™ lure, 4) hoverfly release plus modified lure. Each plot spanned a 30 x 30 m area (4/5 polytunnels, depending on polytunnel width).

Treatments: Originally, *Sphaerophoria rueppelli* hoverfly (PredaNostrum, Koppert UK Ltd) were selected for release during the trial, but due to failed attempts to ship *S. rueppelli* into the UK during the period preceding the trial, another aphidophagous species, *Episyrphus balteatus* (Syrphidend, Koppert UK Ltd), was selected and shipped in for the trial. Hoverfly release commenced when minimum night-time temperature had exceeded 0ºC and daytime temperature was at least 8 ºC to 10 ºC. Details of treatments are:

1. **Control;** No lures, no hoverfly release.
2. **Hoverfly release only;** 7 days before sentinel plant deployment, an open container of *E. balteatus* (in-kind contribution by Jasper Hubert at Koppert UK Ltd) was placed in the plot centre (Fig. 3.1.3c).
3. **Hoverfly release plus MagiPal™ lure (Russell IPM);** 7 days before sentinel plant deployment, a grid of 3 rows of 3 MagiPal™ lures (9 total), spaced at 10 m intervals, were attached to strawberry plants in the plot (Fig. 3.1.3a), then an open container of *E. balteatus* was placed in the plot centre (Fig. 3.1.3c).
4. **Hoverfly release plus modified lure (NRI);** 7 days before sentinel plant deployment, a grid of 3 rows of 3 modified lures (9 total), spaced at 10 m intervals, were attached to strawberry plants in the plot (Fig. 3.1.3b), then an open container of *E. balteatus* was placed in the plot centre (Fig. 3.1.3c).

Lures and hoverflies were not renewed during the trial period (≤1 month).

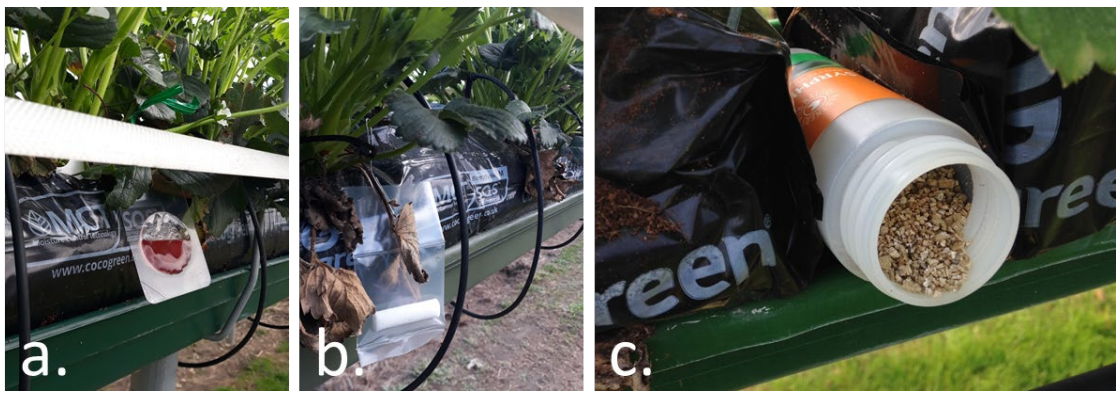



**Figure 3.1.3**. Hoverfly lure attachment to strawberry plants and hoverfly deployment during the aphidophagous hoverfly trial 2021; a) MagiPal™, b) NRI modified lure, c) tube of *E. balteatus* (Syrphidend, Koppert UK Ltd) wedged between strawberry grow bags in the plot centre.

At least two weeks prior to the trial start, growers applied an aphid clean-up spray (lambda-cyhalothrin/spirotetramat) to all plots. Growers were requested not to use insecticides immediately before and during the trial, to prevent residues harming hoverflies and sentinel

aphid. Data loggers recorded temperature and humidity throughout the experimental period in each crop (Appendix 3.1.1).

Assessments: Trial start was determined by temperature and crop flowering. Lures were deployed and hoverflies released when average daytime temperature exceeded 8°C and night-time was 0ºC or above, and all plots within a block were in flower (to provide pollen for hoverfly ovary development as advised by Jasper Hubert, Koppert UK Ltd).

The trial began on 15 April, when lures and hoverflies were first deployed at block 1, and ended 08 June, when the last assessment of block 4 sentinel plants was completed at NIAB EMR. See Table 3.1.1 for week numbers and dates of trial activities.

*Sentinel plants:* Sentinel plants carrying *M. euphorbiae,* were deployed at each plot to attract and compare hoverfly egg laying and subsequent aphidophagy. Seven days before deployment, 6 strawberry plants per plot (cv. Malling Centenary) were infested with 20 *M. euphorbiae* (nymphs and adults), then housed in Bugdorms (100 x 50 x 50 cm) according to plot designation and maintained at NIAB EMR (allowing aphids time to reproduce and produce honeydew and attractive volatiles). After 7 days, winged *M. euphorbiae* were removed. Numbers of *M. euphorbiae* on plants were not re-counted because it was assumed that aphid proliferation on each plant would be similar given that they were maintained under the same conditions. Plants were transported to their designated plots and placed in a hexagon formation around the plot centre (Fig. 3.1.4), anchored to the ground beneath tabletops (to be away from the tabletop plants) and ~5 m within the plot perimeter (Fig. 3.1.5a).

Initially at blocks 1 and 2, sentinel plants were left in the field 4 and 5 days respectively, but no hoverfly life stages were observed after collection. To give hoverflies more time to locate aphids and lay eggs on sentinel plants, at blocks 3 and 4, plants were left in the field 11 days and watered during this period to prevent wilting.

On the day of collection from plots, sentinel plants were kept separate according to plot, and brought back to NIAB EMR where 2 plants per plot were selected at random for destructive sampling. All aphids (dead & alive), hoverfly eggs and larvae and other arthropods were counted and recorded, then plant material frozen. The remaining 4 plants per plot were maintained in a Bugdorm (100 x 50 x 50 cm) (Fig. 3.1.6) for 3 weeks to provide enough time for all 1st generation hoverfly adults to emerge, but not second generation. During this period, hoverflies (larvae/pupae/adults), aphid (dead and alive), mummified aphid, and other arthropods were counted and recorded.

*Crop walk counts of aphid and hoverflies:* To compare numbers of aphid and hoverflies among plots, between 11:00 and 14:00, a 20-minute crop walk survey was done in all plots per block. During the survey, all aphids and adult hoverflies were recorded. This was done just before lure deployment (both aphids and hoverflies), then just before yellow sticky trap deployment (hoverflies only) and the day of yellow sticky collection a week later (aphids only); to allow more time for hoverfly larvae (if present) to reduce aphid numbers in treated plots.

*Yellow sticky traps*: To compare numbers of adult hoverflies between plots, on the day of sentinel plant collection, 6 yellow sticky traps were placed in a hexagon formation in each plot in positions hanging above sentinel plants just before they were collected (Figs. 3.1.4 and 3.1.5b). After 7 days, traps were brought back to NIAB EMR and adult hoverfly species caught on traps were recorded.

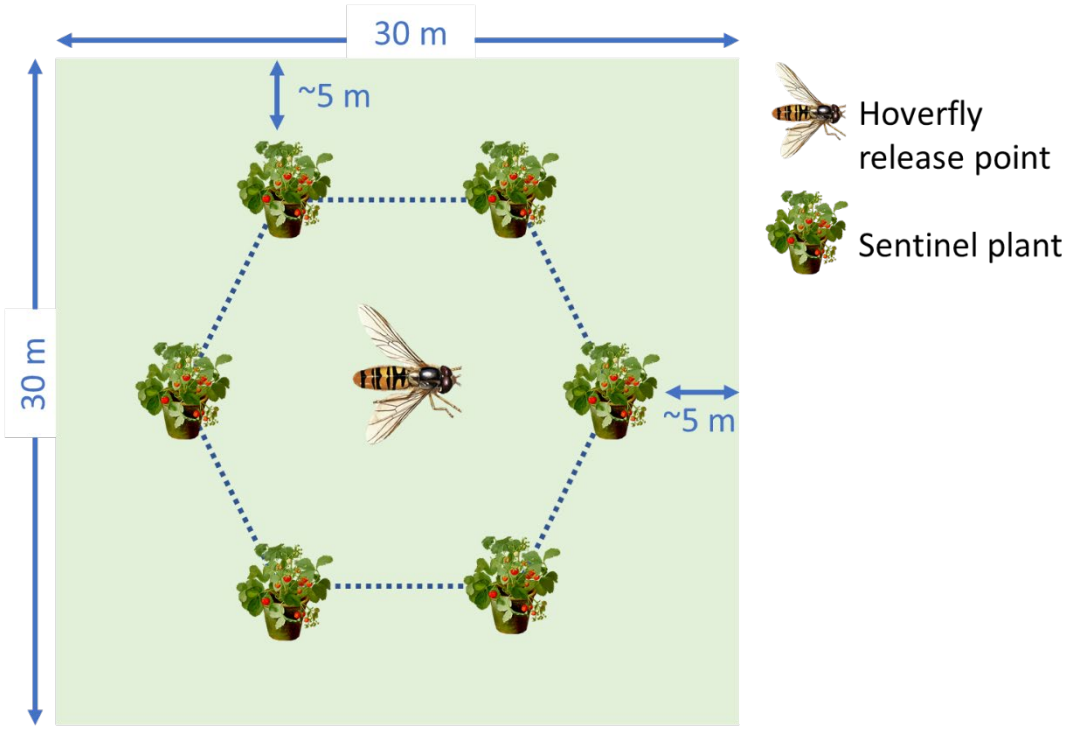



**Figure 3.1.4**. Diagrammatic representation of a plot during the aphidophagous hoverfly trial 2021. Hoverflies were released in the plot centre. Sentinel plants, each carrying *M. euphorbiae* aphid, were placed in a hexagon formation, equal distance from the plot centre to attract hoverfly egg laying (plants were ~5 m from plot perimeter).

**Table 3.1.1**. Weeks and dates of aphidophagous hoverfly trial activities at each block in 2021. Sentinel plants were left in the field 4 and 5 days at blocks 1 and 2 respectively, and 11 days at blocks 3 and 4.

| | Hoverflies and aphids counted in plots<br>Lures deployed | | Hoverflies counted in plots<br>Sentinel plant collection | | |
|---|---|---|---|---|---|
| | Hoverflies deployed | Sentinel plants deployed | Yellow sticky traps deployed<br>Portion of sentinel plants destructively sampled | Aphids counted in plots<br>Yellow sticky traps collected | Sentinel plant incubation end |
| Block | Week (date) | Week (date) | Week (date) | Week (date) | Week (date) |
| 1 | 15 (15 Apr) | 16 (22 Apr) | 17 (26 Apr) | 18 (03 May) | 20 (17 May) |
| 2 | 16 (22Apr) | 17 (29 Apr) | 18 (04 May) | 19 (12 May) | 21 (25 May) |
| 3 | 17 (29 Apr) | 18 (06 May) | 20 (17 May) | 21 (24 May) | 23 (07 Jun) |
| 4 | 17 (29 Apr) | 18 (07 May) | 20 (18 May) | 21 (25 May) | 23 (08 Jun) |

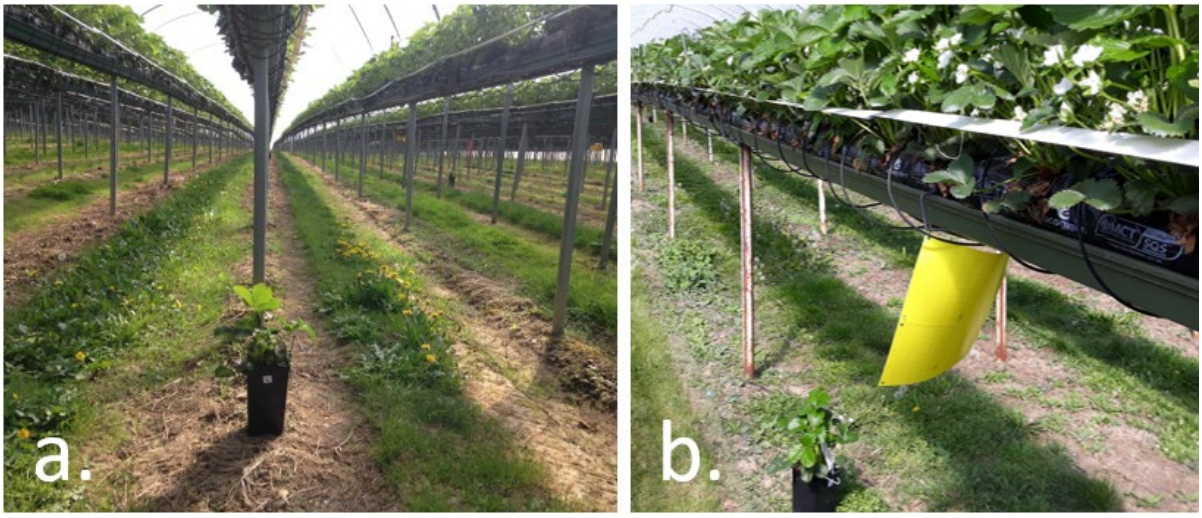



**Figure 3.1.5**. Positions of sentinel plants and yellow sticky traps during the aphidophagous hoverfly trial 2021; a) Sentinel plants were anchored to the ground beneath tabletops (to be away from the tabletop plants), b) Yellow sticky traps were hung from tabletops, above sentinel plant positions, before sentinel plants were collected.

**Figure 3.1.6**. Sentinel plant incubation during the aphidophagous hoverfly trial 2021. Following collection from the field, 4 plants per plot were maintained in a Bugdorm (100 x 50 x 50 cm) for 3 weeks at NIAB EMR, during which *M. euphorbiae*, hoverfly life stages and other arthropods were counted.

## Statistical analyses

To check for a correlation between mean *M. euphorbiae* and hoverfly eggs from sentinel plant destructive counts, an exploratory analysis was performed using ANOVA model with pseudo replication.

To compare numbers of other arthropods counted on sentinel plants according to treatment, an ANOVA analysis was performed with Poisson distributed data.

## Results

*Counts of* M. euphorbiae *and hoverflies on sentinel plants*

There was no clear data to suggest *M. euphorbiae* numbers on sentinel plants were affected by hoverfly and/or semiochemical attractants, probably because aphid numbers per plant after field collection were highly variable. Before deployment, each sentinel plant was infested with ~20 *M. euphorbiae.* Upon collection, grand mean *M. euphorbiae* per plant was 30 (ranging from 0 to 181) and at the end of incubation, grand mean *M. euphorbiae* per plant was 3.7 (ranging from 0 to 88, regardless of treatment).

From sentinel plant destructive counts, there was also no clear treatment effect. Grand mean *M. euphorbiae* per plant was 71.7 (ranging from 0 to 848, regardless of treatment).

There was no clear data to suggest hoverfly numbers on sentinel plants were affected by treatment, because hoverfly numbers per plant after field collection were mostly 0. At incubation end, grand mean hoverfly per plant was 0.08 (ranging from 0 to 2). Interestingly, hoverfly larvae were only found where there was a treatment, but this is unlikely to be statistically significant, because counts were mostly 0 per plant.

From sentinel plant destructive counts, there was also no clear treatment effect. Most plants had 0 hoverfly eggs and larvae, except 2 separate plants, 1 with 18 eggs (grand mean = 0.6), the other with 1 larva (grand mean = 0.03).

The plant carrying hoverfly eggs was collected from the hoverfly plot in block 3. Highest numbers of aphid (total per 2 plants = 1398) were counted on this plant and the other destructively counted, from the same plot (Fig. 3.1.7).

*Crop walk counts of aphid and hoverflies*

There was no clear data to suggest *M. euphorbiae* numbers on the commercial strawberry crop, during crop walks, were affected by treatment, because numbers per block and plot (40 plants) were highly variable. Aphid counts per block at yellow sticky trap collection ranged from 0 (blocks 1 and 4) to 2217 (block 3). Interestingly, at block 3, more than double the

number of aphids were counted in the control plot compared to hoverfly treated plots, but this is not statistically analysable due to only 1 replicate (Fig. 3.1.8).

There was no clear data to suggest adult hoverfly numbers counted during crop walks were affected by treatment, because numbers per plot (40 plants) were low and variable. At sentinel plant collection, a mean of 2 adult hoverflies were counted per plot. These were not identified to species.

There was no clear data to suggest adult hoverfly numbers counted on yellow sticky traps after a week in the field, were affected by treatment, because numbers per plot (6 traps) were low and variable. Grand mean hoverfly per plot was 0.14 (ranging from 0 to 2). Of the 13 hoverflies recorded in total all plots, only 2 were the released species, *E. balteatus.* Both were caught at block 3; 1 in the control plot, the other in the modified lure plot.

*Other arthropods*

Most other arthropods recorded per sentinel plant with numbers suitable for statistical analysis were parasitoids (indicated by mummified aphid and adult parasitoids), but data shows no clear treatment effect (grand mean per plant = 0.3 and 0.05 respectively). From sentinel plant destructive counts similar numbers of both were recorded, but again data shows no clear treatment effect (grand mean per plant = 0.4 and 0.03 respectively).

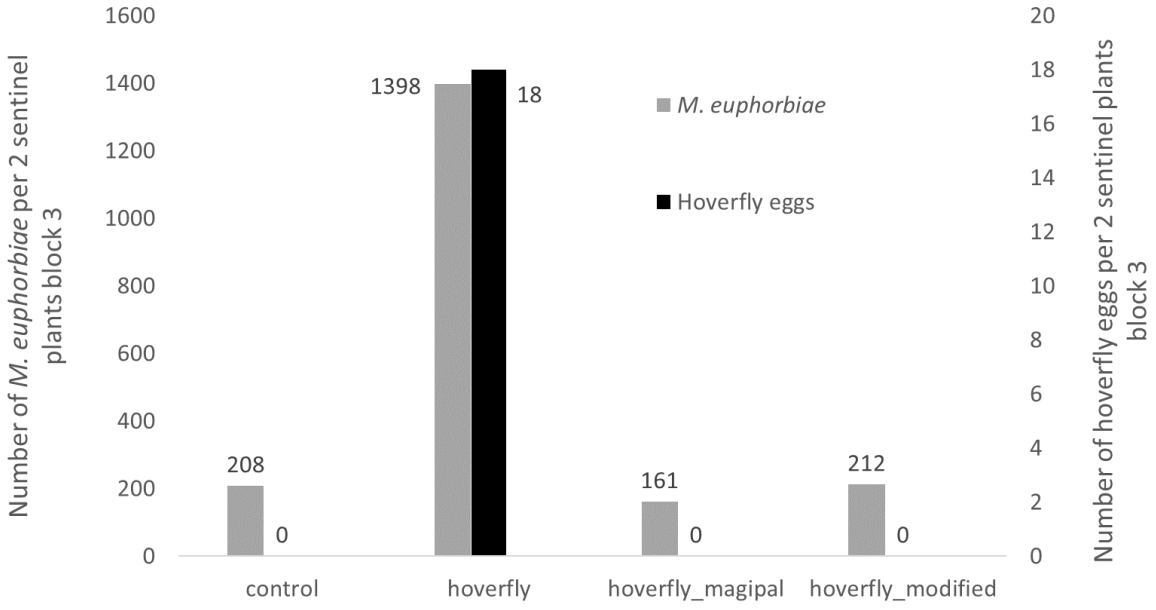



**Figure 3.1.7**. Total numbers of *M. euphorbiae* and hoverfly eggs counted per 2 sentinel plants at each plot in block 3 during the aphidophagous hoverfly trial, 2021. Counts were done the day plants were collected from the field.

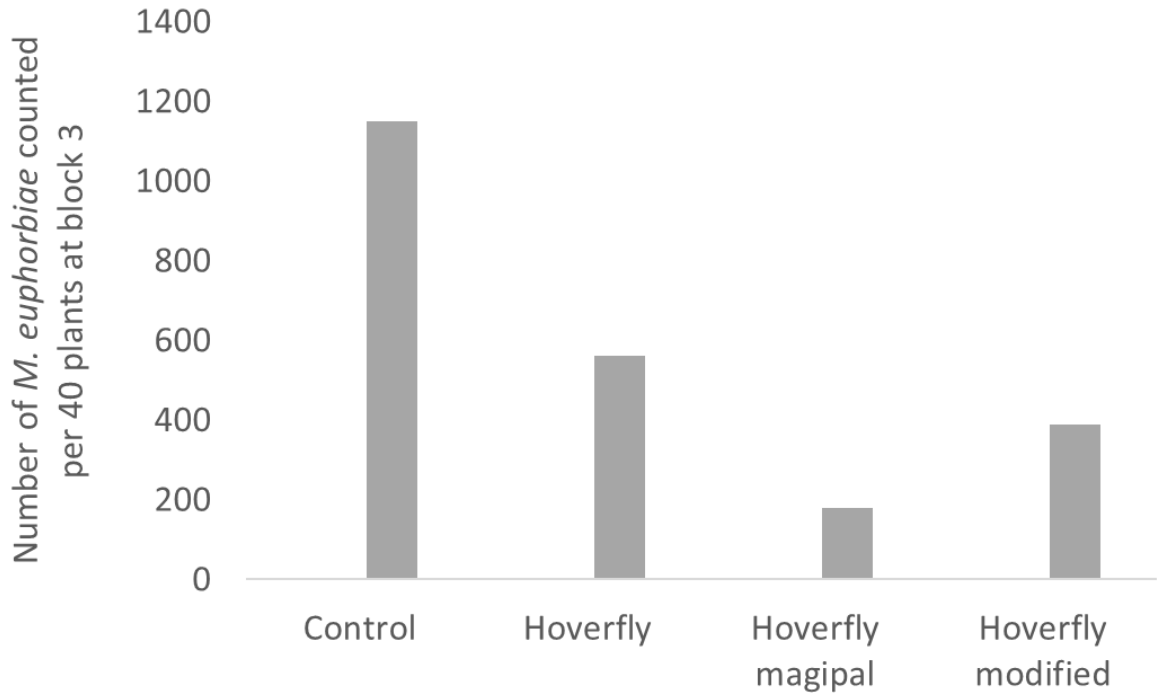



**Figure 3.1.8**. Aphids counted during the second crop walk at block 3 of the aphidophagous hoverfly trial, 2021. More than double the number of *M. euphorbiae* were counted in the control plot compared to treated plots. This data is from 1 replicate only.

## Discussion

During the 2021 aphidophagous hoverfly trial in polytunnel grown commercial June bearer strawberry, we tested whether *E. balteatus* can be deployed to reduce spring populations of aphids. In addition, we tested if this interaction could be enhanced using 2 types of hoverfly lure to retain aphidophagous hoverflies in the crops.

Findings were inconclusive. Sentinel plants, infested with equal numbers of *M. euphorbiae*¸ were deployed in the different treatment plots for 4 to 11 days exposure, then collected and a portion destructively counted, whilst the rest were incubated for 3 weeks. On both groups of plants, numbers of *M. euphorbiae* and hoverfly life stages were counted to compare hoverfly aphidophagy. Data was too variable to find a treatment effect. During sentinel plant destructive counts per plot, grand mean *M. euphorbiae* per plant was 71.7 (ranging from 0 to 848, regardless of treatment). Following incubation of remaining plants per plot, grand mean *M. euphorbiae* per plant had decreased to 3.7 (ranging from 0 to 88, regardless of treatment). Very few hoverflies were evident including egg, larvae and adults. During sentinel plant destructive counts per plot, most plants had 0 hoverfly eggs and larvae, except 2 separate plants, 1 with 18 eggs (grand mean = 0.6), the other with 1 larva (grand mean = 0.03).

Following incubation of remaining plants per plot, grand mean hoverfly per plant was only 0.08 (ranging from 0 to 2).

Low *M. euphorbiae* establishment and proliferation on sentinel plants during this trial might have been why a treatment effect was not witnessed. Despite plenty of young leaf growth in the crown of sentinel plants, populations of *M. euphorbiae* did not increase much between the day of infestation (~20 *M. euphorbiae* per plant) to the day of collection from the field (grand mean = 50% increase) and decreased between day of collection to incubation end (3 weeks later), including those from control plots (grand mean = 87.8% decrease). For comparison, on linseed, *M. euphorbiae* were reported to produce a mean of 23.3 offspring per female within 7.7 days (Lamb et al. 2009) and on excised potato leaves, produced a mean of 67.3 offspring per female in 12 days (MacGillivray & Anderson 1958). Had *M. euphorbiae* increased at similar rates on sentinel strawberry plants during this trial, plants might have been more attractive to hoverfly egg laying. Hodgkiss et al. (2019) reported numbers of hoverfly eggs and larvae were positively correlated to aphid abundance. Indeed, the only plot where hoverfly eggs were found on sentinel plants (total per 2 plants = 18), was the hoverfly plot at block 3. These were the same 2 plants where the most *M. euphorbiae* (total per 2 plants = 1398) were counted during destructive counts on the day of collection. Numbers of *M. euphorbiae* on sentinel plants were comparatively low all other blocks and plots throughout the trial (grand mean per 2 plants = 26.3). During the final crop walk at block 3 (where most *M. euphorbiae* were recorded), more than double the number of *M. euphorbiae* were counted in the control plot compared to hoverfly treated plots. Although hoverfly life stages were not observed during the same crop walks, they might have been present in low numbers, but still enough to reduce aphid. Under natural field conditions, a single *E. balteatus* larvae will consume 400 aphids during its entire larval development period (Tenhumberg 1995). Tap sampling within plots might improve the chance of detecting low numbers of hoverfly larvae. Poor *M. euphorbiae* proliferation on sentinel plants during the trial was possibly due to the sentinel plants being on the ground where other predators (e.g. Carabidae) may have reduced aphid numbers in the strawberry plants. Also, due to unsuitable rearing conditions during incubation. Sentinel plants were maintained in Bugdorms during the 3-week incubation period. It is recommended that his method be reviewed if used again.

Hoverflies deployed during this trial were *E. balteatus. S. rueppelli* (PredaNostrum, Koppert UK Ltd) was originally recommended (personal correspondence with Jasper Hubert, Koppert UK Ltd), but could not be used due to extraordinary shipping complications during the period before the trial start. Of the 13 adult hoverflies recorded on yellow sticky traps during the whole trial, only 2 were *E. balteatus.* Both were caught at block 3, where most aphid were recorded during crop walks and on sentinel plants.

As a result of these findings, we cannot conclude the effectiveness of the 2 different types of hoverfly lure at retaining hoverflies in treated plots and enhancing aphidophagy.

Most other arthropods recorded on sentinel plants were parasitoids (indicated by mummified aphid and adult parasitoids), but data analysis of numbers recorded on sentinel plants found no clear treatment effect, because numbers were low (grand mean = 0.35 and 0.04 respectively) and variable.

## Conclusions

- Trial findings were inconclusive as to whether releases of aphidophagous hoverfly can reduce *M. euphorbiae* early in the season. We also cannot conclude whether the 2 types of hoverfly lure tested enhance aphidophagy in strawberry early in the season.
- This is potentially due to the sentinel plants being on the ground, where other predators (e.g. Carabidae) may have reduced aphid numbers in the strawberry plants.
- We recommend the position of sentinel plants in the crop and method of incubation is reviewed before being repeated. It would also be beneficial to count aphids 7 days after sentinel plants are infested to confirm aphids are reproducing sufficiently.
- Most other arthropods recorded on sentinel plants were parasitoids (indicated by mummified aphid and adult parasitoids), but we found no clear treatment effect, due to numbers being low and variable between replicates.

# Tasks 3.4. Parasitoids for aphid control in overwintered protected strawberry

## Introduction

Early season control of aphids in strawberry (particularly potato aphid, *Macrosiphum euphorbiae*) has become difficult to achieve in recent years. Unfortunately, potato aphid populations can persist in over-wintered crops, surviving at temperatures below freezing and continuing to grow and develop very slowly when the temperature exceeds just 1°C. With the first warmer days of spring, the aphids start to grow and reproduce much more rapidly, leading to early outbreaks and damage. The withdrawal of chlorpyrifos and thiacloprid leaves soft fruit growers with fewer conventional options for early season aphid control, especially when temperatures are too low for biopesticide efficacy. In addition, aphid colonies can be difficult to target with contact-acting PPPs in strawberry, early in the season, because they are often out of spray range in the crown of strawberry plants.

With limited insecticide options now available, growers are increasingly relying on releases of parasitoid wasps in early spring for aphid biocontrol. Two parasitoid species (*Aphidius ervi* and *Praon volucre*) can be particularly effective at parasitizing potato aphid. Both species are present in the mixed parasitoid products available to growers for aphid control on soft fruit (e.g., FresaProtect from Viridaxis, Aphiline Berry from Bioline), and *A. ervi* is also available separately from some biocontrol companies. However, there are three main possible areas of risk and uncertainty associated with release of parasitoids for early-season aphid control:

- Failure of parasitism due to low temperature
- Impact of insecticide residues on parasitism
- Failure of parasitism due to resistance

We aim to address some of these potential risks, so that growers can be better informed in releasing parasitoids appropriately (in terms of species and timing) for effective early season biocontrol of aphids. In addition, it was observed from work in SF 156 that some parasitoids may be surviving in aphids over the winter and ready to emerge the following spring giving a head-start to biological aphid control. However, it is difficult for growers to observe this hidden biocontrol and PPP harmful to emerging parasitoids maybe applied risking early season aphid control.

## Materials and methods

In 2021 three grower's sites that will over-winter strawberry crops and agreed to participate in this trial were selected. Two farms were in Kent, England and one in Angus, Scotland (Table 3.4.1).

**Table 3.4.1.** Crop, variety, and growing systems of trial sites 2021

| Site code | Crop | Variety | Growing system | Location |
|---|---|---|---|---|
| **1** | Strawberry | Majestic | Tabletop | Kent |
| **2** | Strawberry | Malling Centenary | Tabletop | Kent |
| **3** | Strawberry | Magnum | Tabletop | Scotland |

At each site, 4 tunnels infested with aphids were selected, each tunnel representing a plot. Plots (i.e., tunnels) were numbered 1 to 12 across the 3 sites (Fig. 3.4.1).

There was one baseline assessment per month, in August and September 2021. At each plot the tabletop plants were examined until 20 colonies of aphids from different random plants were sampled. A total 80 samples were taken per site, where possible, with variable size colonies. Aphid colonies were sampled from different vegetative material including leaves, flower trusses, and runners. Aphid abundance at site 3 (Angus, Scotland) was very low, therefore, it was only possible to sample 10 colonies at each plot (=tunnel) with a total of 40 samples per visit from this site.

Immediately after collection, each sample was placed in an individual 15 cm Petri dish. The cut petioles were inserted in a cotton ball soaked in 2% sucrose solution (Fig.3.4.2) and labelled with plot (1-12) and sample numbers (1-20).

Aphids were brought back to the laboratory and incubated at 20-23°C for 3 weeks. In the first 24 hours after collection, parasitoids and other aphid's predators were removed from the petri dishes. The size of the colony, parasitoids and aphid predators were recorded for each sample. Assessment of parasitoid emergence from aphids was done at 7, 14 and 21 days of incubation. On each assessment, and for each sample, the following was recorded: i) vegetative material sampled; ii) number of parasitoids emerged; iii) number of mummies present; iv) number of other aphid predators.

Aphids from sites 1, 2 and 3 were sampled and DNA extracted using a sodium hydroxide technique (modification of Klimyuk etal., 1993 and Stanton et al., 1998) and 1ul of the extract was amplified using PCR ready-to go beads (GE Healthcare). A 658bp region in the gene encoding the cytochrome c oxidase I (COI) was amplified using insect barcoding primers LCO1490 and HC02198 (Folmer et al., 1994; Herbert et al., 2003).

PCR products were purified using Qiagen PCR purification and sequenced directly using the BIGdye Terminator V3.1 kit (Applied Biosystems) and an AB13730XL sequencer. The sequence editing software Bioedit 7.0.5 was used to produce consensus sequences, and these were used to search the NCBI databases (GenBank, PubMed) for regions of sequence similarity using BLASTn.

Sequences from individuals collected at sites 1 and 2 matched sequences from Aphis fabae (black bean aphid). The sequence generated from site 3 aphid material matched Chaetosiphon fragaefolli (strawberry-aphid).

All parasitoids emerging during the incubation period were collected and stored in 70% ethanol for subsequent identification. Other natural predators found at each assessment were recorded and removed from the petri dish.

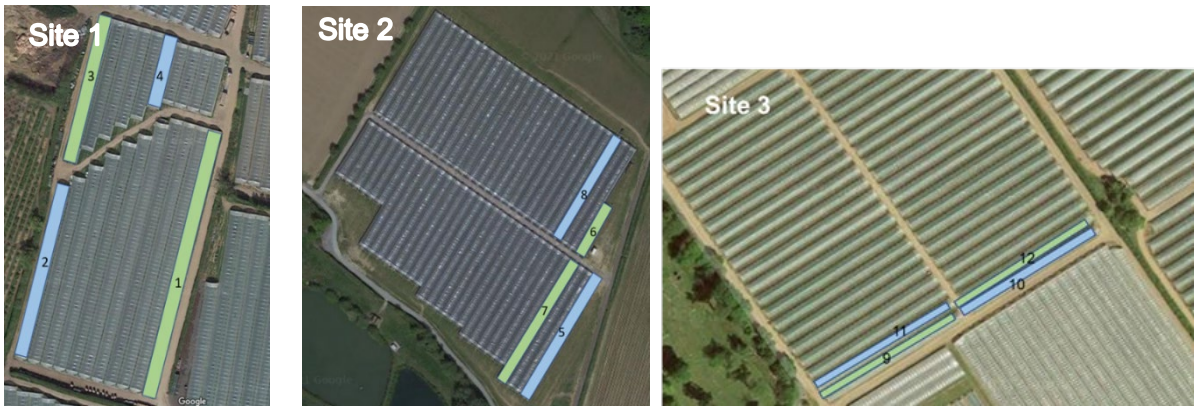



**Figure 3.4.1.** Aerial view and plot representation of the 3 sites used in this trial. Site 1 and 2 in Kent, England and Site 3 in Angus, Scotland. Plots are numbered and in 2022 will be subject to parasitoid releases (blue) or no parasitoid releases (green).

**Figure 3.4.2.** Mesocoms used for parasitoid rearing with cotton ball soaked in 2% sucrose solution (left). Incubated leaf infested with aphids (right).

In 2022, there will be 2 sampling occasions between February and March before any parasitoid release (fig. 3.4.3). After these samplings and depending on the spray programme of each farm a first release of a parasitoid mix product will be made at a rate of 0.25 parasitoids per plant. Approximately 2.5 weeks after the first release there will be another sampling occasion. The second release of parasitoids will happen shortly after this sampling. As before we will aim to sample the aphid population 2.5 weeks after the second release. Two more sampling occasions will take place at approximately 3-week intervals thereafter.

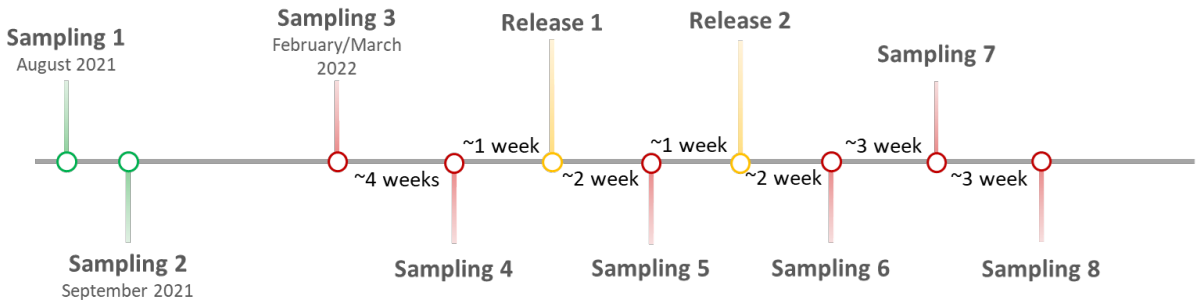



**Figure 3.4.3.** Timeline of sampling and treatments of the aphids in 2022.

## Results

*Site 1:* Aphids collected from the trial plots were incubated for 3 weeks. During that time, mummified aphids and emerging parasitoids were counted. Figure 3.4.4a shows the total number of parasitoids recorded per plot at each week of incubation in August. There was a different peak of parasitoid emergence for each plot. This was probably due to differences in parasitoid development stage in samples collected.

In August, the number of mummified aphids recorded was lower than the number of emerging parasitoids (Fig. 3.4.4b). The week in which the number of mummies was highest was different between plots. We observed higher numbers of both parasitoids emerging and mummified aphids in week 3 for plots 3 and 4. Identification of specimens collected on the 3rd week could help determine if there are different species of parasitoid emerging at that time.

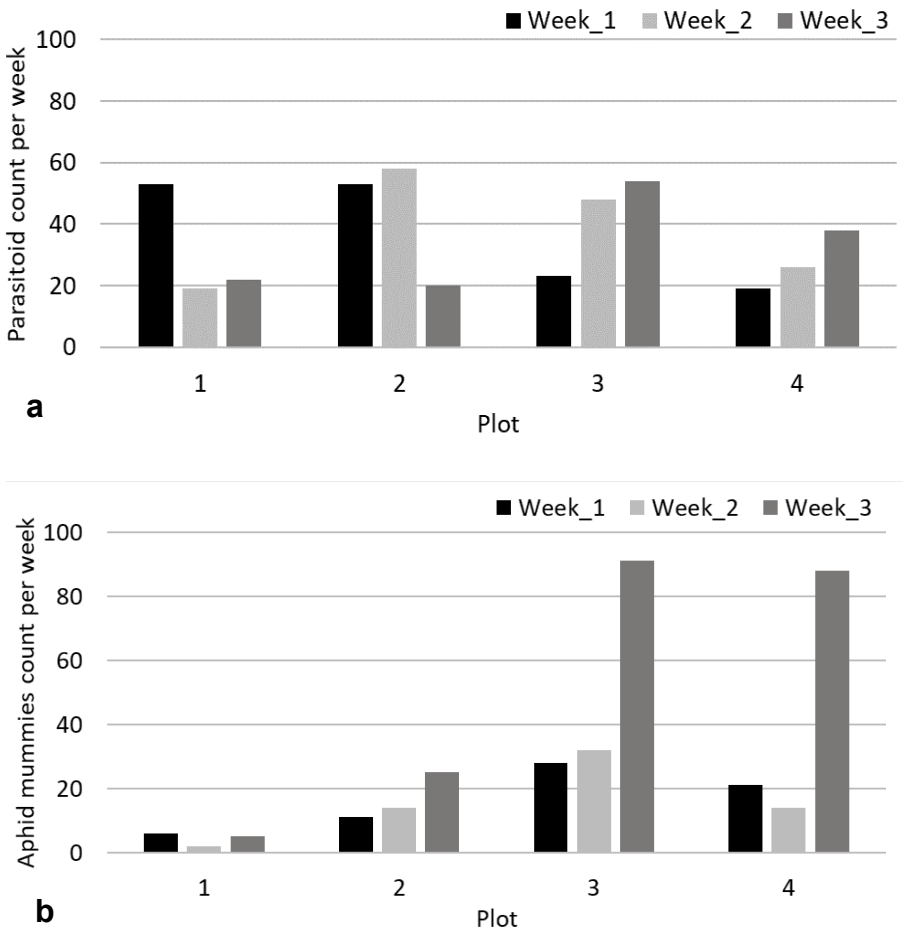



**Figure 3.4.4.** a) Total number of parasitoids and b) mummified aphids per plot (1-4) in August (site 1), 1, 2 and 3 weeks after beginning incubation.

In September, the numbers of mummified aphids and parasitoids emerging decreased in all plots when compared with numbers recorded in August (Fig. 3.4.5). Higher number of parasitoids emerged in the first week of incubation for samples collected at plots 1 and 2. However, for plots 3 and 4, parasitoid emergence was only recorded in week 2 of incubation. Most of the mummified aphids were observed in the first week of incubation for all plots. In September, higher numbers of mummified aphids were observed when compared to numbers of parasitoids emerging.

In August, aphids collected at site 1 were identified as *Aphis fabae* (Black bean aphid) using molecular analyses at JHI. This was confirmed by visual identification in September.

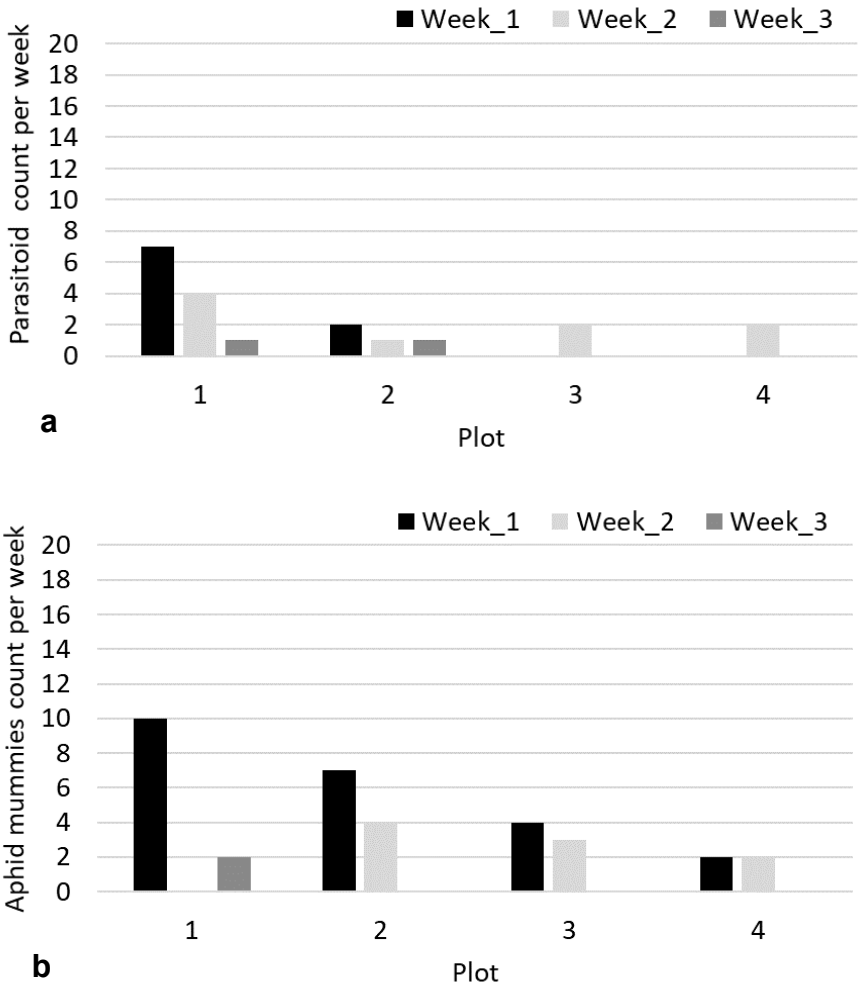



**Figure 3.4.5.** a) Total number of parasitoids and b) mummified aphids per plot (1-4) in September (site 1), 1, 2 and 3 weeks after beginning incubation.

Due to the large size of the colonies found at that time, colony size was classified in 3 classes for sites 1 and 2 located in England:

- **Class 1** <10 aphids
- **Class 2** 10 to 30 aphids
- **Class 3** >30 aphids

In August and September, the average size of the colonies was similar between the plots at Site 1 with colonies of 10 to 30 aphids (Fig. 3.4.6).

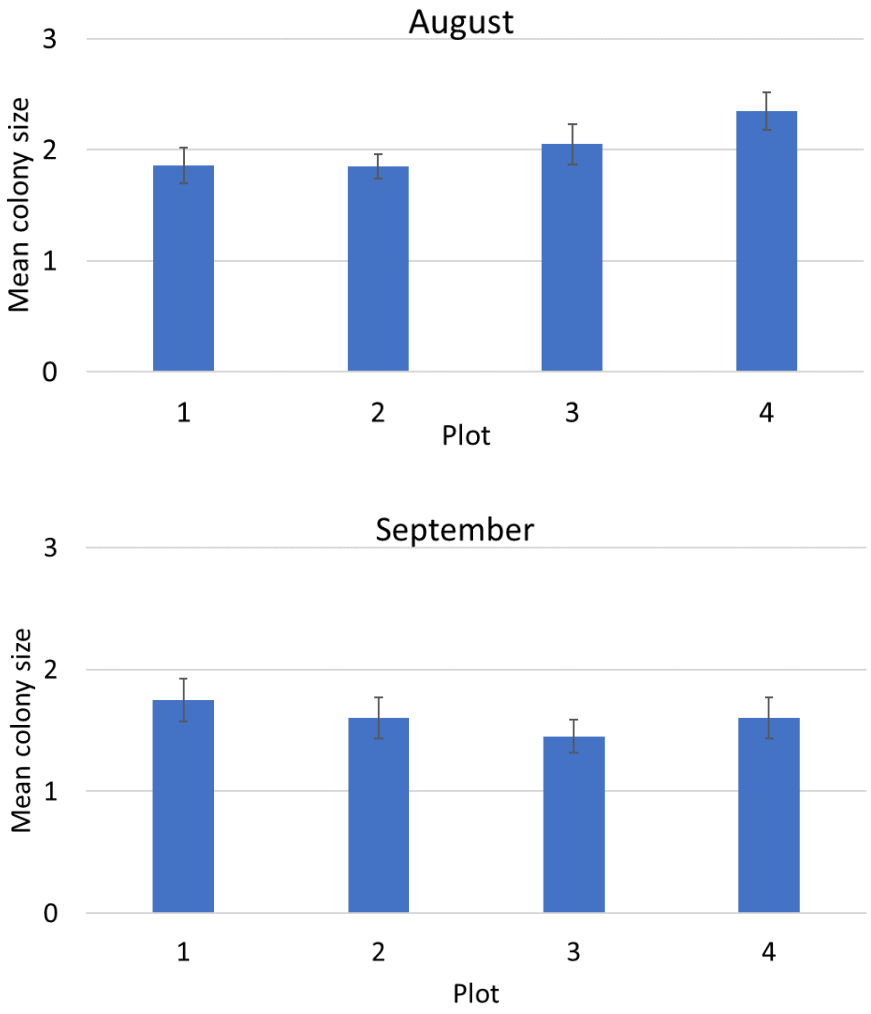



**Figure 3.4.6.** Average of classed aphid colony size per plot (1-4) in August (top) and September (bottom) at site 1. Class 1 - <10 aphids, class 2 - 10 to 30 aphids, class 3 - >30 aphids.

*Site 2:* In August, a total of 6 parasitoids emerged from site 2 over the 3 weeks of incubation and only one mummified aphid was found in plot 7 (Fig. 3.4.7). Colonies collected at site 2 were mostly small consisting of 10 aphids or fewer. In September, number of parasitoids

emerging from site 2 samples increased when compared to numbers recorded in August (Fig. 3.5.8). However, the colonies sampled in September were also bigger. No new mummified aphids were found after the first week of incubation.

Aphids collected were identified as *Aphis fabae* through molecular analyses in August. Due to degradation of the colonies, an accurate visual identification was not possible for Site 2 in September.

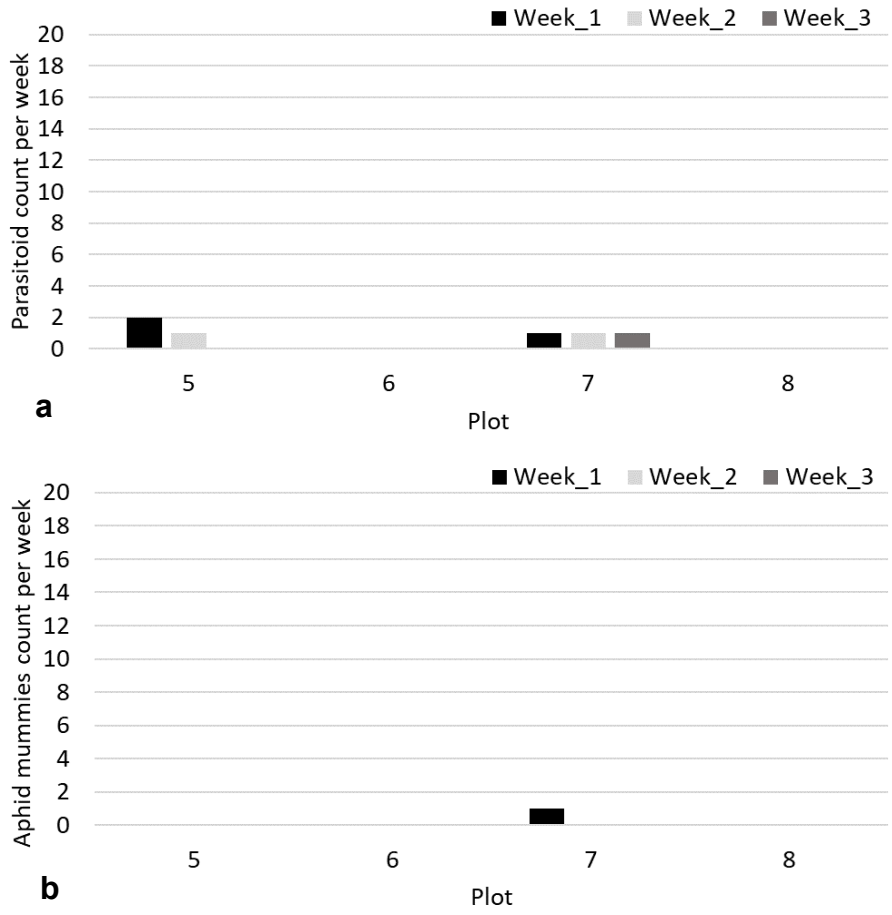



**Figure 3.4.7.** a) Total number of parasitoids and b) mummified aphids per plot (5-8) in August (site 2), 1, 2 and 3 weeks after beginning incubation

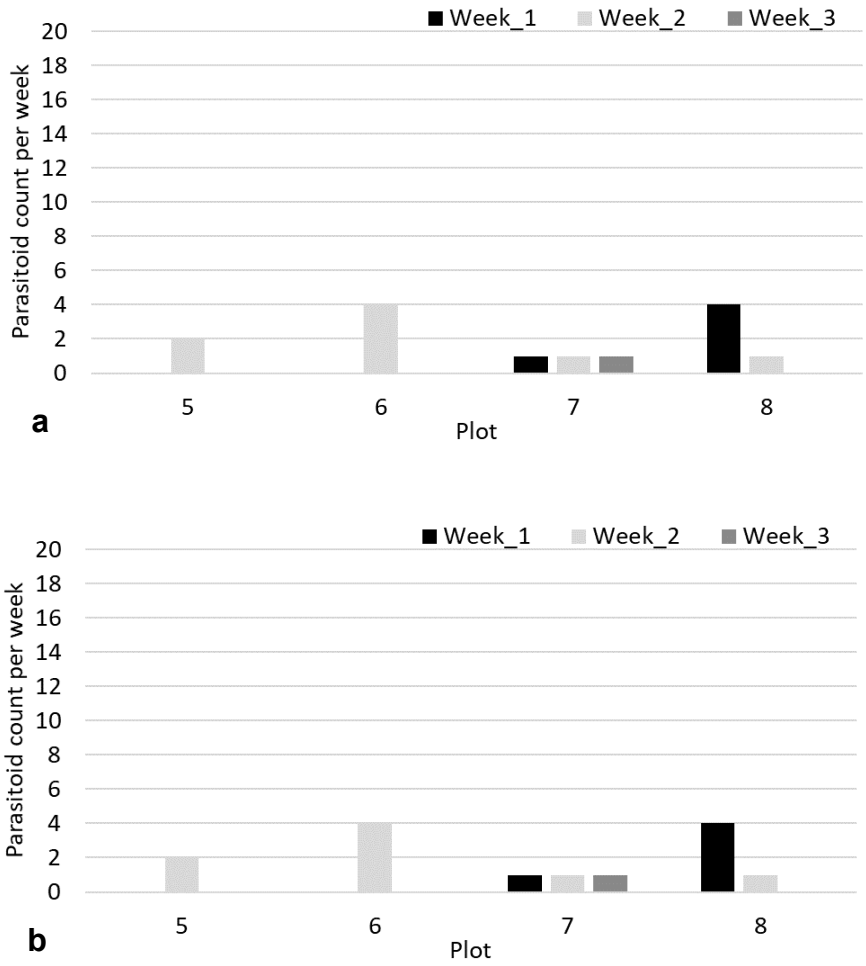



**Figure 3.4.8.** a) Total number of parasitoids and b) mummified aphids per plot (5-8) in September (site 2), 1, 2 and 3 weeks after beginning incubation.

The colony size at site 2 had a slight increase from August to September (Fig.3.4.9). This comes in accordance with the increase in number of parasitoids also recorded in September for this site.

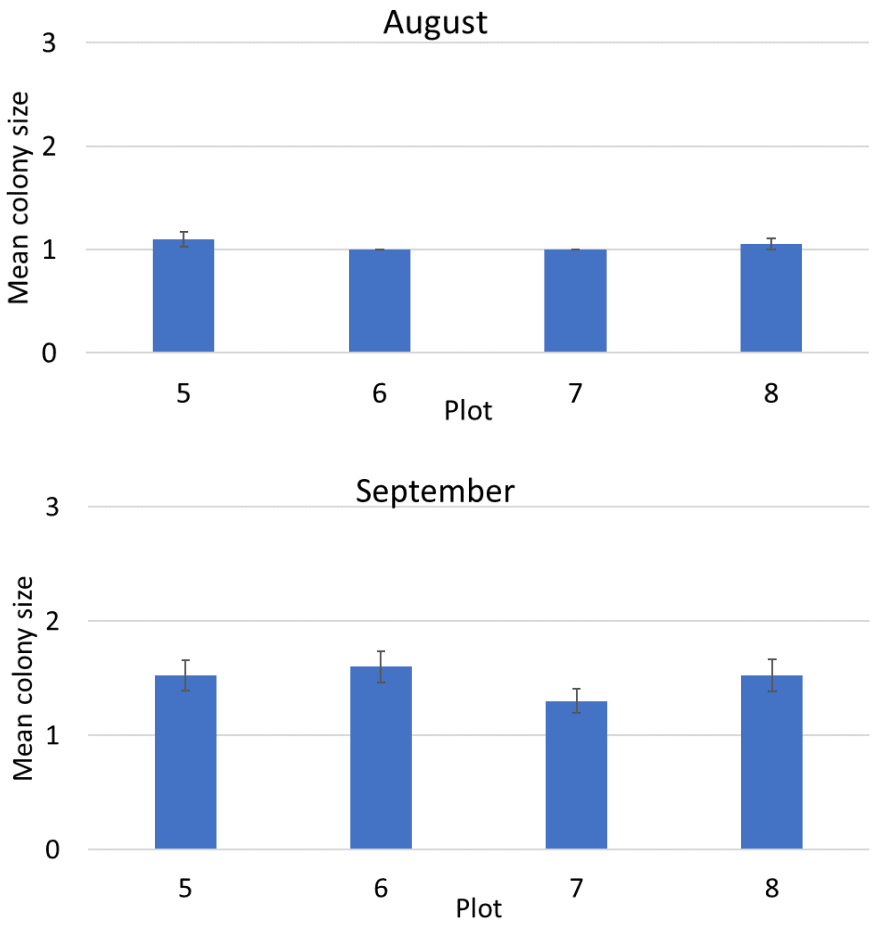



**Figure 3.4.9.** Average of classed aphid colony size per plot (5-8) in August (top) and September (bottom) at site 2. Class 1 - <10 aphids, class 2 - 10 to 30 aphids, class 3 - >30 aphids.

*Site 3:* Figure 3.4.10a and b shows the total number of parasitoids and mummies recorded per plot at each week of incubation in August. As with sites 1 and 2, in September, the number of mummified aphids and parasitoids emerging decreased in all plots when compared with numbers recorded in August (Fig. 4.3.11a and b). Aphids collected at site 3 were identified as *Chaetosiphon fragaefolli* (strawberry aphid) using molecular analyses.

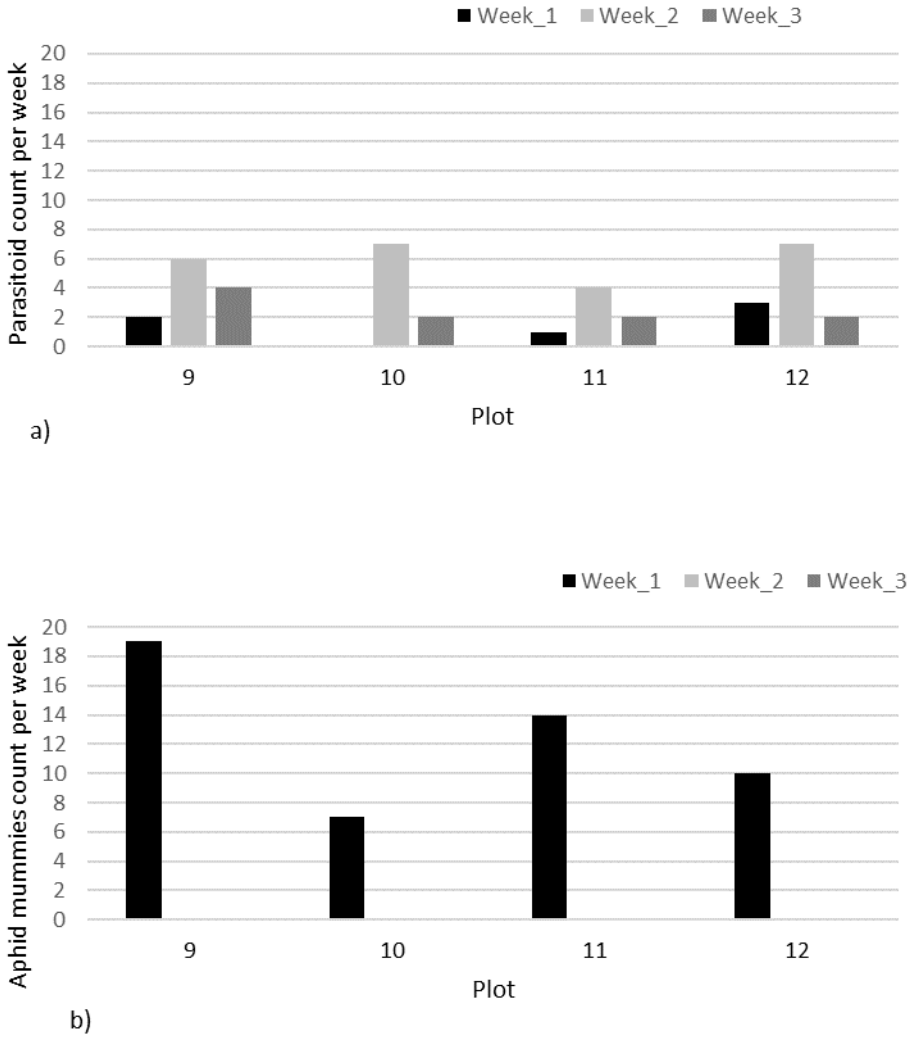



**Figure 3.4.10.** a) Total number of parasitoids and b) mummified aphids per plot (9-12) in August (site 3), 1, 2 and 3 weeks after beginning incubation.

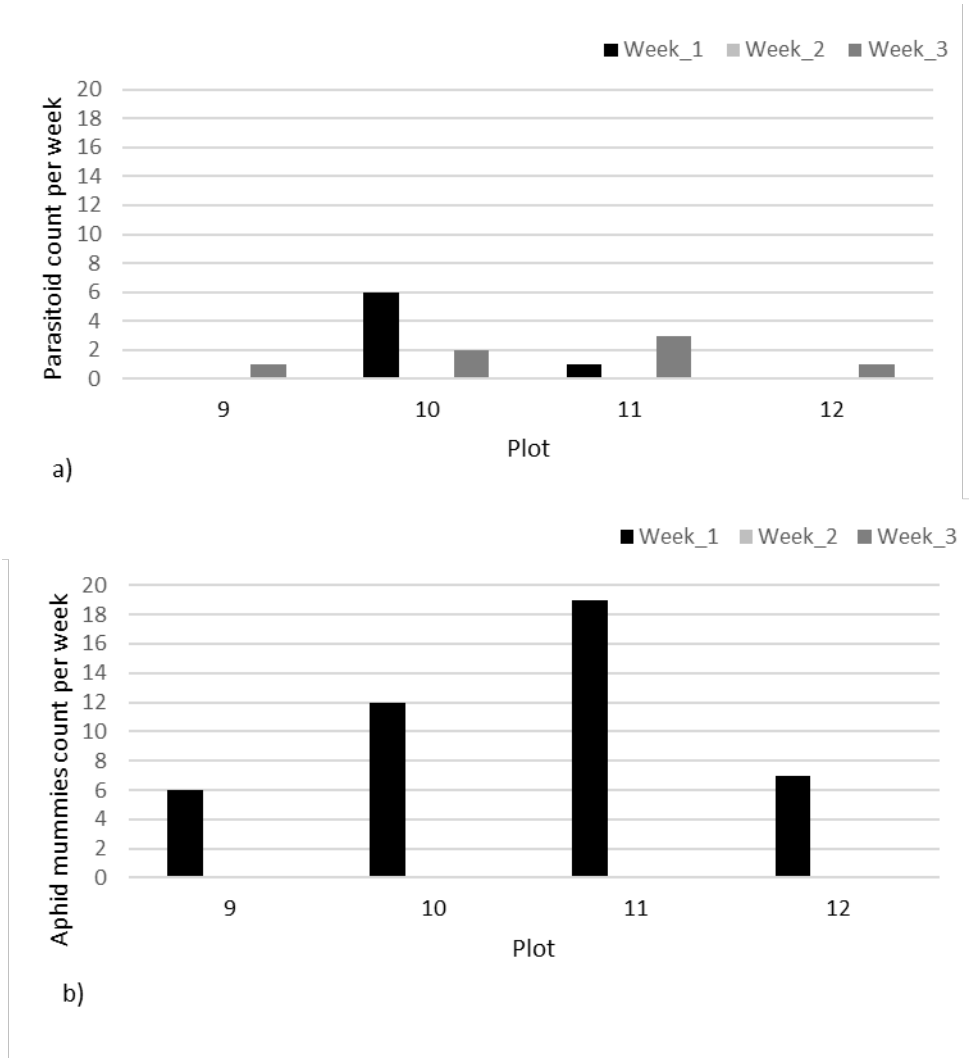



**Figure 3.4.11.** a) Total number of parasitoids and b) mummified aphids per plot (9-12) in September (site 3), 1, 2 and 3 weeks after beginning incubation.

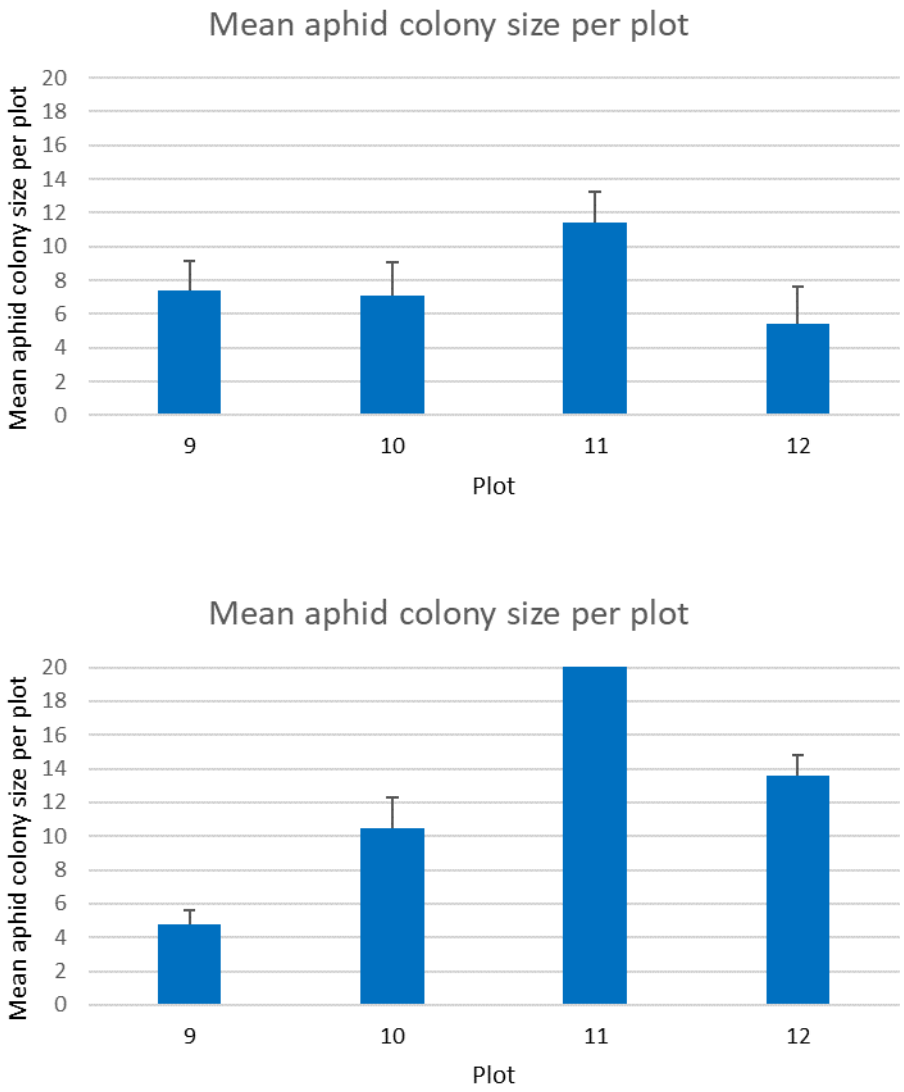



**Figure 3.4.12** Average aphid colony size per plot (9-12) in August (top) and September (bottom) at site 3.

The average size of the colonies was not classified for site 3 as the abundance of aphids was lower than at sites 1 and 2. The average size of the colonies was broadly similar between the plots at site 3 at both collection points with colonies of between 4 and 20 aphids.

*Overall parasitism:* Parasitism was found in all plots. Table 3.4.2 shows the percentage of successful parasitism recorded for each plot at the 3 sites. Overall levels of parasitism recorded was higher in August. We observed higher percentages of parasitism at site 1 where plots 1 and 2 recorded and average of parasitism over 50%. Parasitism in Sept was highest at Site 3.

**Table 3.4.2.** Mean percentage +/- SEM of ten samples per tunnel of parasitism per sample recorded for each plot at sites 1, 2 (n=20) and 3 (n=10).

| | Plot | August | September |
|---|---|---|---|
| Site 1 | 1 | 50.9% (+21.7) | 3.4% (+2.1) |
| | 2 | 53.8% (+15.5) | 2.0% (+1.2) |
| | 3 | 30.9% (6.0) | 1.3% (+1.0) |
| | 4 | 22.5% (+5.7) | 0.5% (+0.4) |
| Site 2 | 5 | 3.0% (+1.6) | 0.5% (+0.3) |
| | 6 | 0 | 1.3% (+1.0) |
| | 7 | 3.0% (+1.3) | 1.7% (+1.0) |
| | 8 | 0 | 1.8% (+0.8) |
| Site 3 | 9 | 41.0% (±11.6) | 13.1% (±6.5) |
| | 10 | 10.1% (±5.9) | 12.6% (±4.3) |
| | 11 | 13.6% (±4.1) | 6.2% (±2.2) |
| | 12 | 32.9% (±12.9) | 5.0% (±2.0) |

## Discussion and Conclusions

- No parasitoid treatment was applied in 2021. Data collected will be used as a baseline between sites.
- Levels of parasitism were higher in August than September and were highest at Sites 1 and 3
- Different species of aphids in Angus and Kent.
- Numbers of parasitoid emerging between sites are very variable, probably due to management practices and number of aphids present. For example, discussion with the manager of site one at the beginning of sampling revealed no insecticides had been used up to the point of first sampling.

## Ongoing study

- Pre-treatment sampling visits in Feb/March
- Parasitoid release in half of the plots at each site in March and follow-up sampling visits in April-June
- Identify parasitoids
- Collection of crop management and environmental monitoring data
- Analyse data to examine relation between aphid control, parasitoid treatments and environmental conditions

## Task 3.5. Ability of floral margins to support natural enemies and pests in proximity to soft fruit crops (Year 1-2, Lead; NIAB EMR)

### Introduction

A literature review has been published partly funded by the AHDB on the impact of organic treatments and floral margins for pest and disease control in orchards (Shaw et al. 2021; Fountain 2022). In 2019, a replicated experiment of floral margins was sown around the WET Centre at NIAB EMR to reduce runoff from polytunnel structures but provide secondary benefits of boosting natural enemies and pollinators in the vicinity of the tunnel (Holistic Water for Horticulture, HWH). The data from the first year will be collated and funding from and Interreg-NSR, BEESPOKE project facilitated surveys of pollinating insects.

Several research studies have implemented floral margins which are thought to benefit strawberry crops, but with very little evidence of the species or phenology of natural enemies in the crop or which flora might be attractive to crop pests. The wildflower margins, that are part of the other projects, offer an ideal opportunity to monitor margins for beneficial and pest species of soft fruit crops including ladybirds, lacewings, and hoverflies, but also capsids, and thrips.

With a growing need for alternatives to plant protection products, the implementation of wildflower margins that support natural enemies is a potential contributing solution. Floral resources implemented near crops have been shown to be effective in increasing the abundance of pollinators and natural enemies (Fountain 2022). Crops themselves do not provide the diversity that most natural enemies need to establish a stable and growing population throughout the year (Ramsden et al. 2017). A properly managed floral resource could provide a food source for natural enemies in the form of alternative prey, pollen, and nectar, and as a shelter and overwintering habitat.

In the first year, the replicated plots (unsown, sainfoin, chicory, perennial meadow mix (Emorsgate, EM1)) established around the WET Centre (strawberry crop) at NIAB EMR in 2019 were surveyed for soft fruit natural enemies and pest species. Single species plots had more than 90% coverage of the sown species, sainfoin and chicory. The EM1 meadow seed mix covered 72% of the plots with wild carrot and common knapweed being the better-established flowering species. Single species plots like sainfoin and chicory had shorter flowering periods than unsown and EM1 plots. Longer flowering periods provided a better food and habitat resource for natural enemies and pollinators. The meadow mixture (EM1) had a higher floral resource in June 2020. Arthropod group diversity was highest with approximately

1 specimen of each group recorded per 1.5 $m^2$. Chicory plots had fewer arthropods when compared with all other treatments. In August 2020 unsown and EM1 plots were dominated by predatory spiders, and groundbugs, thought to be from genus *Nysius* (not a soft fruit pest).

Most arthropod herbivores or potential soft fruit pests found during this trial were capsids and aphids. No strawberry pest aphids were found in the floral resources. Three capsid species were identified using the floral margins: Common green capsid, European tarnished plant bug, and potato capsid. Common green capsid was found in high numbers in all treatments except in chicory. The meadow mix (EM1) was less attractive to capsids than the unsown treatment.

In June 2020, yarrow contained on average 5.2 ±1.0 *Thrips tabaci* (onion thrips) per flower, known to affect soft fruit crops. White clover had 5.1 ±4.1 *Frankliniella intonsa* (flower thrips) per flower also found on strawberry crops. Other unsown plant species had fewer than 2 thrips per flower or had thrips species not found on soft fruit. In sown plots, wild carrot had higher numbers of *Thrips tabaci* per flower head in June 2020 and July 2020 (respectively, 6.7 ±2.3 and 4.4 ±1.4). Common knapweed attracted *Frankliniella occidentalis* (WFT) (2.0 ±0.3) a known pest of strawberry crops and 2.2 ±0.6 'other' thrips not found in soft fruit crops. The extraction device from project SF 156 gave very good recovery of adult thrips (at least 90%) but was less efficient at extracting larval thrips (around 50%) from flower heads.

Predatory thrips (Aeolothrips), parasitoids, ground beetles and *Orius* nymphs and adults were present in flower heads.

In 2021, we aimed to:

1. Monitor the establishment and floral resource in the margins on commercial farms in the vicinity of soft fruit crops
2. Monitor and assess floral margins in the proximity of soft fruit crops as a support for beneficials and soft fruit pests
3. Estimate the impacts of floral margins on pests, natural enemies and pollinators in soft fruit crops

## Materials and Methods

Between 2019-2020, soft fruit growers established floral margins adjacent to four soft fruit crops (Table 3.5.1). In 2021, all floral resources sown on commercial farms were successfully established and ready for assessments both in the floral margins and at distances into the crop.

**Table 3.5.1.** Farms (blocks), growers, crop and starting assessment dates for the floral margin trial 2020. NB: EM1 was a basic perennial mix available from Emorsgate Seeds, UK.

| Site Code | Crop | Floral resource | Seed mix | Sown in | Assessed from |
|---|---|---|---|---|---|
| 7 | Strawberry | Margin | 50/50 Chicory/Sainfoin | 2020 | 2021 |
| 10 | Raspberry | Margin | EM7 mix (Emorsgate) | 2020 | 2021 |
| 14 | Strawberry | Margin | Chicory or Sainfoin or EM1 mix or unsown | 2019 | 2020 |
| B1F | Raspberry | Margin | Bespoke for SMOOPS (Appendix 1) | 2017 | 2021 |

Site 14: Site 14 was established in 2019 and assessments started in 2020. Single species (Chicory or Sainfoin) and a species mix (EM1, sourced from Emorsgate Seeds) of wildflowers was sown (broadcast, rolled and irrigated in 2019) around WET centre polytunnels. Tunnels were 50 m x 8.5 m (Fig. 3.5.1). An untreated (no sowing) control was included and allowed to establish as 'tumbledown'. There were 8 replicates of each treatment. The tunnel was divided into two – one half had water capture, so very little water runs off the polythene onto the ground, and the other half was normal commercial practice. In 2021, only the plots located on the westside of the tunnels were assessed as those at the tunnel ends were not representative due to farm machinery driving over them.

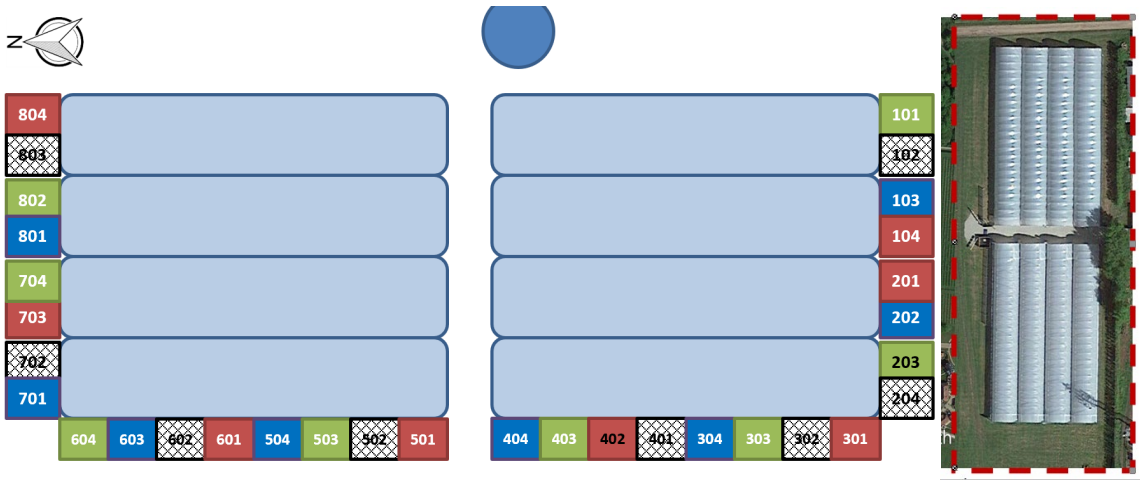


**Figure 3.5.1.** Left: Schematic of WET centre (site 14) polytunnels at NIAB EMR with commercial practice and advanced water capture and treatment practice. North & South plot are approx. 4x4 m and West plots 6x6 m. Tunnels to the left do not have water capture from the cladding, whereas those on the right capture water in a gutter system. Plots: Green = untreated, Red = sainfoin, Blue = chicory and White/black = Meadow mix EM1. Right: Aerial photo of Water Efficient Technologies (WET) Centre polytunnels.

Commercial sites

At site 7, 11,000 $m^2$ of chicory plus sainfoin was sown in 2020 at the north end of strawberry tunnels. The tunnels were approximately 90 m long.

At site 10, 3000 $m^2$ of wildflowers mix (EM7 from Emorsgate) was sown in 2020 at the west end of a raspberry crop. The crop was approximately 30 m from the floral resource separated by a hedge (Fig. 3.5.2).

At site B1F, 614 $m^2$ was sown with a wildflower mix (see Appendix 3.5) in 2017. Tunnels of raspberries were adjacent to the floral resource. Tunnels were ~200 m long.


**Figure 3.5.2.** Aerial photograph (Google Maps) of proximity of floral margin and raspberry crop at site 10.

There were three assessments per farm between June and September depending on the flowering time of the crop. Each assessment occasion included;

1. The percentage **vegetation coverage** in all floral plots in July. Photographs of plots were. Floral margins and crop ground coverage were assessed in 10 replicates of 50x50 cm quadrat per plot (2 reps of 50x50 cm per plot at the WET centre, site 14).
2. **Floral units** were measured by placing 4 replicates of 50x50 cm quadrat at flower height in each floral resource and recording the number and identification of flowering heads. This was done from June to September depending on when the crop started flowering.
3. **Pests, herbivores and beneficials** in the floral margins were sampled using a sweep net. Four sweeps were taken in each floral margin in commercial farms and one per plot at the WET centre. The net was then slowly unfolded, and arthropods recorded. Herbivores and beneficials in the crop (strawberry or raspberry) were sampled by tap sampling plants over a tray. Ten plants were randomly tap sampled at each distance in the crop. For all samples, macro-arthropods were identified into broad groups e.g., spiders, lacewings, ladybirds, ground beetles, all considered natural enemies in strawberry. Insects considered a potential pest were identified further, e.g., capsids (adults and juveniles), aphids, blossom weevil, SWD, etc.
4. **Thrips** were sampled from flower heads from each flowering species in each plot. A standard number of flower heads for each species was determined depending on flower size. Between 1 and 5 flower heads were sampled per plot. Four replicates of each flower species were collected and no more than 5 different flower species collected per site. Flowers were stored in 70% ethanol immediately after picking until processed by washing extraction (NIAB EMR SOP 780). Total numbers of adult thrips and larvae in each sample were counted and a sub-sample (a third of the thrips from each sample with a minimum of 5 and a maximum of 15 specimens) mounted on microscope slide in polyvinyl alcohol media. Only species recognised as potential strawberry pests were identified to species.

At each assessment occasion the following distances into the crop was sampled for arthropods (above point 3 and 4):

- Floral margin
- Edge of the crop closest to the floral margin
- 5 meters into the crop (from the edge)
- 10 meters into the crop (from the edge)
- 50 meters into the crop (from the edge)

## Results

Number of flower heads and vegetation cover in floral sown plots

Quadrat counts of flower heads (a proxy for floral resource) demonstrated how flower availability varies through the season and depends on the flowering species in the floral margin (Fig. 3.5.3). Strawberry sites, site 7 and 14, were sampled June to August as the crop started flowering in June. Raspberry sites, site 10 and B1F, were sampled July to September as the crop started flowering in July.

On site 7, a higher number of flowering heads (27 ±4.3 flower heads per 50 $cm^2$) was recorded in June. At that time the most common species flowering was sainfoin and numbers of flower heads declined steadily after June. Sowed species in the floral margin were chicory and sainfoin and these established well with 59% and 30% respectively. The single species plots of chicory or sainfoin continue to establish well with 77% and 99%, respectively (Fig. 3.5.5). The wildflower mix (EM1) plots were dominated by sowed species. Sowed non-competitive grasses like crested dog's-tail and smaller cat's-tail covered, in average, 16% and 25% of the plots respectively. Oxeye daisy (49%) was the most common flowering species at the time of assessment. Sowed fescue grasses (5%), wild carrot (1%) and common knapweed (3%) were also present.

Site 10 followed the same trend at site 7 with higher numbers of flowers (12.2 ±1.1 flower heads per 50 $cm^2$) recorded in July and decreasing thereafter. The primary species flowering at that time were oxeye daisy, wild carrot, red campion, and viper's bugloss. EM7 wildflower mix from Emorsgate was sowed at site 10. Many of the wildflower species incorporated in the mix established well, including oxeye daisy (8%), wild carrot (8%), red campion (2.5%), white campion (2%), self-heal (8%) and viper's-bugloss (9%). Non-competitive grasses, in the floral mix, like crested dog's-tail and smaller cat's-tail covered, respectively, 8 and 28 % of the floral margin area.

Site 14 had less variability in flower heads through the season. More flower heads (17.9 ±3.5 flower heads per 50 $cm^2$) were observed in July and the species most commonly present were chicory, yarrow, hawkbit, and common knapweed.

Site B1F, had higher number (22.2 ±3.8 flower heads per 50 $cm^2$) later in August. The species recorded were birdsfoot trefoil, red clover, yarrow, wild carrot, oxeye daisy, common dandelion, and common knapweed.

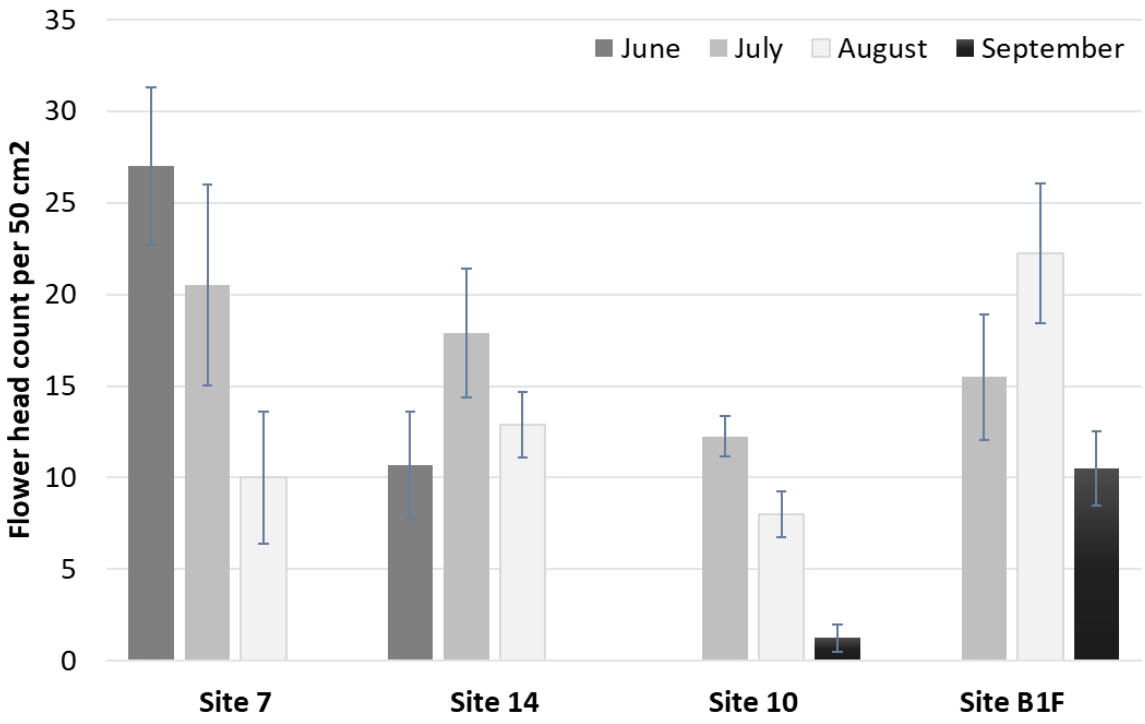



**Figure 3.5.3**. Mean number (±SE) of flower heads per 50 $cm^2$ in floral margins between June and August at sites 7 and 14, and July and sites 10 and B1F in September. Period of assessment was dependent on the flowering start of the crop.

Vegetation cover within crops

In July, the most common ground cover within the crops were grasses, dry or dead vegetation and bare ground, but in different proportions.

The vegetation under the tabletops at Site 7 was mostly bare ground (64%) with patches of grasses (34%) and very little dry or dead vegetation (2%) (Fig. 3.5.4.).

Site 10 was potted raspberries plants on the ground and alleyways were mostly covered by dry or dead vegetation (73%) (Fig. 3.5.4). The presence of bare ground (20%) and grass (7%) were also recorded.

Site B1F was also raspberry crop with potted plants at ground level. Most of alleyways were covered with grass (87%) (Fig. 3.5.5). Docks (0.5%), creeping buttercup (3.7%), common daisy (1%), dandelion (2%), greater plantain (1%) and dry/dead vegetation (4.7%) were also recorded but with smaller coverage area.

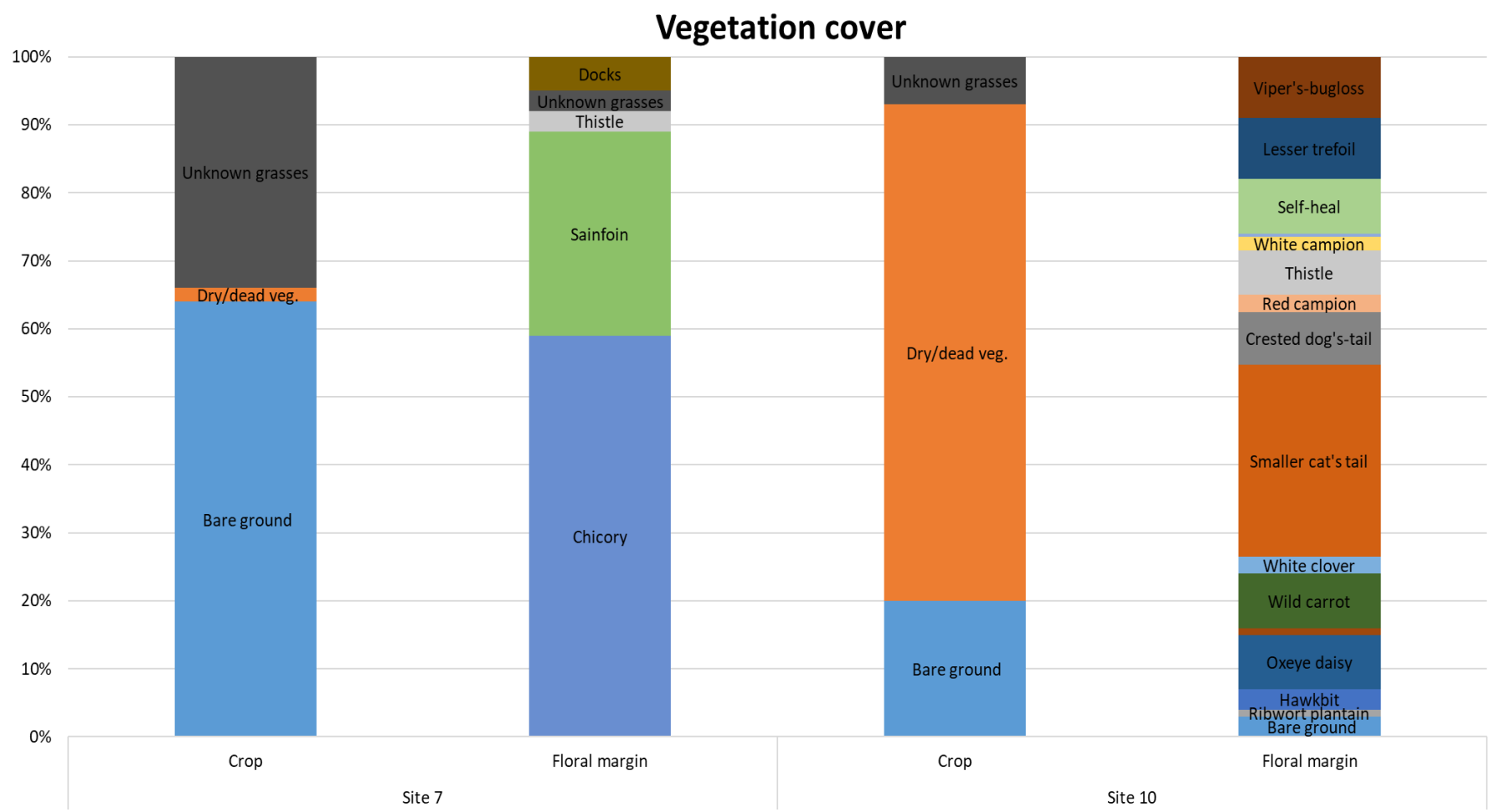



**Figure 3.5.4.** Mean percentage ground coverage of plant species in each floral margin and crop in July at site 7 and 10. Measurements were taken with a 50 x 50 cm quadrat.

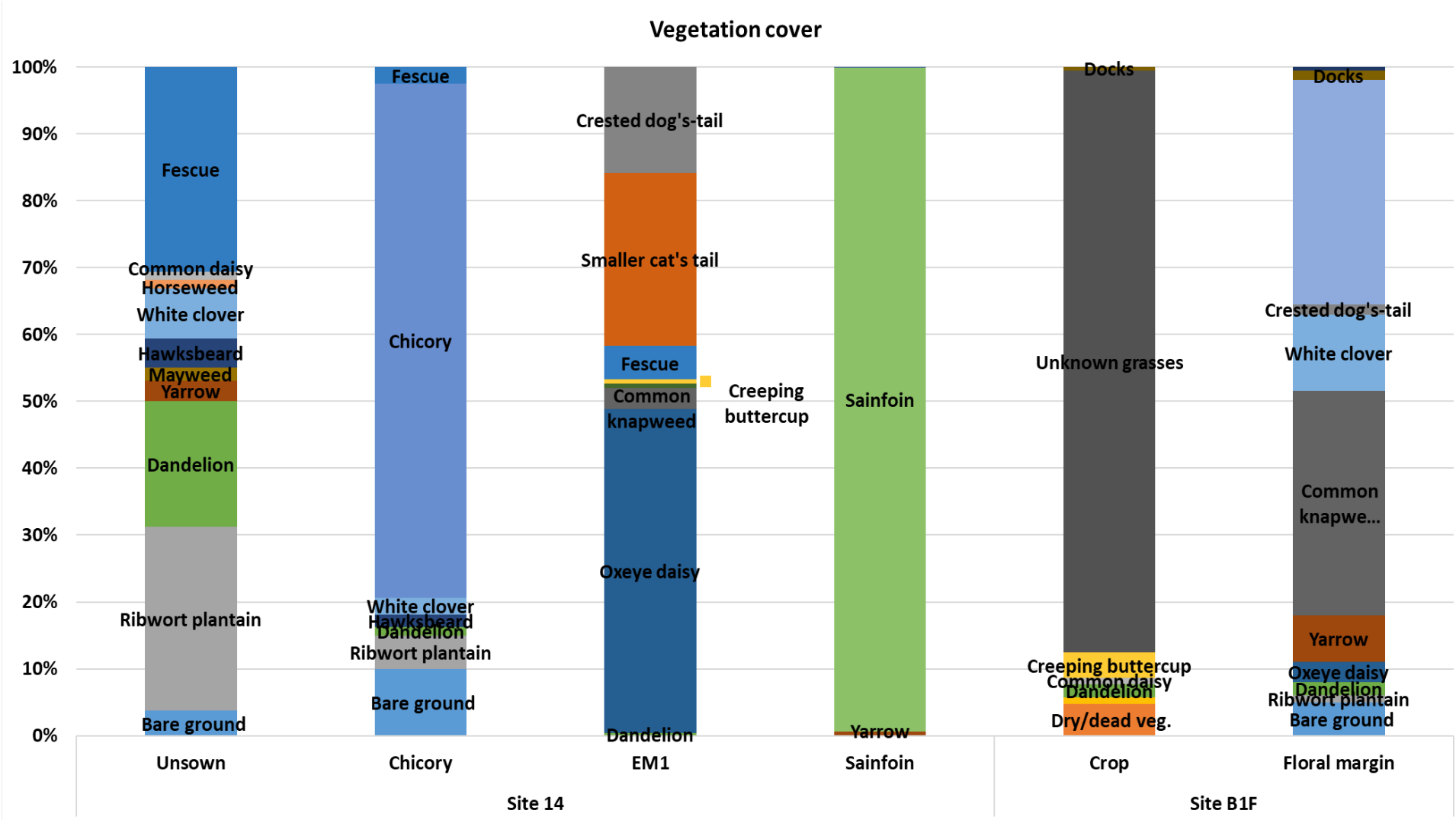



**Figure 3.5.5.** Mean percentage ground coverage of plant species in each floral margin and crop in July at site 14 and B1F. Measurements were taken with a 50 x 50 cm quadrat.

Arthropods in floral margin and crop

Floral margin and crop areas were only assessed once the crop was flowering.

By June, (sites 7 and 14) strawberry crops had started flowering. Capsids and aphids were found in the floral margins, but not in the crop. In the floral margins and crops parasitoids, spiders, ants, and flies recorded. Except for spiders and ants, all arthropods were too few for statistical analyses (Fig. 3.5.6). No significant differences were found between the number of spiders or ants recorded in different areas. Total numbers of beneficials recorded for floral and crop area revealed that there were higher numbers of beneficial arthropods in the floral area (Fig. 3.5.7). Number of beneficials were significantly higher in the floral margins compared with 5 meters into the crop ($p = 0.018$).

In July, all four sites were flowering. Herbivores in the floral margin were capsids and aphids, with only one capsid was found in the crop. There were significantly more aphids in floral margins when compared to the crop edge ($p = 0.007$), 5 meters ($p < 0.001$), 10 meters ($p = 0.001$) and 50 meters ($p = 0.011$) in the crop.

Spiders, parasitoids, ants, pollen beetles and ladybirds were found in all areas surveyed (Fig. 3.5.9). Ladybirds' numbers were too low to analyse. There were higher number of parasitoids, spiders and ants in the floral margins compared to numbers recorded in the crop. Only spiders were significantly more abundant in the floral margin than in the crop ($p_{edge}= 0.009$, $p_{5m}= 0.0004$, $p_{10m}= 0.004$, $p_{50m}= 0.004$). No other significant difference was found.

In August, aphids were found at all sites, while capsid were only found in the floral margins of strawberry crops (site 7 and 14). Low numbers of aphids (<0.25 aphids per sweep/plant) were found overall (Fig.3.5.10). Beneficial arthropods observed in August were parasitoids, spiders, lacewings, anthocorids, ladybirds, hoverflies, and harvestman. Ladybirds, hoverflies, and harvestman were too low to analyse. Higher numbers of parasitoids, spiders and anthocorids were recorded in floral margin (Fig. 3.5.11). Spider numbers were significantly lower at the crop edge ($p = 0.003$), 5 meters ($p = 0.009$), 10 meters ($p = 0.006$) and 50 meters ($p = 0.004$) in the crop compared to floral margins. Parasitoid numbers appeared to decrease with increasing distance into the crop, but no significant difference was observed.

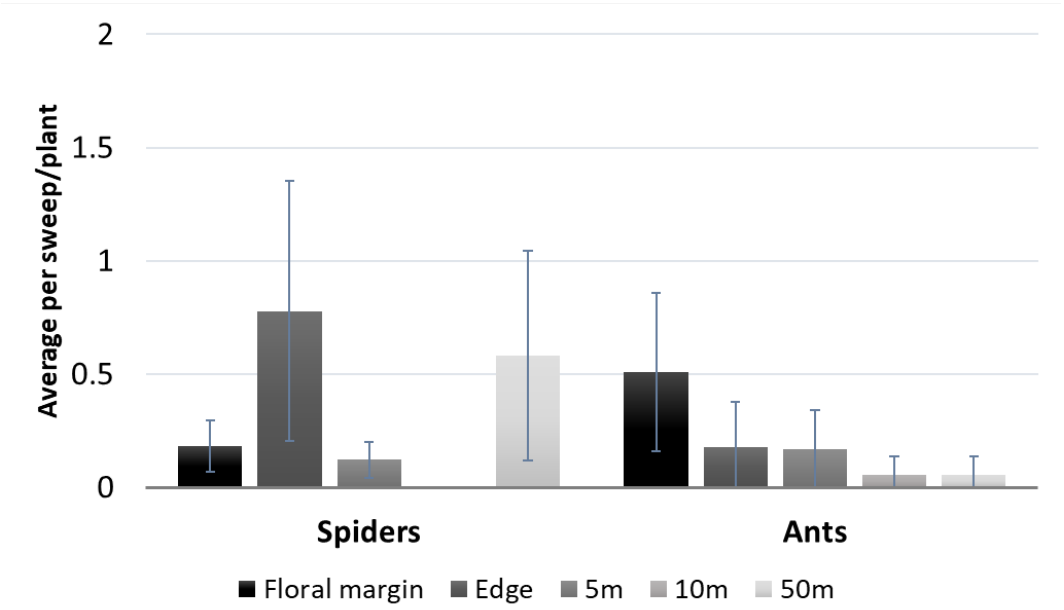



**Figure 3.5.6.** Overall mean (±SE) of spiders and ants in the floral margin (per sweep) and at different distances in the crop (per plant), in June for site 7 and site 14. No significant differences found.

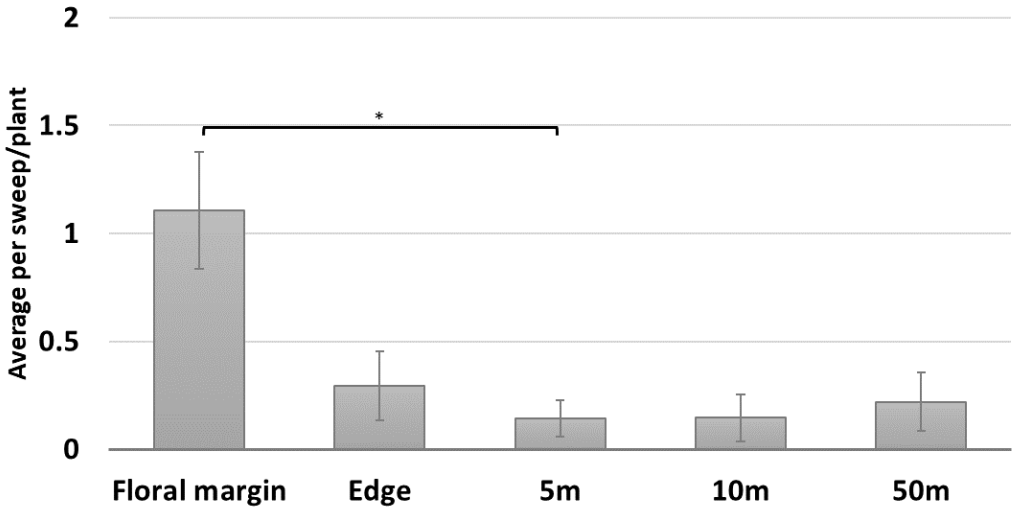



**Figure 3.5.7.** Overall mean (±SE) of total beneficials observed in the floral margin (per sweep) and at different distances in the crop (per plant), in June for site 7 and site 14. No significant differences found. Lines and asterisks indicate significant differences (*<0.05, **<0.01, ***<0.001).

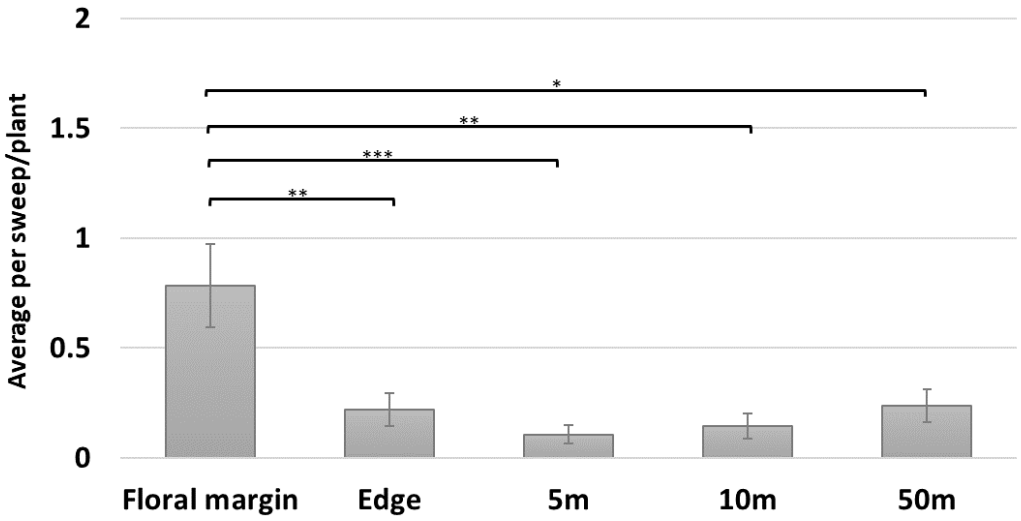



**Figure 3.5.8.** Overall mean (±SE) of aphids observed in the floral margin (per sweep) and at different distances in the crop (per plant), in July at all sites. Lines and asterisks indicate significant differences (*<0.05, **<0.01, ***<0.001).

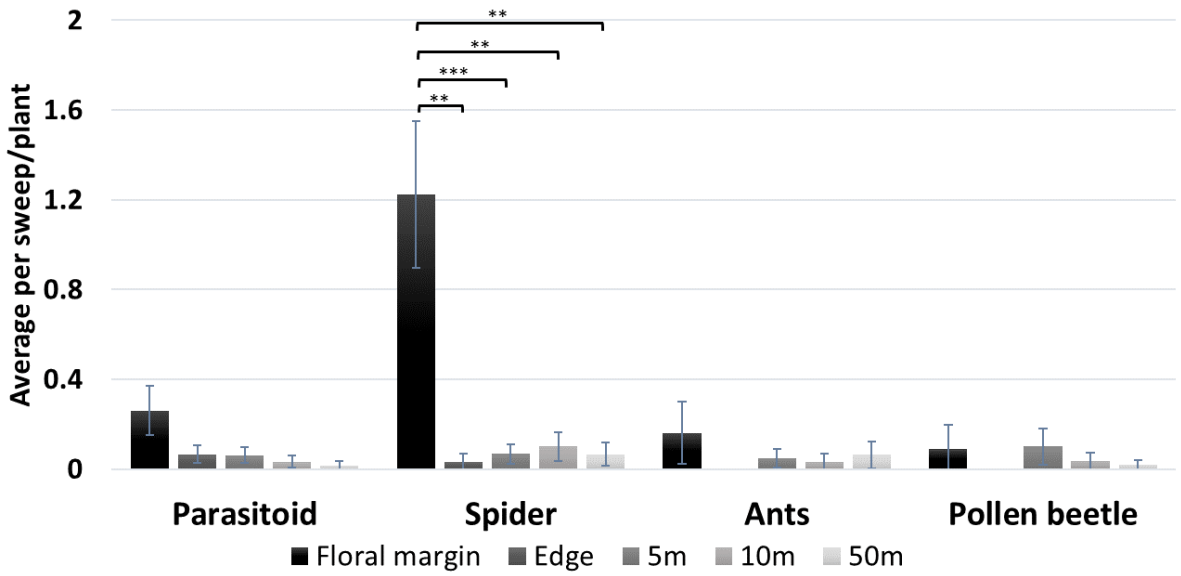



**Figure 3.5.9.** Mean (±SE) of parasitoids, spiders, ants, and pollen beetles observed in the floral margin (per sweep) and at different distances in the crop (per plant), in July at all sites. Lines and asterisks indicate significant differences (*<0.05, **<0.01, ***<0.001).

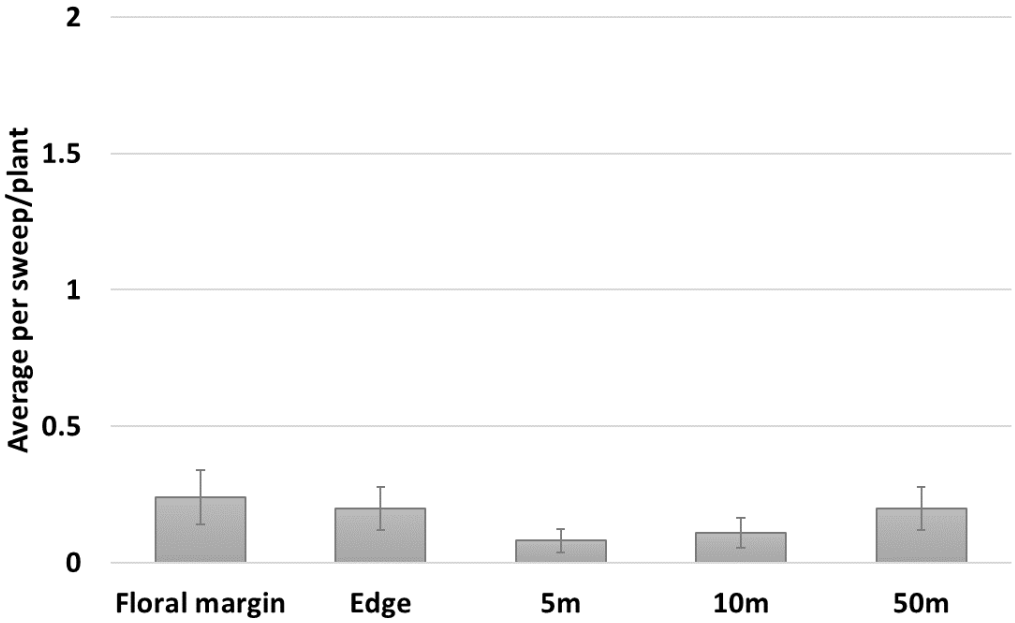



**Figure 3.5.10.** Mean (±SE) of aphids observed in the floral margin (per sweep) and at different distances into the crop (per plant), in August at all sites. No significant differences found.

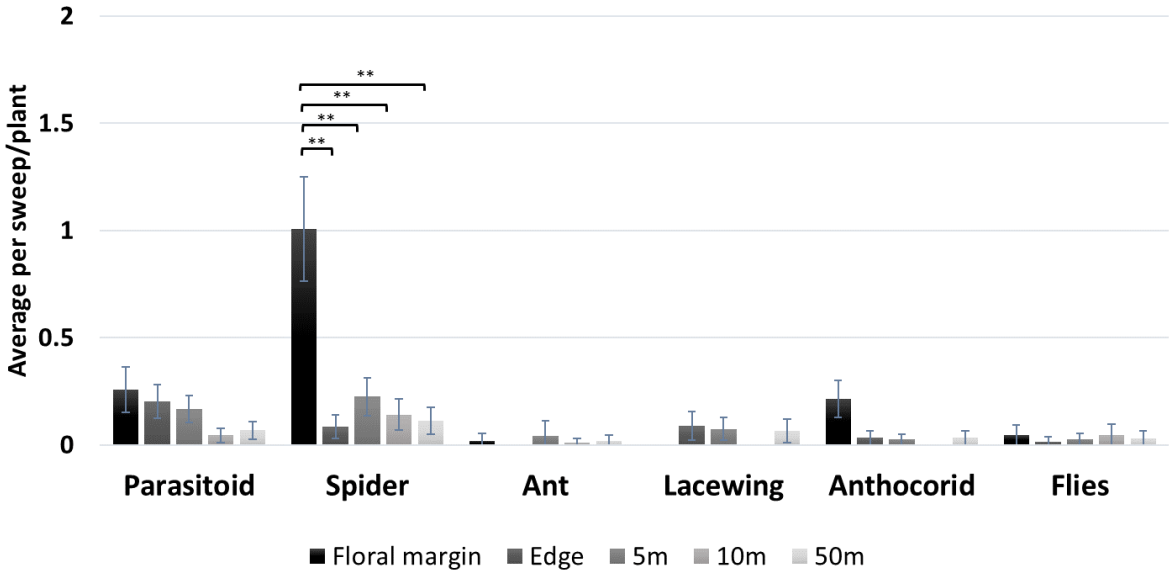



**Figure 3.5.11.** Mean (±SE) of parasitoids, spiders, ants, lacewings, anthocorids, and flies observed in the floral margin (per sweep) and at different distances into the crop (per plant), in August at all sites. Lines and asterisks indicate significant differences (*<0.05, **<0.01, ***<0.001).

In September, assessments were carried out on site 10 and B1F. Capsids recorded were too low to analyse. Aphids were found in the floral margins and crop but in very low numbers (<0.2 aphids per sweep/per plant) (Fig. 3.5.12). Only spiders and groundbugs were found in floral margins in September. Groundbug counts could not be analysed, as they only occurred in floral margins. In the crop spiders, anthocorids, Anystis (predatory mite), and ants were recorded. Like July and August, spider numbers were significantly higher in the floral margins when compared to the crop edge ($p$ = 0.02), 5 meters ($p$ = 0.003), 10 meters ($p$ = 0.003) and 50 meters ($p$ = 0.004) in the crop (Fig.3.5.13).

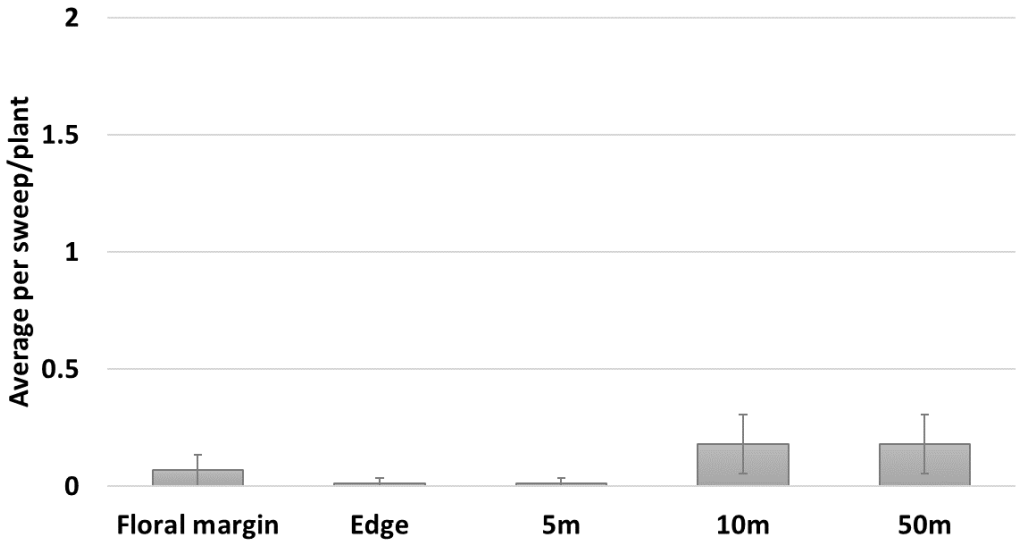



**Figure 3.5.12.** Mean (±SE) of aphids observed in the floral margin (per sweep) and at different distances in the crop (per plant), in September at all sites. No significant differences found.

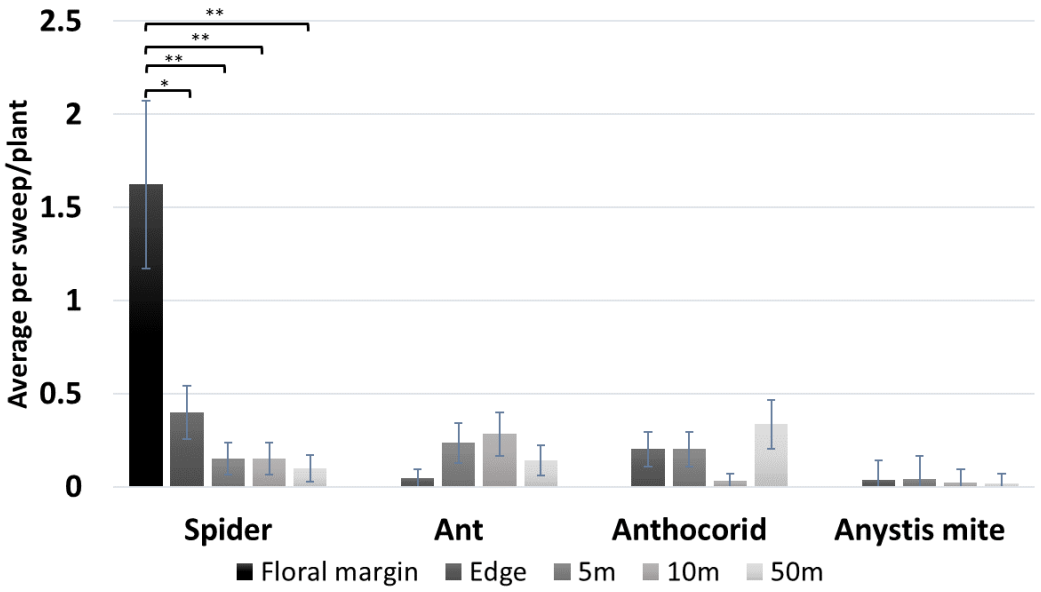



**Figure 3.5.13.** Mean (±SE) of spiders, ants, anthocorids and predatory Anystis mite observed in the floral margin (per sweep) and at different distances in the crop (per plant), in September at all sites. Lines and asterisks indicate significant differences (*<0.05, **<0.01, ***<0.001).

Thrips in floral margins and crops

In June, western flower thrips (WFT, *Frankliniella occidentalis*), onion thrips (*Thrips tabaci*), and rose thrips (*Thrips fuscipennis*) were observed in the floral margins but in the crop, rose thrips was the only species recorded. Numbers of rose thrips were significantly higher at the edge of the crop when compared with numbers in the floral margin ($p$ = 0.007) and 5 m ($p$ = 0.006) in the crop (Fig. 3.5.14).

In July 1 or fewer thrips per 4 flowers was recorded for WFT, onion thrips, Rubus thrips (*Thrips major*), and rose thrips (Fig. 3.5.15). WFT numbers were significantly higher 5 m in the crop when compared with numbers in the floral margin ($p$ = 0.0005). Numbers of onion thrips in the floral margin were significantly higher than numbers found in the crop ($p_{edge}$ = 0.019, $p_{5m}$ = 0.012. $p_{10m}$ = 0.036, $p_{50m}$ = 0.018). Rose thrips were again found in higher number at the edge of the crop and were significantly higher when compared to numbers 10 m ($p$ = 0.006) and 50 m ($p$ = 0.004) in the crop. Numbers of rose thrips at 5 m were also significantly greater than at 50 m ($p$ = 0.027). Other species of thrips that are not documented as soft fruit pests were only found in the floral margin in July.

In August numbers of thrips remained low (Fig. 3.5.16). Apart from onion thrips in the floral margin (1.9 ±0.2 thrips per 4 flowers), all other species recorded in average less than 1 thrips per 4 flowers. Onion thrips were significantly more abundant in the floral margin compared

with the crop areas ($p_{edge}$ = 0.0001, $p_{5m}$ = 0.0002. $p_{10m}$ = 0.0001, $p_{50m}$ = 0.0001). No other significant differences were found.

In September we recorded onion thrips in very low number in the crop ($mean_{edge}$= 0.13 ±0.13, $mean_{5m}$= 0.13 ±0.13, $mean_{10m}$= 0.19 ±0.18, thrips per 4 flowers). Other species of thrips that are not documented as soft fruit pests were only found in the floral margin at a mean of 3.4 ±1.7 per 4 flower heads.

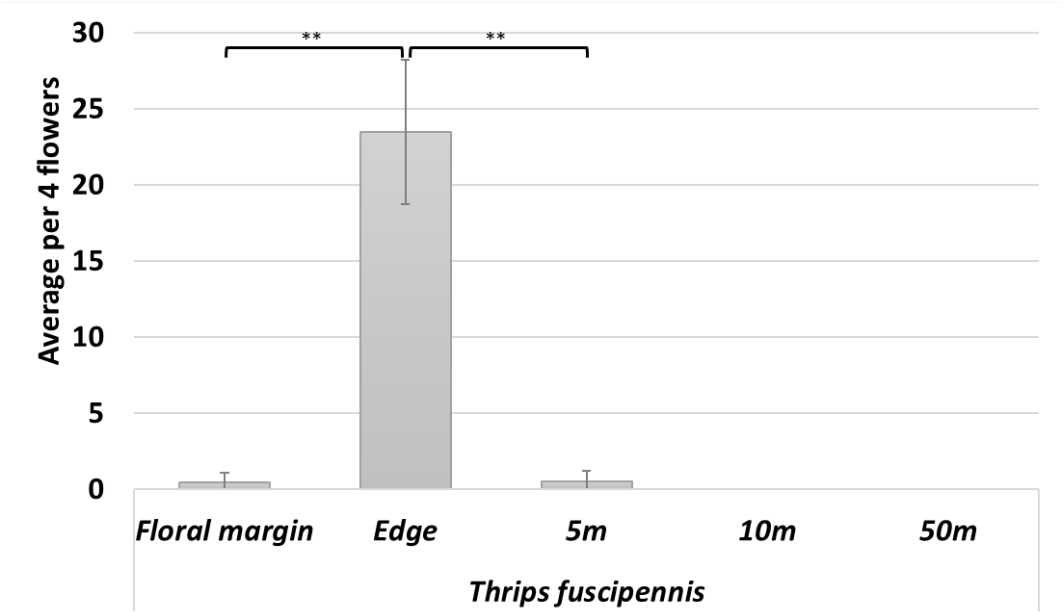



**Figure 3.5.14.** Mean (±SE) of *Thrips fuscipennis* (rose thrips) per 4 flowers observed in the floral margin and at different distances in the crop (strawberry), in June for site 7 and site 14. Lines and asterisks indicate significant differences (*<0.05, **<0.01, ***<0.001).

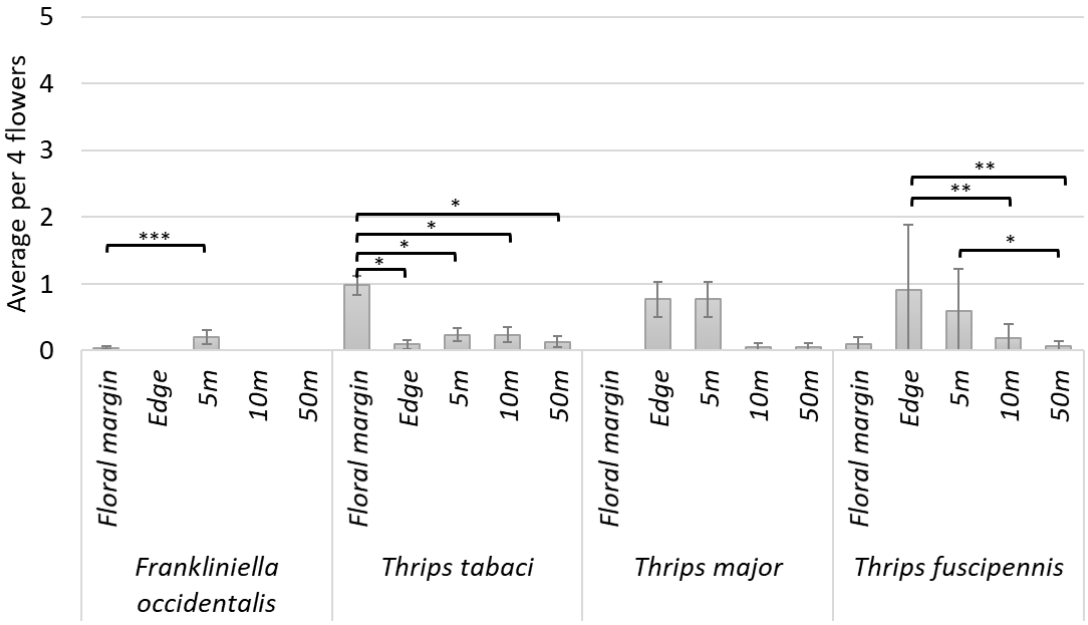


**Figure 3.5.15.** Mean (±SE) of WFT (*Frankliniella occidentalis*), onion thrips (*Thrips tabaci*), Rubus thrips (*Thrips major*), and rose thrips (*Thrips fuscipennis*) per 4 flowers observed in the floral margin and at different distances in the crop (strawberry and raspberry), in July for all sites. Lines and asterisks indicate significant differences (*<0.05, **<0.01, ***<0.001).

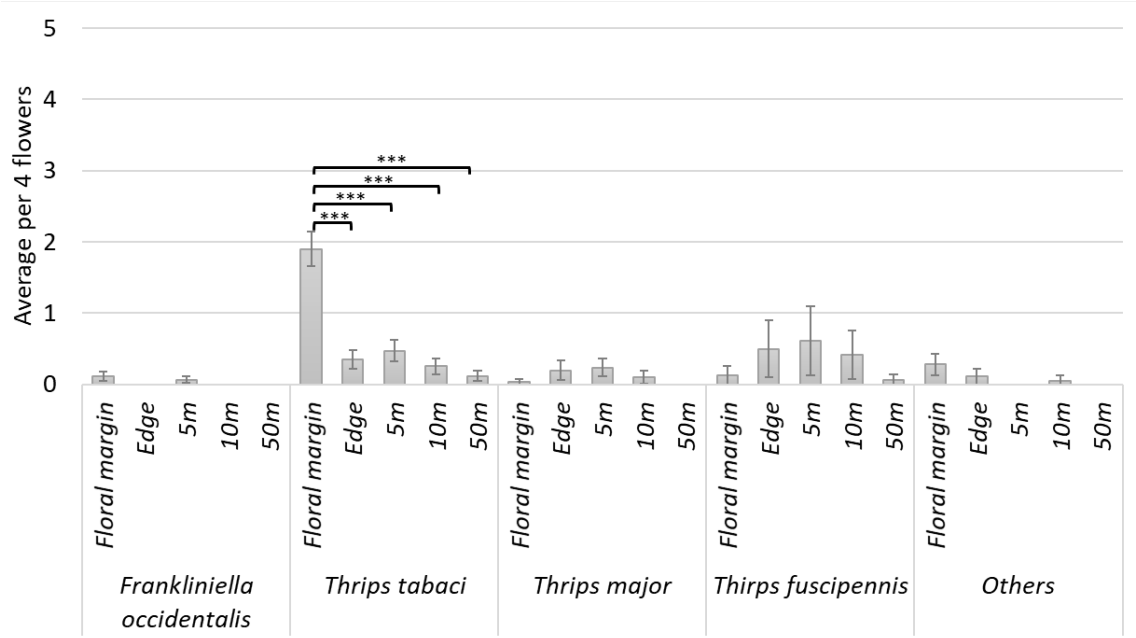



**Figure 3.5.16.** Mean (±SE) of WFT (*Frankliniella occidentalis*), onion thrips (*Thrips tabaci*), Rubus thrips (*Thrips major*), rose thrips (*Thrips fuscipennis*), and other species of thrips (Others) per 4 flowers observed in the floral margin and at different distances in the crop (strawberry and raspberry), in August for all sites. Lines and asterisks indicate significant differences (*<0.05, **<0.01, ***<0.001).

Thrips in flower heads

In June we collected flowers heads from 8 flowering species (sainfoin, oxeye daisy, meadow buttercup, red campion, dandelion, common daisy, ribwort plantain and strawberry) across 2 sites (Fig. 3.5.17). No thrips species were found in red campion or ribwort plantain. We recorded higher numbers of WFT in meadow buttercup (5.5 thrips per 4 flowers) and sainfoin (4.1 thrips per 4 flowers). Onion thrips were found in higher numbers in dandelion (16.0 thrips per 4 flowers), oxeye daisy (7.7 thrips per 4 flowers) and sainfoin (5.1 thrips per 4 flowers). Rose thrips numbers were significantly lower in all wildflower species (1 or fewer thrips per 4 flowers) when compared to numbers found in strawberry flowers (23.9 thrips per 4 flowers). Numbers of other thrips species, not documented as soft fruit pests, were associated with dandelion (78.5 thrips per 4 flowers). Meadow buttercup had 11.4 thrips per 4 flowers. Both dandelion ($p$ = 0.001) and meadow buttercup ($p$ = 0.009) had significantly more other thrips overall than strawberry flowers.

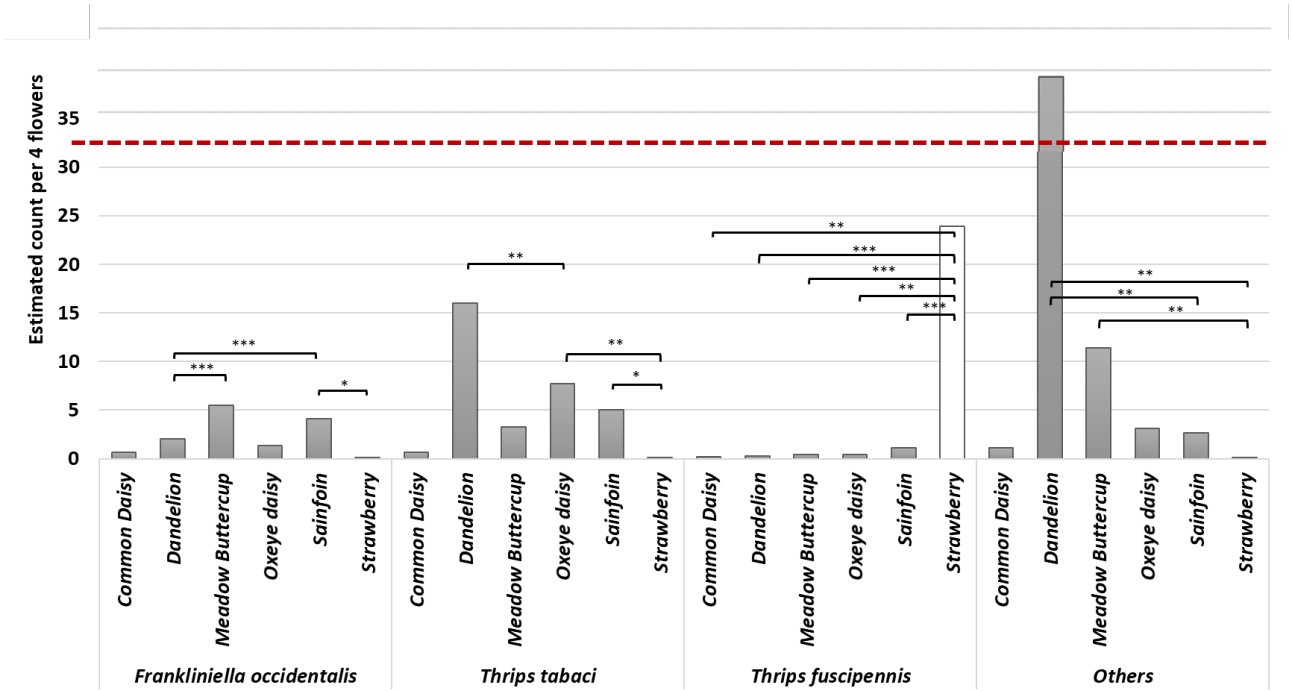



**Figure 3.5.17.** Estimated count of WFT (*Frankliniella occidentalis*), onion thrips (*Thrips tabaci*), Rubus thrips (*Thrips major*), rose thrips (*Thrips fuscipennis*), and other thrips species per 4 flowers in each plant species sampled in June at sites 7 and 14. Lines and asterisks indicate significant differences (*<0.05, **<0.01, ***<0.001). Red line indicates break in y-axis. White bars refer to the crop.

In July, flowering species diversity increased. We collected samples from 15 different flowering plants. Chicory had significantly fewer thrips of any species when compared to all other sampled plants. Low numbers of WFT were observed in all sampled flower heads and hence no significant differences were found (Fig 3.5.18, top). Sainfoin and strawberry had the highest estimated count, respectively, 1.8 and 2.1 thrips per 4 flowers. Numbers of onion thrips were higher in oxeye daisy (9.8 per 4 flowers) and yarrow (10.6 per 4 flowers) (Fig. 3.5.18, middle). Both wildflower species had significantly more onion thrips than raspberry ($p_{oxeye}$ = 0.0001, $p_{yarrow}$ = 0.003) and strawberry ($p_{oxeye}$ = 0.005, $p_{yarrow}$ = 0.02). Rose thrips was more abundant in sainfoin (17.3 per 4 flowers), strawberry (8.9 per 4 flowers), and white clover (4.0 per 4 flowers) (Fig. 3.5.18, bottom). Numbers of Rubus thrips were low in every flower species sampled (Fig. 3.5.19, top). Raspberry had the highest number of rubus thrips 3.0 thrips per 4 flower) but no significant differences were found. Other species of thrips not identified as soft fruit pests were abundant in common knapweed (9.8 thrips per 4 flowers), hawkbit (22.6 thrips per 4 flowers), and red campion (13.1 thrips per 4 flowers) (Fig. 3.5.19 bottom) and could be alternative prey for natural enemies.

In August overall numbers of thrips increased, except for Rubus thrips (1.0 thrips per 4 strawberry flowers) (Fig. 3.5.21, top). Chicory had significantly fewer thrips of any species when compared to all other flower species. Common knapweed had the highest numbers of WFT (16.6 thrips per 4 flowers) from all flower species sampled and was significantly ($p$ = 0.003) higher than WFT in strawberry (1.0 thrips per 4 flowers) (Fig. 3.5.20 top). Numbers of onion thrips recorded were higher in yarrow (12.1 thrips per 4 flowers) and significantly ($p$ = 0.027) higher than numbers in raspberry (0.1 thrips per 4 flowers) (Fig 3.5.20, middle). Rose thrips were observed in low numbers (Fig. 3.5.20, bottom). Red clover had the highest number of thrips, 7.1 per 4 flowers. Other thrips species not documented as soft fruit pests were predominantly found on hawkbit (24.6 thrips per 4 flower) (Fig. 3.5.21, bottom). This was significantly ($p_{strawberry}$ < 0.001, $p_{raspberry}$ = 0.003) different from numbers found in raspberry (0.3 thrips per 4 flowers) and strawberry (0.3 thrips per 4 flowers).

In September, small numbers of WFT, onion thrips, and rose thrips were recorded. Other species of thrips not recorded as soft fruit pests were present in high numbers. At that time flowering species available for sampling were oxtongue (*Helminthotheca* spp.), raspberry, red clover, wild carrot, and yarrow (Fig. 3.5.22). Oxtongue had the highest number of thrips observed of 63 thrips per 4 flowers. No significant differences were found.

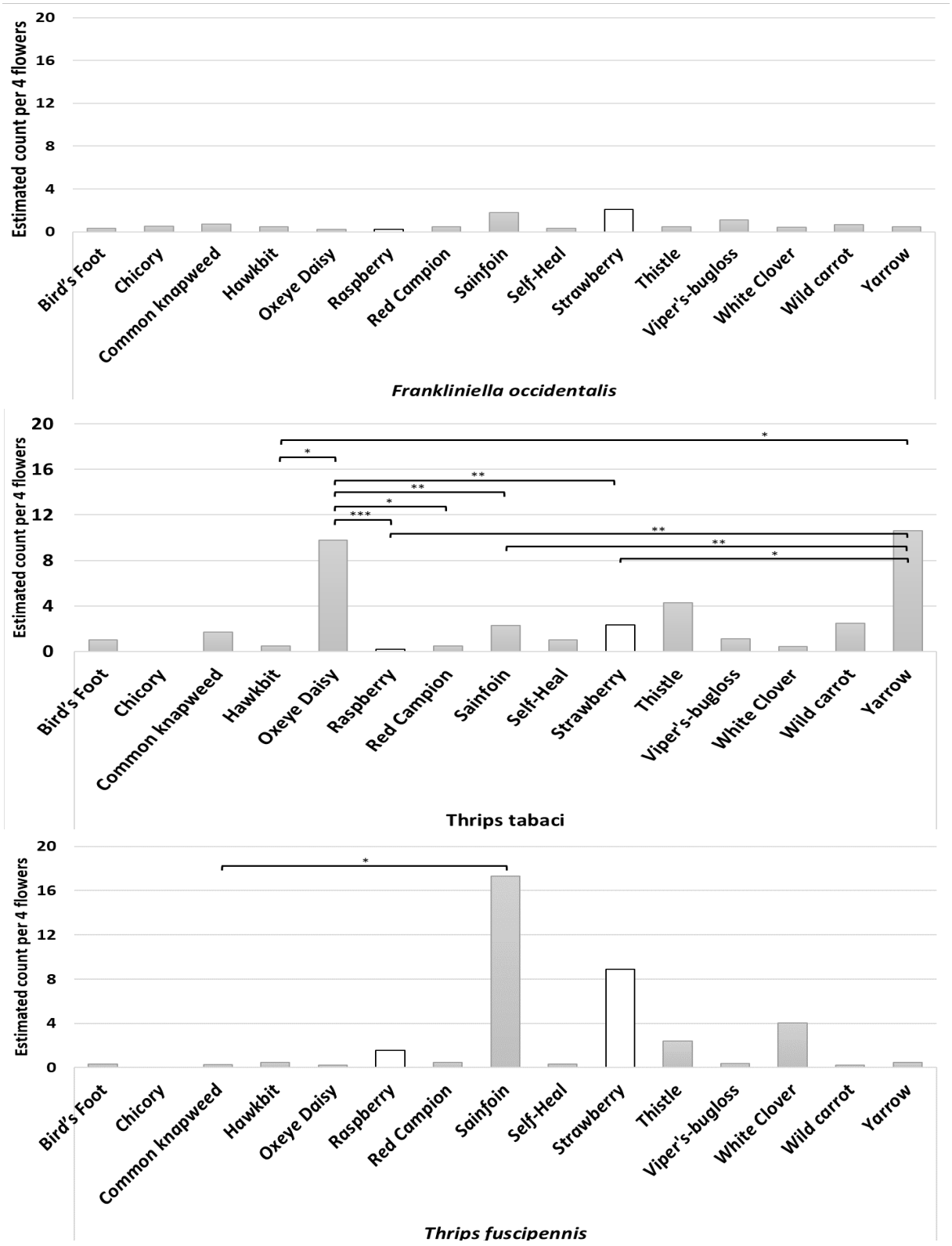



**Figure 3.5.18.** Estimated count of WFT (*Frankliniella occidentalis*, top), onion thrips (*Thrips tabaci*, middle), and rose thrips (*Thrips fuscipennis*, bottom) per 4 flowers in each plant species sampled in July at all sites. Lines and asterisks indicate significant differences (*<0.05, **<0.01, ***<0.001). White bars refer to the crop.

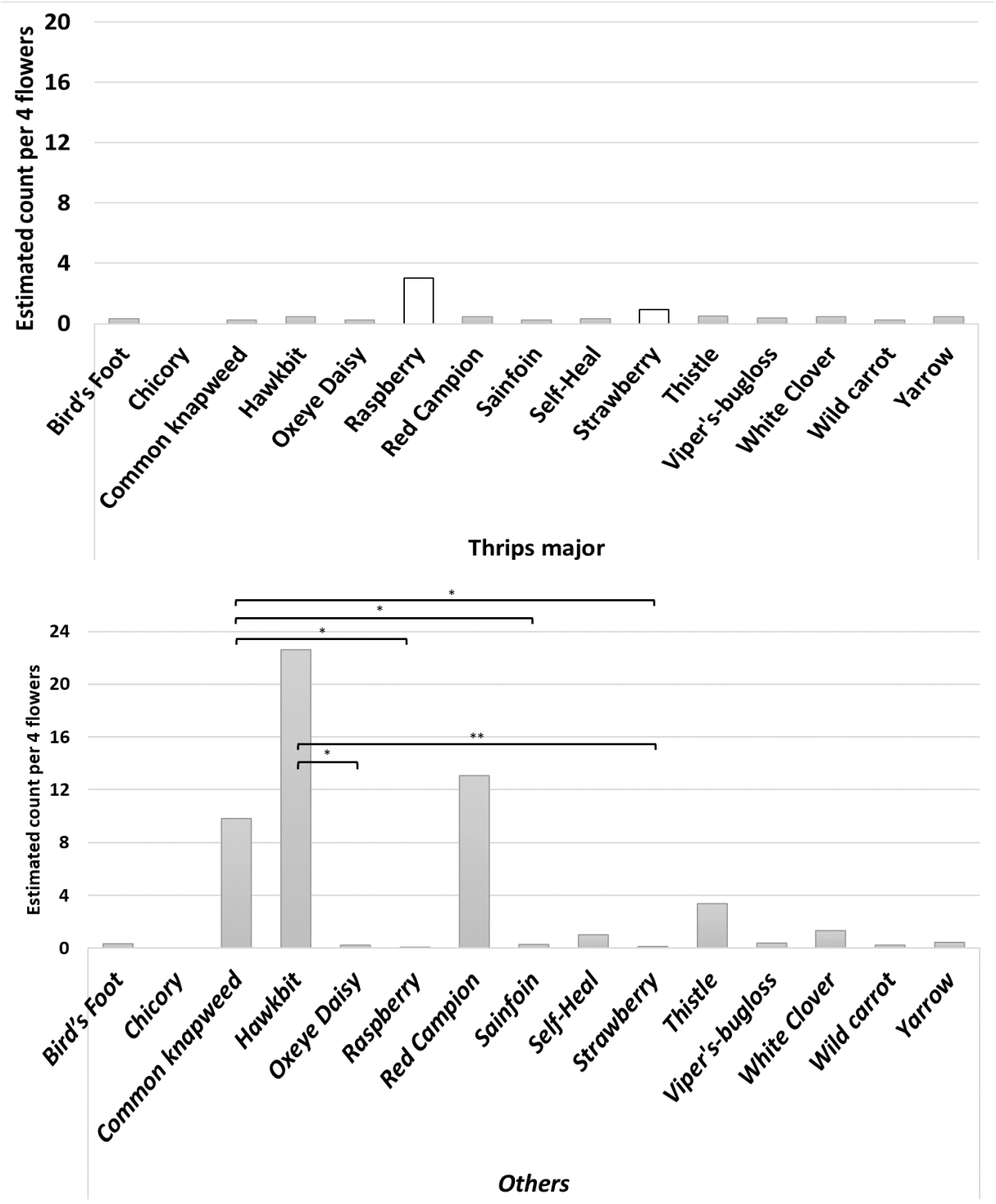



**Figure 3.5.19.** Estimated count of Rubus thrips (*Thrips major*, top), and other thrips not documented as soft fruit pests (bottom) per 4 flowers in each plant species sampled in July at all sites. Lines and asterisks indicate significant differences (*<0.05, **<0.01, ***<0.001). White bars refer to the crop.

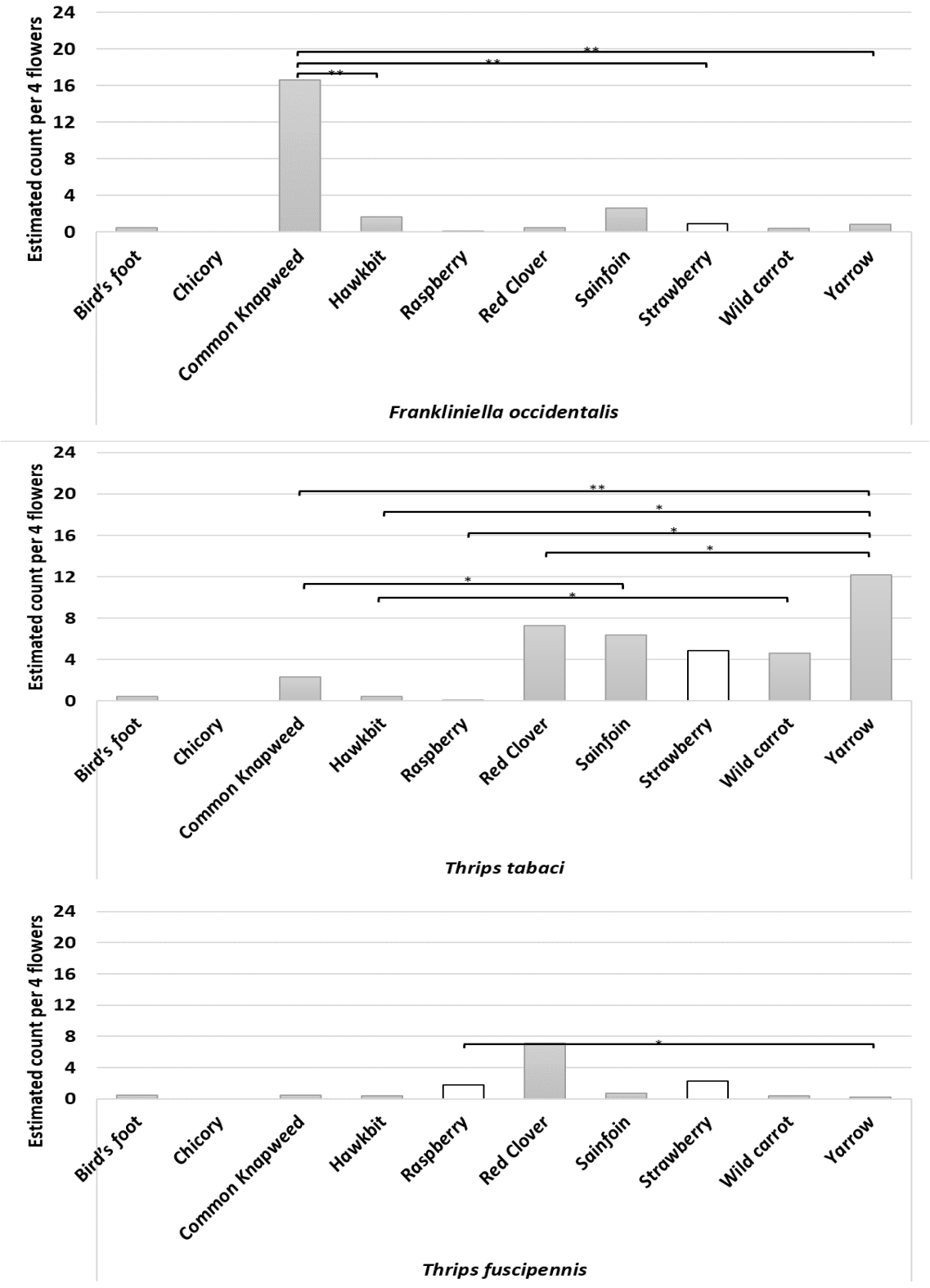



**Figure 3.5.20.** Estimated count of WFT (*Frankliniella occidentalis*, top), onion thrips (*Thrips tabaci*, middle), and rose thrips (*Thrips fuscipennis*, bottom) per 4 flowers in each plant species sampled in August at all sites. Lines and asterisks indicate significant differences (*<0.05, **<0.01, ***<0.001). White bars refer to the crop.

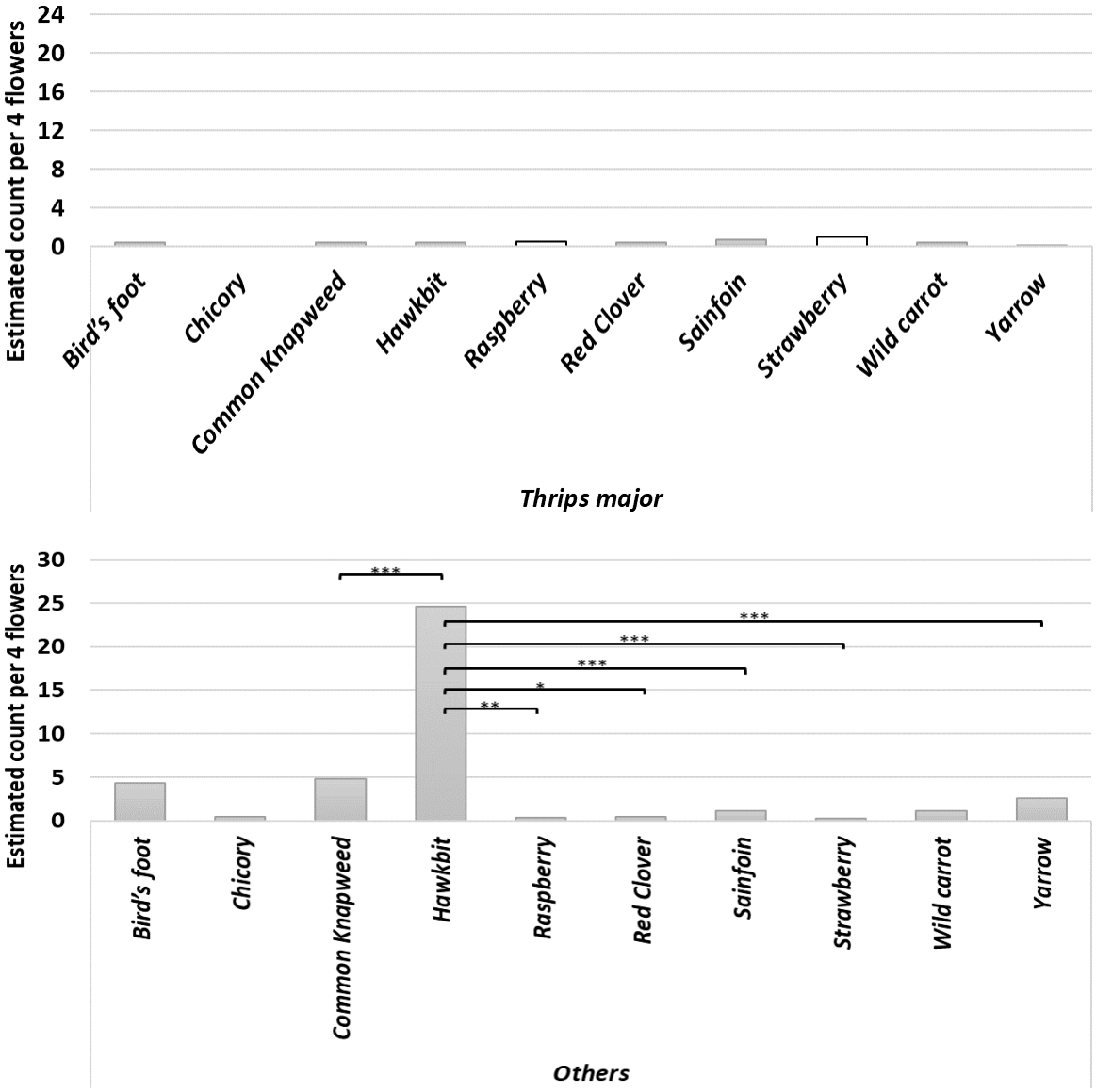



**Figure 3.5.21.** Estimated count of Rubus thrips (*Thrips major*, top), and other thrips not documented as soft fruit pests (bottom) per 4 flowers in each plant species sampled in August at all sites. Lines and asterisks indicate significant differences (*<0.05, **<0.01, ***<0.001). White bars refer to the crop.

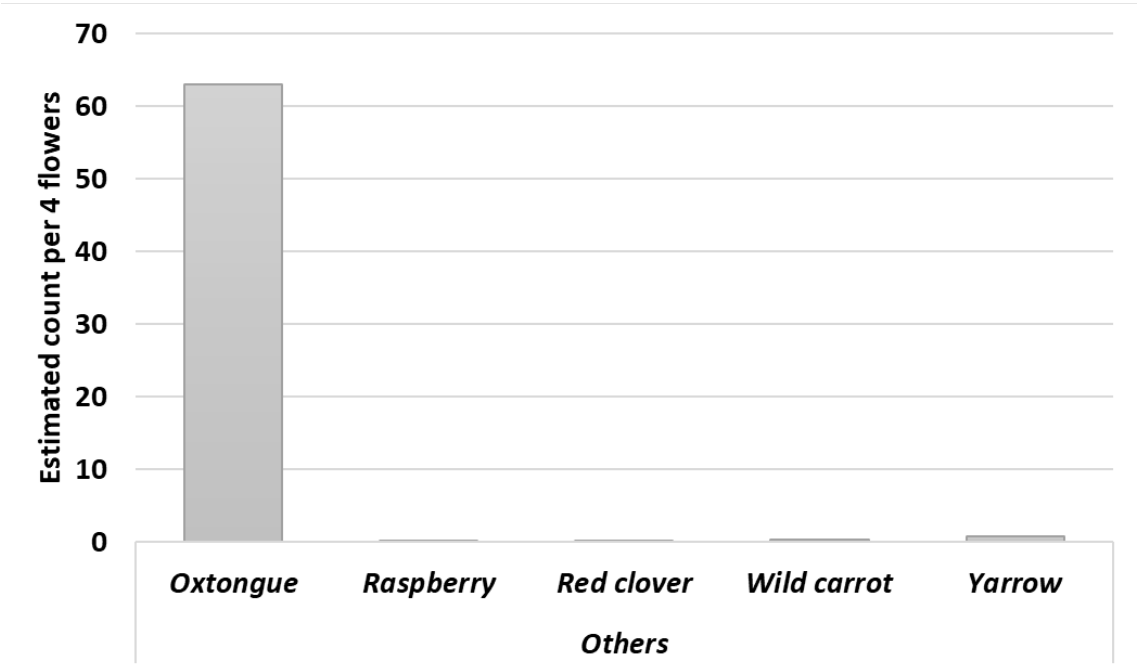



**Figure 3.5.22.** Estimated count of other thrips not documented as soft fruit pests (bottom) per 4 flowers in each plant species sampled in September at all sites. Lines and asterisks indicate significant differences (*<0.05, **<0.01, ***<0.001). Strawberry crops not sampled in September.

Pollinators

Two pollinator surveys were done in June and July at each site. Both crop and floral margin were flowering at the time surveys were carried out. No significant differences on numbers of pollinators species were observed between the floral margins and the different distances into the crop (Figure 3.5.23). At all areas surveyed bumblebees and honeybees were the most common pollinators recorded. However, numbers of bumblebees are higher in the floral margin, while honeybees are more abundant in the crop. Variation in numbers of pollinators recorded between sites was high. Other insect pollinators recorded were hoverflies, solitary bees, flies, and butterflies.

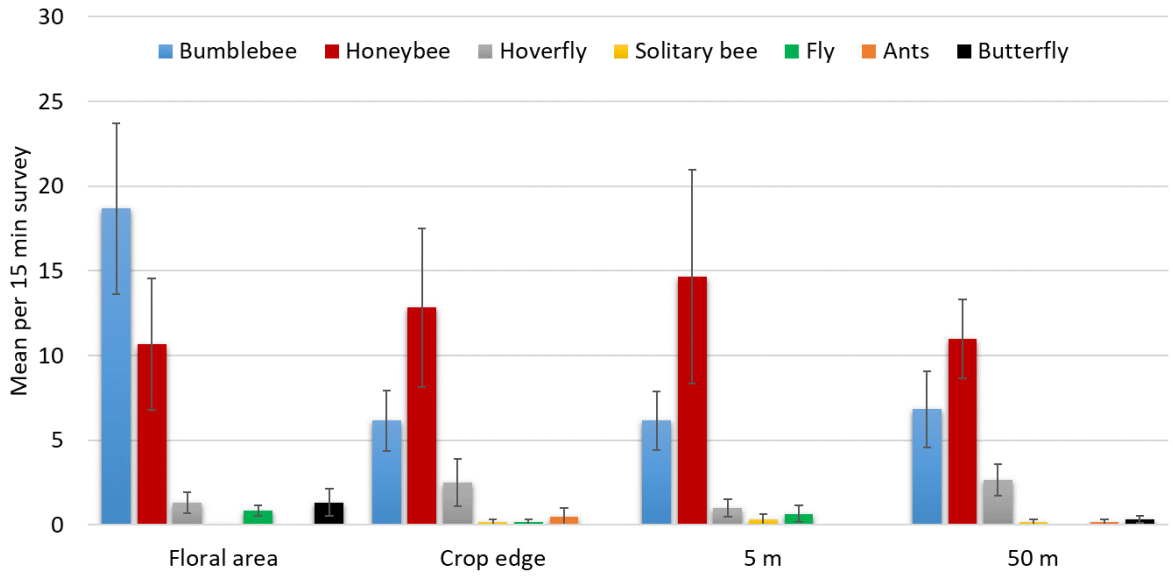



**Figure 3.5.23**. Mean number (±SE) of pollinators recorded over a 15 minute survey in the floral margin, at the edge of the crop, 5 meters into the crop and 50 meters into the crop in strawberry and raspberry crops. No significant differences found.

## Conclusions

- All sown plots established successfully. Single species plots had more than 70% coverage of the sown species, sainfoin and chicory. EM1 seed mix species covered 99% of the plots with oxeye daisy and common knapweed being the better-established flowering species.
- Most herbivores or potential soft fruit pests found during this trial were capsids and aphids. No strawberry pest aphids were found in the floral resources. Aphids were only present in the crop from July to September and in low numbers (average of < 0.2 aphids per plant).
- Capsid (mirids) were recorded in low numbers in the floral margins and were not analysed. No capsids of soft pests were found during the assessments.
- Although the number of flowering species varied between sampling dates, thrips numbers and species in each flower type (species) were consistent.
- Parasitoids, spiders and anthocorids were the most abundant beneficials in the floral margins and crops.
- Overall numbers of adult thrips in the crop were low (< 1 thrips per 4 flowers). Thrips in floral margins did not appear to enter crops in significant numbers at up to 50 m into the crop.
- The flower margin species, with the highest numbers of WFT, was common knapweed, in August (16 thrips per 4 flowers). Numbers of onion thrips were higher in dandelion (16 per 4 flowers), in June and in yarrow (12.1 thrips per 4 flowers), in August. Rose thrips were more abundant in strawberry in June (23.9 per 4 flowers), and in sainfoin (17.3 per 4 flowers) in July.
- No significant differences on numbers of pollinators species were observed between the floral margins and distances up to 50 m into the crop. Bumblebees and honeybees were the most common pollinators recorded. However, numbers of bumblebees were higher in the floral margin, while honeybees are more abundant in the crop.

# WP 4 Control thrips species other than western flower thrips damaging to strawberry crops

## Introduction

Successful IPM programmes for management of western flower thrips (WFT), *Frankliniella occidentalis* on strawberry have been developed using knowledge of its biology and behaviour. These programmes are based on the use of the predatory mite, *Neoseiulus cucumeris*, the predatory bug, *Orius laevigatus* and on some farms, 'mass monitoring' with blue roller traps, with or without the WFT aggregation pheromone lure which can increase numbers of WFT caught. (Sampson, 2014; Harnden *et al*. 2015; Raffle *et al*. 2015). Strategies for controlling WFT on strawberry are not effective against several other species of thrips which fly in as adults and can damage fruit (Brown & Bennison, 2017; Seymour *et al.*, 2020). The potential options for 'mass monitoring' or 'push-pull' strategies for controlling adults of these other thrips species were reviewed (Seymour *et al.*, 2020).

Magipal is currently marketed as an attractant for natural enemies but has also been found to be a general pest repellent. Magipal gave promising results in a preliminary trial on strawberry in a push-pull strategy together with blue roller traps and the WFT aggregation pheromone for WFT control within an IPM programme at a site where WFT was the main thrips species (Griffiths & Sampson, personal communication, 2020). Lurem-TR is a non-pheromone lure containing methyl isonicotinate (MI), which is the most widely internationally studied non-pheromone semiochemical used as a thrips attractant. Lurem-TR has been found to increase catches of 12 different species of thrips, including WFT, the rubus thrips (*Thrips major*), and the onion thrips (*Thrips tabaci),* (Teulon, 2017). However, there is no published evidence, yet that Lurem-TR attracts the rose thrips, *Thrips fuscipennis* or the flower thrips, *Frankliniella intonsa*. However, it has been tested predominately in countries where these species did not occur.

In 2020, in this project, using Magipal as the 'push' and Lurem-TR as the 'pull', we tested the different components of the push-pull effect separately with four treatments including an untreated control at each of two sites where thrips species other than WFT predominated. However, thrips numbers per flower were low at both sites in both treated and control plots and there were no significant differences in thrips numbers between treatments. In 2021, we set up two push-pull trials and monitored the site with the highest numbers of thrips for a longer period than the second site. We compared only two treatments: untreated and push-pull, in larger plots than in 2020. In addition, we tested the individual 'push' and 'pull' components in a smaller trial with high replication.

The objectives of these trials were to test whether:

1. Thrips numbers per flower and fruit damage are reduced by using MagiPal (push) combined with Lurem-TR and blue roller traps (pull) compared to in control plots.
2. The roller traps used in the push-pull strategy have a negative impact on beneficials in the crop.
3. The addition of Lurem-TR, Magipal or a new kairomone lure (Thripnok) to blue monitoring traps has a significant impact on the catches of thrips and beneficials.

## Materials and methods

After evaluating thrips species from nine potential sites with histories of problems with thrips species other than WFT, in March 2021, two sites were selected for testing the push pull strategy and the effects of the semiochemicals upon trap catch. *Thrips fuscipennis* (rose thrips) was the predominant or only species at both selected sites when the sites were selected and both sites had a history of *T. fuscipennis* problems in previous years.

*Sites:*

- Site 1 (Surrey) – protected everbearer strawberry cv. Murano (*Fragaria* x *ananassa* 'Murano'), first year crop. Six tabletops per tunnel. Grass on ground beneath tabletops.
- Site 2 (Worcestershire) – protected everbearer strawberry, cv. Prize (*Fragaria* x *ananassa* 'Prize'), second year crop. Five tabletops per tunnel. Ground cover matting on ground beneath tabletops.

**Figure 4.1:** Site 1, protected strawberry

**Figure 4.2**: Site 2, protected strawberry

**Push-pull trial**

*Treatments:*

1. Control (grower's own IPM programme) with no push-pull treatments or roller traps
2. Push-pull strategy with Magipal as 'push' and Lurem-TR together with blue roller traps as 'pull', superimposed onto the grower's own IPM programme

*Trial design and setup:* There were six replicate blocks at each site with each block containing two randomised plots (a control and push-pull treatment in each block). Each plot spanned an approximate 20 x 20 m (three polytunnels in width). Three polytunnels width and 20 m length were used as buffers in between plots to avoid semiochemical crossover.

Site 1 was set up on 19 May and Site 2 on 5 May before the expected first arrival (June) of the target thrips species adults. At Site 2, the roller traps were blown down on 26 May in a severe storm, so were replaced with fresh, reinforced traps on 11 June.

In the push-pull plots in Treatment 2, six Magipal and eight Lurem–TR sachets were used per plot along with roller traps secured to the underside of the outer tabletop rows. Once set up the Magipal and Lurem-TR sachets were not replaced during the trial.

In the treated plots (Treatment 2), the 'push' and 'pull' components were set up as follows:

**Push**: MagiPal repellent sachets (Figure 4.3) were deployed at 5 m and 15 m in each treated plot, attached to a cane in the crop at just above crop height (to avoid interfering with the spray boom) in the central row of each tunnel with a total of six Magipal sachets per plot.

**Figure 4.3.** MagiPal sachet deployed in crop

**Pull:** Leg rows were weeded before trap deployment. Blue roller traps (20 m long) were deployed in four leg rows per plot, as high as they could be placed (25 m trap length per row

was required to allow for wrapping around supports), in each plot. Lurem-TR was placed every 5 and 15 m on each leg row trap with a total of eight Lurem-TR sachets per plot. The sachets were stuck onto the roller traps.

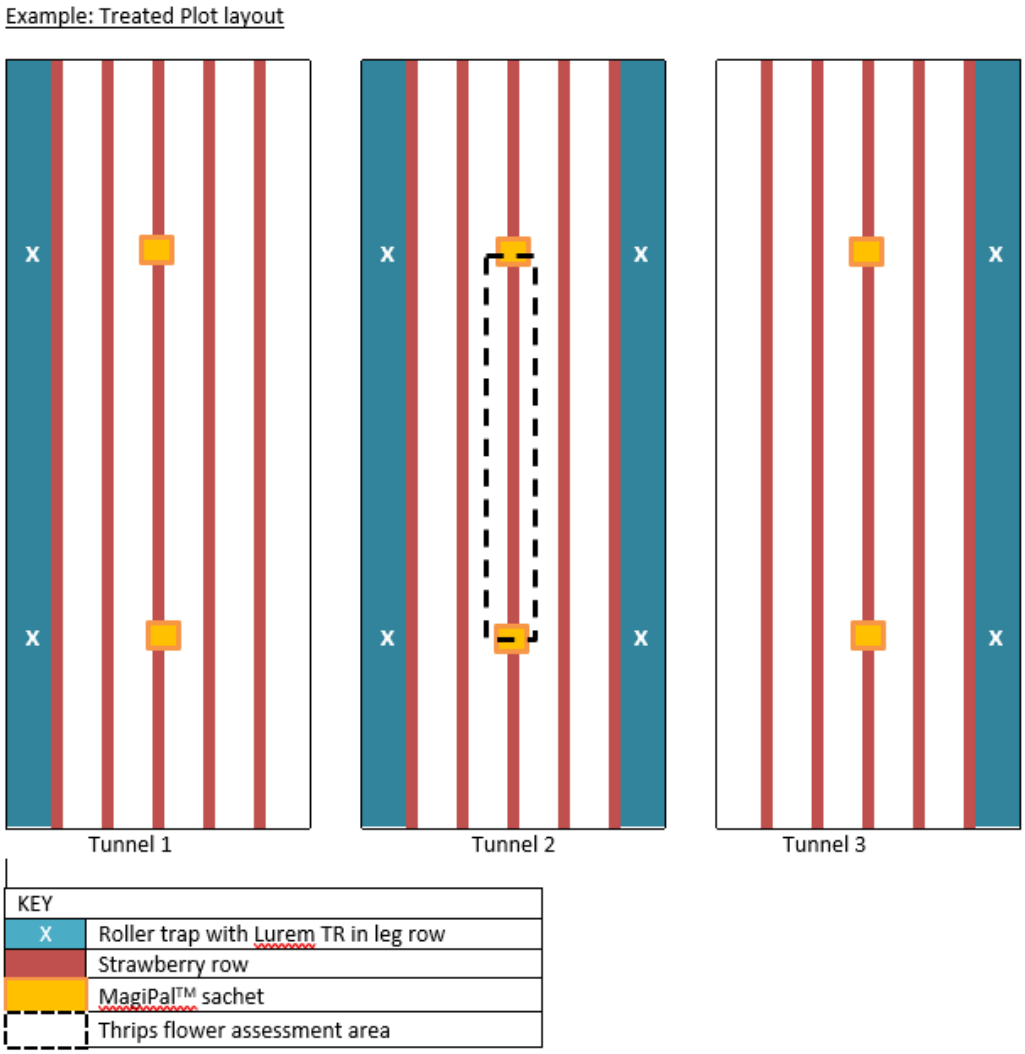



**Figure 4.4**. Push-pull plot layout: an example of the plot layout of the roller traps in push-pull plots at both sites. Each plot spanned three polytunnels with an area approximately 20 m long x 20 m wide (each polytunnel approximately 8 m wide).

## Semiochemical trial

*Treatments:*

1. Untreated control (blue traps only)
2. Lurem-TR on blue traps ('pull' component used in main push-pull trial)
3. Magipal on blue traps ('push' component used in the main push-pull trial)
4. Thripnok (new kairomone lure) on blue traps

*Trial design:* This trial was done at Site 2, but in a different set of tunnels separate to the push-pull trial. Twenty replicates of each of the four treatments were undertaken. Each of the replicates was a single 'dry glue' blue sticky trap, 25 x 10 cm, mounted on a cane, with the appropriate treatment sachet cable-tied directly underneath the trap. A buffer space of 10m was left between each trap to avoid the semiochemicals mixing.

The traps were set up during the estimated peak of non-WFT thrips activity, on 15 July. The individual traps were mounted vertically in a landscape orientation on a cane using elastic bands and all traps were aligned at right angles to the tabletops (Figure 4.5). The traps were left in position for two weeks, then collected into labelled plastic bags and returned to the laboratory on 3 August.

**Figure 4.5:** Sticky trap and Magipal sachet mounted on cane during semiochemical trial.

*Assessments – push-pull trial*

At each assessment (including setup date) 20 flowers per plot were collected from each plot (240 per site per assessment), once every two weeks from 19 May to 15 July at Site 1 and 20 flowers per plot from 23 June to 03 August at site 2. Additionally, on each assessment date in the push-pull treatment, two sections of roller sticky trap were covered with clear plastic sheets per plot to assess numbers of thrips and beneficials caught prior to that date. Further details of the assessment methods are given below.

*Flower sampling:* The 20 flowers per plot were taken from the central 2m of the two central sampling rows. Only upward facing mid-aged flowers (all petals present, anthers brown rather than yellow) at the top of each plant were sampled. All flowers were collected into screw-

capped specimen tubes (one tube per plot) containing 70% alcohol and returned to the laboratory for thrips extraction and identification using the procedures detailed below (Extraction and Identification).

*Flower counts:* In one monitoring plot in each block, five plants were sampled in the field and the numbers of flowers on each plant recorded. This was carried out because often thrips damage to fruit is more severe when there are few flowers available, as thrips adults congregate in the few available flowers, leading to more intensive feeding on the young developing fruit.

*Fruit damage:* When white fruit were available, percentage fruit area with thrips bronzing damage was assessed *in situ* on 20 white fruit per plot on each sampling date.

*Trap sampling:* At every assessment date, two clear plastic sheets (30 x 40cm) per treated plot were placed over the roller traps with labels stating the plot, treatment, and date. These sheets were placed at varying random points along the trap and were cut out and brought back to the laboratory when the trial was taken down. Once the portions of roller traps had been taken back to the lab, a sticky trap (25 x 10cm) was traced around on top of the bagged trap ensuring that the entire width of the trap was included. The outline of the trap marked where the counts of thrips and beneficials would be taken from.

*Thrips extraction – push-pull trial*

In the laboratory, thrips and any beneficial invertebrates were extracted from the flowers from each of the 12 plots using the following methods. (1) A square piece of thrips proof mesh (120 microns) was secured over the top of a beaker using an embroidery hoop. (2) A depression was made in the mesh to prevent spillage of alcohol and thrips. (3) The flowers and alcohol were gently agitated in the sampling tube. (4) 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. (5) The flowers were removed from the sieve using forceps and placed back in the tube and alcohol added to the tube. Steps 2-5 were repeated twice more (a total of three flower rinses). The flowers were then discarded. The alcohol in the beaker was kept for washing further flower samples. The mesh was removed and placed on top of a laminated sheet of white paper and examined under a dissecting microscope. The following were recorded:

- Numbers of *Thrips* spp. and *Frankliniella* spp. females and numbers of male thrips (it was not possible to assign males to genus as males of both genera look similar under a low power dissecting microscope i.e. yellow and smaller than females).
- Numbers of thrips larvae
- Numbers of *Aeolothrips* spp. (predatory thrips) adults

- Numbers of *Orius* spp. adults and nymphs, and numbers of other beneficial insects such as lacewings, hoverflies, and bumble bees

*Identification of thrips and beneficials in flowers – push-pull trial*

A minimum of one thrips adult per monitoring plot was identified, i.e., a minimum total of 12 thrips adults 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 morphological keys (Mound *et al*., 1976 for adults; Vierbergen *et al*., 2010 for larvae).

Additional thrips adults were mounted on slides to ensure enough females could be identified (only females should be used when keying out the species) as some may lie in an awkward angle on the slide to enable species confirmation. Numbers of each species were recorded.

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.

*Identification of thrips and beneficials on roller traps - push-pull trial and semiochemical trial*

In the laboratory, each trap was examined under a low power binocular microscope and the total number of thrips adults and beneficials on each side of the trap was recorded. Numbers of *Thrips* spp. females, *Frankliniella* spp. females, males (of either *Thrips* spp. or *Frankliniella* spp. as both are smaller than females and yellow, thus difficult to identify to genus on a sticky trap under a low power binocular microscope) and predatory thrips (*Aeolothrips* spp.) were recorded on each trap. Numbers of beneficial insects were also recorded (*Orius* spp., other Anthocorid bugs, bees, hoverflies, lacewings and ladybirds) as was the number of capsids.

A small subsample of thrips was removed from the semiochemical trial individual traps (thrips were too degraded on the roller traps used in the main push-pull trial so were not removed for identification) at Site 2 using white spirit. To do this, a small square was cut from 24 of the 80 traps containing ~30 thrips each. The individual squares were immersed in separate glass beakers containing a small volume of white spirit, agitated, and left for one hour. After an hour, using tweezers, the plastic film on either side of the trap was removed. The exposed trap was then left in white spirit overnight to allow thrips to slowly detach from the sticky trap surface. The following day the white spirit containing the now liberated thrips was poured through a thrips proof mesh. Thrips samples were gently washed in water before transferring

to a labelled 2ml Eppendorf tube containing a small volume of 70% ethanol. Thrips were then mounted onto slides for identification.

## Data analysis

Mean adult thrips numbers and larvae in flowers from the five sampling dates at Sites 1 and 2 were evaluated independently by life stage and site using Analysis of Variance in GenStat 16. The percentage area and incidence of fruit bronzing at site 2 only was also analysed using Analysis of Variance in GenStat 16. Five further Analyses of variance were performed on the semiochemical chemical trial results, evaluating differences between treatments upon the counts of total thrips, *Thrips* spp. females, *Frankliniella* spp. females, bees and hoverflies. All analysis was completed by Chris Dyer, the ADAS statistician.

### Data loggers: temperature and humidity

At site 1, one data logger was used to monitor temperature and humidity for the trial duration. At site 2 two data loggers used.as there were spare loggers available. These were attached underneath the tabletops using cable ties and marked with ringots.

## Results

*Push pull trial results*

Mean number of thrips per flower and flowers per plant: Site 1

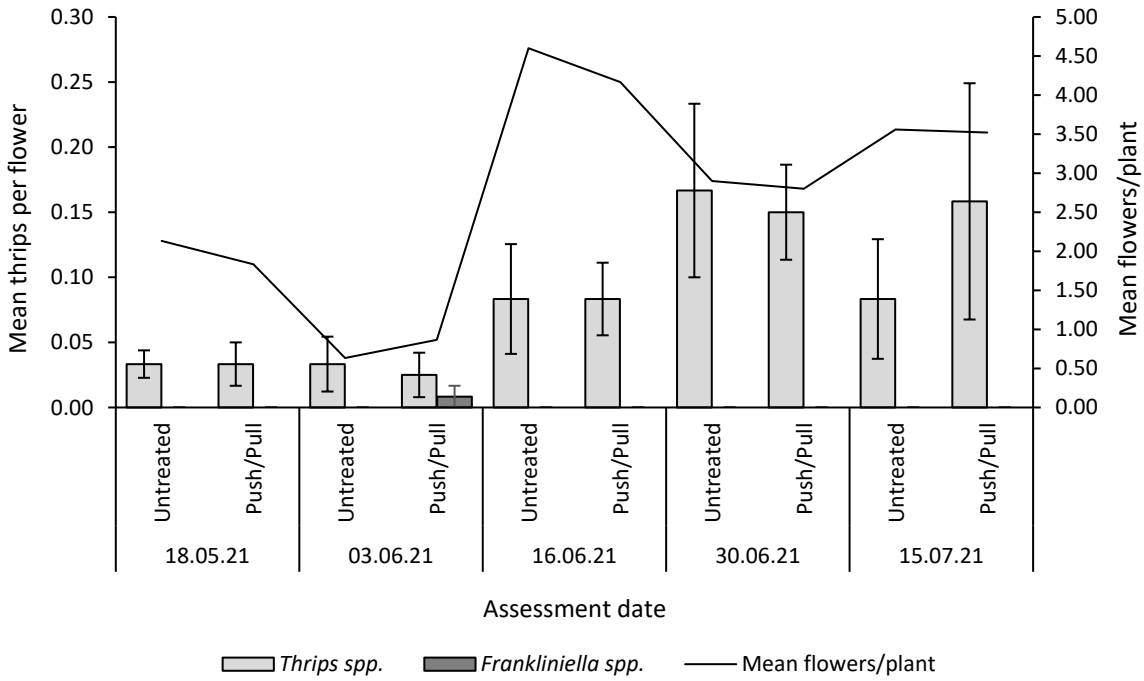



**Figure 4.6** Mean numbers of *Thrips* spp. and *Frankliniella* spp. adults per flower (+/- standard error) in the untreated and push-pull plots at site 1 on the different assessment dates. Mean flowers per plant plotted on the Z axis. Owing to low numbers of *Frankliniella* spp. found at site 1, only results for *Thrips* spp. were analysed. No significant differences in numbers of *Thrips* spp. between treatments or assessment dates.

Site 1 had low numbers (means of below 0.2 per flower) of both *Thrips* spp. and *Frankliniella* spp. on all five assessment dates (Figure 4.6). At this site, across all assessment dates only one *Frankliniella* spp. individual was found. This individual was found in a flower in a push-pull treated block on the second assessment date, on 03.06.21. Owing to this small sample, no statistical analysis of *Frankliniella* spp. from flowers was undertaken for this site.

*Thrips* spp. numbers were lowest on the first two assessment dates (18.05.21 and 03.06.21), where mean numbers of *Thrips* spp. adults ranged from 0.025-0.033 (Table 4.1). Number of *Thrips* spp. adults per flower slightly increased on the three subsequent assessment dates, with mean numbers per flower in untreated plots ranging from 0.08-0.17 and mean numbers per flower in push-pull blocks ranging from 0.08-0.16 (Table 4.1). No significant differences

in mean *Thrips* spp. adults per flower were identified between treatments (F(1,25)=2.09, P=0.112) or between assessment dates (F(4,25)=2.09, P=0.112). Mean number of flowers per plant varied notably between assessment dates. At the first assessment, an average of 1.98 flowers were recorded per plant however this decreased to 0.75 during the second assessment. The greatest numbers of flower per plant were recorded on the third assessment with an average of 4.38 with this dropping marginally to 2.85 and 3.54 on the fourth and fifth assessment dates.

**Table 4.1** Mean numbers of *Thrips* spp. and *Frankliniella* spp. adult females per flower under either an untreated or push-pull regime at site 1 on each of the five assessment dates. Owing to low numbers of *Frankliniella* spp. found at site 1, only results for *Thrips* spp. were analysed. No significant differences in numbers of *Thrips* spp. between treatments or assessment dates.

| Treatment | Genus | Assessment date | | | | |
|---|---|---|---|---|---|---|
| | | 18.05.21 | 03.06.21 | 16.06.21 | 30.06.21 | 15.07.21 |
| Untreated | *Thrips* spp. | 0.033 | 0.033 | 0.083 | 0.167 | 0.083 |
| | *Frankliniella* spp. | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Push-Pull | *Thrips* spp. | 0.033 | 0.025 | 0.083 | 0.150 | 0.158 |
| | *Frankliniella* spp. | 0.000 | 0.008 | 0.000 | 0.000 | 0.000 |

Mean number of thrips per flower and flowers per plant: Site 2

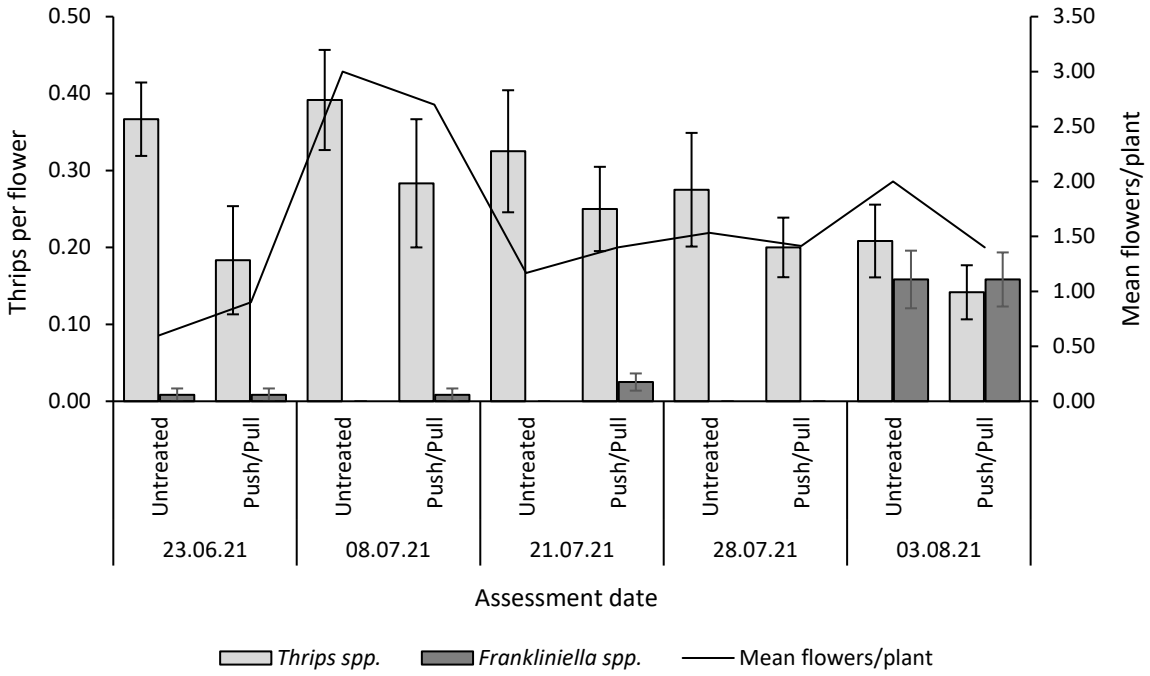



**Figure 4.7** Mean numbers of *Thrips* spp. and *Frankliniella* spp. adults per flower (+/- standard error) in the untreated and push-pull plots at site 2 on the different assessment dates. Mean flowers per plant plotted on the Z axis. No significant differences in numbers of *Thrips* spp. and *Frankliniella* spp. between treatments or assessment dates.

Although numbers of *Thrips* spp. per flower were lower in the push-pull plots than in untreated plots on all assessment dates, these differences were not statistically significant.

For *Thrips* spp., neither treatment ($F(1,25)=0.05$, $P=0.833$) nor assessment date ($F(4,25)=1.22$, $P=0.327$) significantly affected the mean number of *Thrips* spp. per flower. Similarly, for *Frankliniella* spp. neither treatment ($F(1,25)=0.44$, $P=0.515$) nor assessment date ($F(4,25)=2.43$, $P=0.074$) significantly affected the average number of *Frankliniella* spp. per flower.

Mean numbers of both *Thrips* spp. and *Frankliniella* spp. were notably higher at site 2 than at site 1 but were still below 0.4 per plant (Figures 4.6 and 4.7). On the first four of the five assessment days (23.06.21, 08.07.21, 21.07.21 and 03.08.21), the average number of *Thrips* spp. per flower was markedly higher than *Frankliniella* spp. (Figure 4.7). On these first four assessment dates, *Frankliniella* spp. were very low in number, with a range across treatments of 0-0.025 per flower and individuals being found in untreated blocks on only one of the four assessment dates and in push-pull blocks on three of the four assessment dates. At the fifth

assessment (03.08.21) however, the mean number of *Frankliniella* spp. per flower was markedly increased, with an average of 0.158 per flower for both treatments (Figure 4.7).

*Thrips* spp. conversely proved more abundant on all five assessment dates, although still below means of 0.4 per flower in untreated plots. Mean numbers of *Thrips* spp. per flower ranged from 0.208-0.392, with the lowest mean seen during the fifth assessment (03.08.21) and the highest mean seen during the second assessment (08.07.21). In push-pull plots, the mean number of *Thrips* spp. per flower was slightly (but not significantly) lower than in untreated plots, ranging from 0.142-0.283, with the lowest mean again seen during the fifth assessment (03.08.21) and the highest mean also again seen during the second assessment (08.07.21).

In common with site 1, between assessment dates the mean number of flowers per plant at site 2 was found to vary. At the first assessment, a mean of 0.75 flowers per plant were recorded. On the second assessment date, this increased to 2.85. The mean number of flowers on assessments date three, four and five became more consistent, with means of 1.28, 1.47 and 1.70 flowers per plant.

**Table 4.2** Mean numbers of *Thrips* spp. and *Frankliniella* spp. adult females per flower under either an untreated or push-pull regime on each of the five assessment dates. No significant differences in numbers of *Thrips* spp. and *Frankliniella* spp. between treatments or assessment dates.

| Treatment | Genus | Assessment date | | | | |
|---|---|---|---|---|---|---|
| | | **23.06.21** | **08.07.21** | **21.07.21** | **28.07.21** | **03.08.21** |
| Untreated | *Thrips* spp. | 0.367 | 0.392 | 0.325 | 0.275 | 0.208 |
| | *Frankliniella* spp. | 0.008 | 0.000 | 0.000 | 0.000 | 0.158 |
| Push-Pull | *Thrips* spp. | 0.183 | 0.283 | 0.250 | 0.200 | 0.142 |
| | *Frankliniella* spp. | 0.008 | 0.008 | 0.025 | 0.000 | 0.158 |

*Species of thrips adults identified in flowers*

At Site 1, 96 thrips from flowers were identified to species while at Site 2, 364 were identified. Across both sites, most thrips identified were *Thrips* spp. (415 of 460).

At site 1, only a single *Frankliniella* spp. (*F. intonsa*) individual was identified across all five assessment dates, with this individual representing 12.5% of the identified thrips at site 1 at the second assessment date (03.06.21) (Table 4.3). At site 2 a broadly similar trend was observed, with *Frankliniella* spp. only representing 3.0%, 1.2%, 4.1% of the total identified thrips on assessment dates 1, 2 and 3 respectively (23.06.21, 08.07.21 and 21.07.21). On the fifth assessment at site 2 however (03.08.21), notably more *Frankliniella* spp. were found, with 38 individuals being identified, representing 45.2% of the identified thrips (Table 4.3). Across both sites all but one identified *Frankliniella* spp. individuals were confirmed to be *F. intonsa*, with only one individual of *F. occidentalis* being found at site 2 - at the first assessment date (23.06.21).

At Site 1, of the identified *Thrips* spp., *T. fuscipennis* and *T. major* were the most prevalent in flowers on assessment dates 2, 3, 4 and 5 (03.06.21, 16.06.21, 30.06.21 and 15.07.21), representing a combined total of 87.5%, 100.0%, 91.5% and 100.0% of the identified thrips on these dates (Table 4.3). Of these two species, *T. major* was more prevalent, representing a higher percentage of the thrips sample on assessments dates 2 and 5 and matching the prevalence of *T. fuscipennis* on assessment days 3 and 4. While *T. fuscipennis* was also common on assessment date 1 (18.05.21) representing 28.6% on the identified thrips, a different species, *T. minutissimus*, was found to be more prevalent on this date (five individuals recorded) representing 71.4% of the total identified thrips. The number of identified thrips on the first and second assessment dates however were low with a total of only seven and eight individuals identified on each date.

At Site 2, on the first four assessment dates (23.06.21, 08.07.21, 21.07.21 and 28.07.21), a similar trend was noted for *Thrips* spp. as at Site 1. Both *T. fuscipennis* and *T. major* were the most prevalent in flowers however, compared to site 1 their relative abundance was reversed, with *T. fuscipennis* being the most common species, representing 58.8%, 56.1%, 49.3% and 78.9% of the identified thrips while *T. major* represented 35.3%, 37.8%, 37.0% and 14.0% (Table 4.4). The *Thrips* spp. trend on assessment date 5 (03.08.21) however was notably different, with *T. tabaci* being the most prevalent *Thrips* species representing 42.9% of the identified thrips.

**Table 4.3** Summary of the number and proportion of identified thrips species adults in the flowers during the five assessment dates at Site 1.

| Species | Metric | Date | | | | |
|---|---|---|---|---|---|---|
| | | 18.05.21 | 03.06.21 | 16.06.21 | 30.06.21 | 15.07.21 |
| *T. fuscipennis* | Number identified | 2 | 2 | 10 | 15 | 5 |
| | % of total | 28.6 | 25.0 | 50.0 | 42.9 | 19.2 |
| *T. major* | Number identified | 0 | 5 | 10 | 17 | 21 |
| | % of total | 0.0 | 62.5 | 50.0 | 48.6 | 80.8 |
| *T. minutissimus* | Number identified | 5 | 0 | 0 | 0 | 0 |
| | % of total | 71.4 | 0.0 | 0.0 | 0.0 | 0.0 |
| *T. simplex* | Number identified | 0 | 0 | 0 | 0 | 0 |
| | % of total | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| *T. tabaci* | Number identified | 0 | 0 | 0 | 3 | 0 |
| | % of total | 0.0 | 0.0 | 0.0 | 8.6 | 0.0 |
| *T. vulgatissimus* | Number identified | 0 | 0 | 0 | 0 | 0 |
| | % of total | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| *F. intonsa* | Number identified | 0 | 1 | 0 | 0 | 0 |
| | % of total | 0.0 | 12.5 | 0.0 | 0.0 | 0.0 |
| *F. occidentalis* | Number identified | 0 | 0 | 0 | 0 | 0 |
| | % of total | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Total thrips adults identified | | 7 | 8 | 20 | 35 | 26 |

**Table 4.4** Summary of the number and proportion of identified thrips species adults in the flowers during the five assessment dates at Site 2.

| Species | Metric | Date | | | | |
|---|---|---|---|---|---|---|
| | | 23.06.21 | 08.07.21 | 21.07.21 | 28.07.21 | 03.08.21 |
| *T. fuscipennis* | Number identified | 40 | 46 | 36 | 45 | 6 |
| | % of total | 58.8 | 56.1 | 49.3 | 78.9 | 7.1 |
| *T. major* | Number identified | 24 | 31 | 27 | 8 | 0 |
| | % of total | 35.3 | 37.8 | 37.0 | 14.0 | 0.0 |
| *T. minutissimus* | Number identified | 0 | 0 | 0 | 0 | 0 |
| | % of total | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| *T. simplex* | Number identified | 0 | 0 | 0 | 0 | 4 |
| | % of total | 0.0 | 0.0 | 0.0 | 0.0 | 4.8 |
| *T. tabaci* | Number identified | 2 | 4 | 6 | 4 | 36 |
| | % of total | 2.9 | 4.9 | 8.2 | 7.0 | 42.9 |
| *T. vulgatissimus* | Number identified | 0 | 0 | 1 | 0 | 0 |
| | % of total | 0.0 | 0.0 | 1.4 | 0.0 | 0.0 |
| *F. intonsa* | Number identified | 1 | 1 | 3 | 0 | 38 |
| | % of total | 1.5 | 1.2 | 4.1 | 0.0 | 45.2 |
| *F. occidentalis* | Number identified | 1 | 0 | 0 | 0 | 0 |
| | % of total | 1.5 | 0.0 | 0.0 | 0.0 | 0.0 |
| Total thrips adults identified | | 7 | 68 | 82 | 73 | 57 |

*Mean numbers of thrips larvae per flower, Thrips spp. adults per flower and Frankliniella spp. adults per flower*

Across all five assessments and both sites, thrips larvae proved uncommon in flowers (Table 4.5). At Site 1, thrips larvae were only found on the third assessment date (16.06.21), with a mean of 0.0004 per flower being found and none of these were possible to identify to species. While more larvae were found in flowers at Site 2, their abundance was still very low ranging from means of 0.0003-0.002 per flower over the five assessment dates (Table 4.5). The greatest numbers of larvae per flower were seen at Site 2 on the fifth assessment date (03.08.21), with a mean of 0.002. The single larva identified at Site 2 on 23.06.21 was *T. tabaci* and the five larvae identified on 3.08.21 were *T. major*.

Owing to low numbers of larvae being found at site 1, numbers of larvae were only analysed for Site 2. Neither treatment ($F(1,25)=1.30$, $P=0.265$) nor assessment date ($F(4,25)=1.15$, $P=0.358$) significantly affected the mean number of larvae per flower.

**Table 4.5** Summary of the mean numbers of thrips larvae and *Thrips* spp. and *Frankliniella* spp. adults per flower on the five assessment dates at Site 1 and Site 2. No significant differences in numbers of larvae between treatments or assessment dates.

| Site 1 | | | | Site 2 | | | |
|---|---|---|---|---|---|---|---|
| Date | Mean larvae per flower | Mean *Thrips* spp. adults per flower | Mean *Frankliniella* spp. adults per flower | Date | Mean larvae per flower | Mean *Thrips* spp. adults per flower | Mean *Frankliniella* spp. adults per flower |
| 18.05.21 | 0 | 0.0833 | 0 | 23.06.21 | 0.0017 | 0.2750 | 0.0083 |
| 03.06.21 | 0 | 0.1583 | 0 | 08.07.21 | 0.0003 | 0.3375 | 0.0042 |
| 16.06.21 | 0.0042 | 0.0292 | 0.0042 | 21.07.21 | 0.0056 | 0.2875 | 0.0125 |
| 30.06.21 | 0 | 0.1208 | 0 | 28.07.21 | 0.0017 | 0.2375 | 0 |
| 15.07.21 | 0 | 0.0333 | 0 | 03.08.21 | 0.0023 | 0.1750 | 0.1583 |

Fruit Bronzing

*Percentage damaged fruit area*

Mean percentage white fruit area with bronzing damage at Site 1 was low, with bronzing detected on fruit during only three of the six assessment dates (03.06.21, 16.06.21 and 15.07.21) (Table 4.6). Where fruit bronzing was detected at Site 1, in all cases bronzing was very minor ranging from 0.02-0.07% of white fruit area. At Site 2, a similar trend was observed during the first three assessment dates (03.06.21, 16.06.21 and 23.06.21), with mean percentage damage ranging from 0.01-0.10% (Table 4.6). Percentage damage however increased to a mean of 0.71% on assessment date four (08.07.21) before further increasing on assessment dates five and six to a mean across treatments of 3.26% and 2.63% respectively (Table 4.6).

Owing to minimal bronzing damage at Site 1, percentage bronzing damage was analysed only for Site 2. Analysis for Site 2 revealed no significant difference in mean bronzing damage on white fruit between control and push-pull treated plots ($F(1,30)=2.33$, $P=0.067$). Analysis did however reveal a significant difference in mean bronzing damage between assessment dates ($F(5,30)=6.77$, $P=<0.01$), with significantly greater mean percentage area of white fruits damaged during the final two assessments (Table 4.6).

**Table 4.6** Mean percentage white fruit area with bronzing damage on the six assessment dates at Sites 1 and 2. No significant differences in percentage damaged fruit area between treatments. Significantly higher percentage damaged fruit area was however seen during the final two assessments at site 2. Columns sharing a letter are statistically similar.

| Site 1 | | | | Site 2 | | | |
|---|---|---|---|---|---|---|---|
| Date | percent area bronzed | | | Date (2021) | percent area bronzed | | |
| | Untreated | Push Pull | Combined treatments | | Untreated | Push Pull | Combined treatments |
| 20.04.21 | 0 | 0 | 0 | 03.06 | 0.02 | 0.05 | 0.04 a |
| 18.05.21 | 0 | 0 | 0 | 16.06 | 0.01 | 0.01 | 0.01 a |
| 03.06.21 | 0.04 | 0.03 | 0.04 | 23.06 | 0.06 | 0.10 | 0.08 a |
| 30.06.21 | 0 | 0 | 0 | 08.07 | 0.72 | 0.71 | 0.71 a |
| 16.06.21 | 0.02 | 0 | 0.01 | 28.07 | 1.57 | 4.94 | 3.26 b |
| 15.07.21 | 0.07 | 0.03 | 0.05 | 03.08 | 2.29 | 2.98 | 2.63 b |

*Percentage bronzing incidence*

At Site 1 the incidence of fruit with any bronzing was consistently low across all six assessment dates and both treatment regimes, ranging from 0-2.5% (Table 4.7). The highest bronzing incidence at Site 1 was seen on the final assessment date (15.07.21), where 2.0% of fruit under an untreated regime were bronzed while 2.5% of fruit under a push-pull treatment regime were bronzed. The incidence of bronzing on all five earlier assessments dates was uniformly low, ranging from 0-0.6%. The incidence of fruit bronzing at site 2 was notably higher than at Site 1, ranging across all assessments and treatments from 0.5-12% (Table 4.7). Owing to low incidence at site 1, bronzing incidence was only analysed for site 2. Statistical analysis showed no significant difference in bronzing incidence at site 2 between untreated and push-pull treated blocks ($F(1,5)=0.74$, $P=0.398$). A significant difference was identified however in bronzing incidence between different assessment dates at Site 2 ($F(5,30)=32.04$, $P=<0.01$), with post hoc tests revealing significant differences between earlier and later assessment dates ($P=<0.05$). The lowest bronzing incidence was seen on the second assessment date (16.06.21), where 0.67% of fruit under an untreated regime were bronzed while 0.50% of fruit under a push-pull treatment regime were bronzed. Bronzing incidence increased significantly and sequentially at later assessment dates, averaging 4.08% at assessment date three (23.06.21), 9.0% at assessment date four (08.07.21) before peaking at 12.08% at assessment date five (28.07.21).

**Table 4.7** Mean percentage incidence of white fruit bronzing on the six assessment dates at Sites 1 and 2. No significant differences in percentage damaged fruit area between treatments. Significantly higher percentage damaged fruit area at the final two assessments at site 2. Columns sharing a letter are statistically similar.

| Site 1 | | | | Site 2 | | | |
|---|---|---|---|---|---|---|---|
| Date | Bronzing incidence (%) | | | Date (2021) | Bronzing incidence (%) | | |
| | Untreated | Push Pull | Combined treatments | | Untreated | Push Pull | Combined treatments |
| 20.04.21 | 0.01 | 0.01 | 0.01 | 03.06 | 1.67 | 1.83 | 1.75 ab |
| 18.05.21 | 0.10 | 0.10 | 0.10 | 16.06 | 0.67 | 0.50 | 0.59 a |
| 03.06.21 | 0.42 | 0.60 | 0.51 | 23.06 | 3.83 | 4.33 | 4.08 b |
| 30.06.21 | 0 | 0 | 0 | 08.07 | 8.17 | 9.83 | 9.00 c |
| 16.06.21 | 0.40 | 0.10 | 0.25 | 28.07 | 11.33 | 12.83 | 12.08 d |
| 15.07.21 | 2.00 | 2.50 | 2.25 | 03.08 | 12.00 | 11.83 | 11.92 d |

*Mean numbers of Thrips spp. and Frankliniella spp. and beneficials on roller traps: Site 1*

At Site 1, under a push-pull treatment regime, roller trap catches of predatory thrips and other beneficials (bees, hoverflies, ladybirds, lacewing, *Orius* spp. and other anthocorids) was notably low with a mean of only 0.08 per 0.05m$^2$ trap area of each being found on roller traps after 56 days (Figure 4.8). Where *Thrips* spp. and *Frankliniella* spp. were considered together, a mean of 3.7 thrips per 0.05m$^2$ area of trap after 15 days, 4.3 after 28 days, 6.0 after 42 days and 8.0 thrips after 56 days (Figure 4.8). While thrips catch at this site was universally low, a marginally higher catch of *Thrips* spp. was observed relative to *Frankliniella* spp. with a ratio of 3:2 (Figure 4.9). Where trendlines were fitted to evaluate the rate of roller trap catch of *Thrips* spp. and *Frankliniella* spp. females and male thrips, a linear trendline was found to fit well the data for all three thrips groups – indicating a consistent catch of 0.0167 *Thrips* spp. females day$^{-1}$ 0.05m$^{-2}$, 0.0135 *Frankliniella* spp females. day$^{-1}$ 0.05m$^{-2}$ and 0.0009 male thrips day$^{-1}$ 0.05m$^{-2}$.

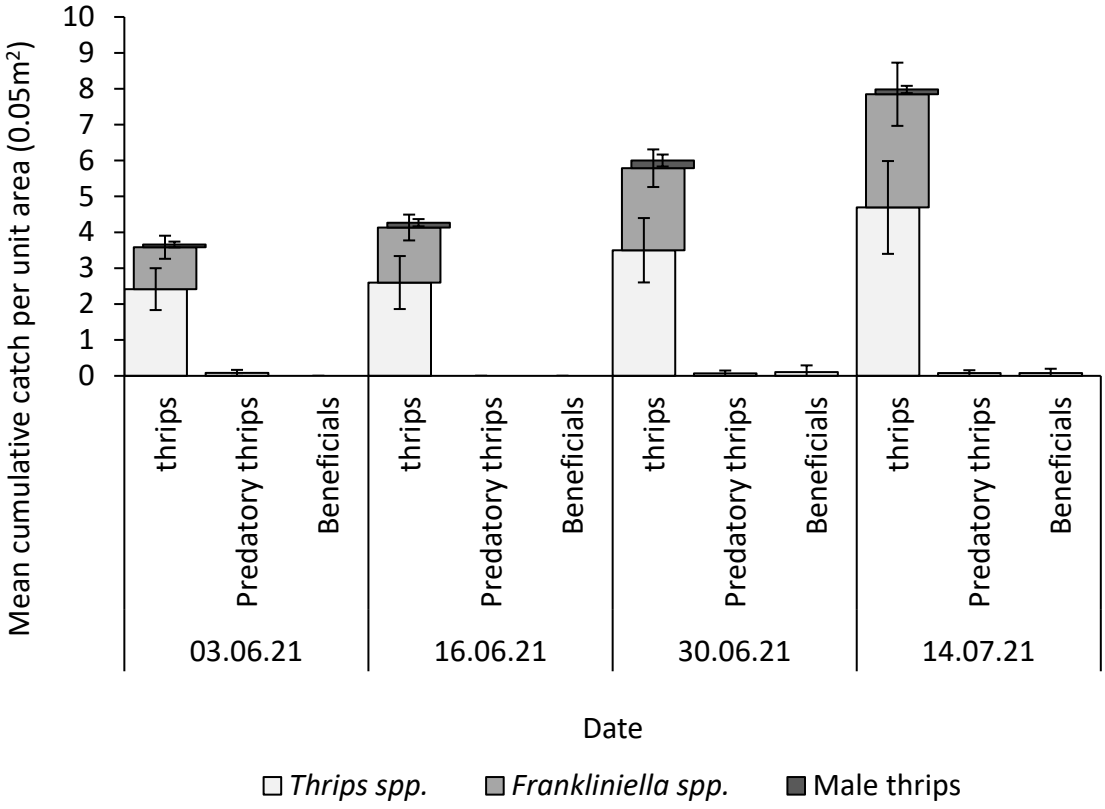



**Figure 4.8** Mean cumulative catch (+/- standard error) of thrips (*Thrips* spp., *Frankliniella* spp. and males), predatory thrips (*Aeolothrips* spp.) and other beneficials (bees, hoverflies, ladybirds, lacewing, *Orius* spp. and other anthocorids) per 0.05m$^2$ area of trap at Site 1 on roller traps under a push-pull treatment regime. Trap catches at site 1 were counted on four occasions and represent cumulative catch, with the dates representing 15, 28, 42 and 56 days of exposure respectively.

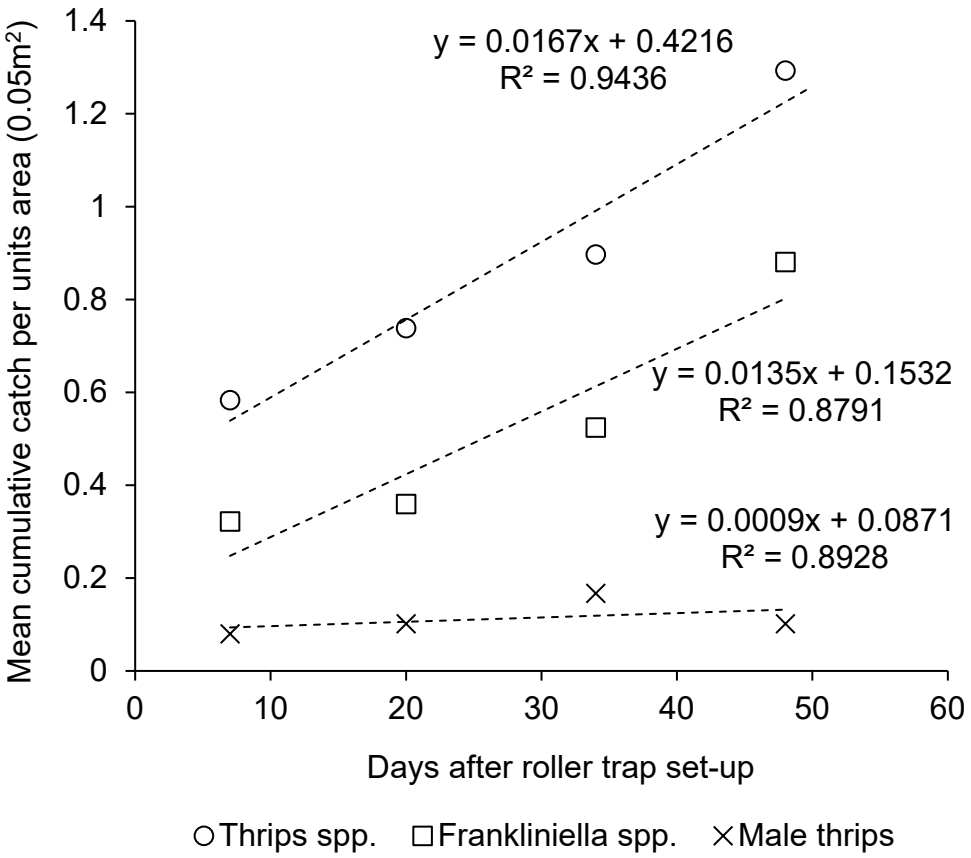



**Figure 4.9** Mean cumulative catch *Thrips* spp. females, *Frankliniella* spp. females and male thrips at Site 1 on roller traps under a push-pull treatment regime. At this site, a relatively linear catch of *Thrips* spp. and *Frankliniella* spp. females and male thrips was observed.

*Mean numbers of thrips and beneficials on sticky traps: Site 2*

At Site 2, under a push-pull treatment regime, no predatory thrips (*Aeolothrips* spp.) were found on roller traps (Figure 4.10). Catch of other beneficials (bees, hoverflies, ladybirds, lacewing, *Orius* spp. and other anthocorids) was also low, averaging 0.139 per 0.05m$^2$ after 53 days. Where pest thrips species were considered together, a mean of 11.7 thrips were found on traps after 6 days, 21.3 after 27 days, 67.8 after 40 days, 90.8 after 47 days and 109.6 thrips after 53 days (per 0.05m$^2$) (Figure 4.10). Roller trap catches of *Thrips* spp. and *Frankliniella* spp. were consistently similar throughout the monitoring period, differing only on the final counts after 53 days when a mean of 51.1 *Frankliniella* spp. per 0.05m$^2$ were trapped relative to 43.4 *Thrips* spp. per 0.05m$^2$. Where trendlines were fitted to evaluate the rate of roller trap catch of *Thrips* spp., *Frankliniella* spp. and male thrips, exponential trendlines were found to fit well the data for all three thrips groups – indicating a growing thrips catch during the experiment period.

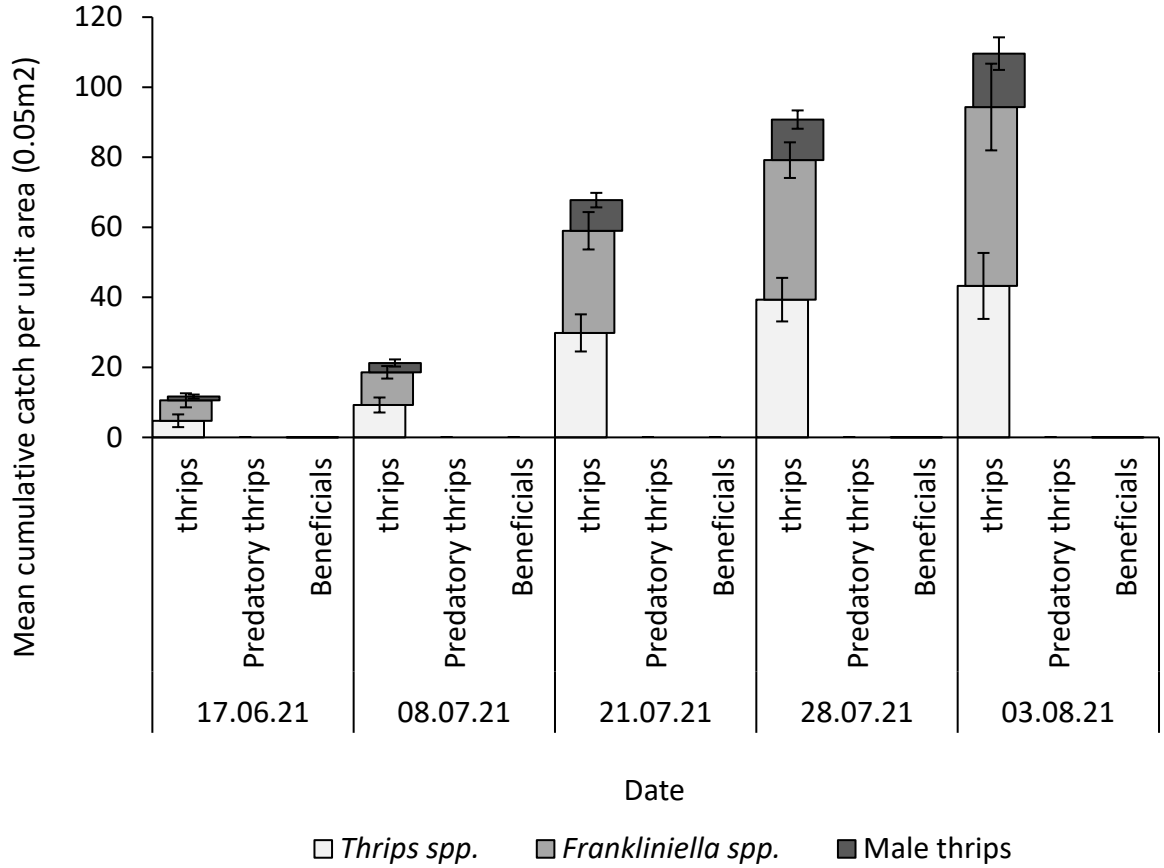



**Figure 4.10** Mean cumulative catch of thrips (*Thrips* spp. and *Frankliniella* spp. females and male thrips), predatory thrips (*Aeolothrips* spp.) and other beneficials (grouped) at Site 2 per 0.05m$^2$ area of roller trap under a push-pull treatment regime, +/- standard error. Trap catches at site 2 were counted on five occasions and represent cumulative catch, with the dates representing 6, 27, 40, 47 and 53 days of exposure respectively.

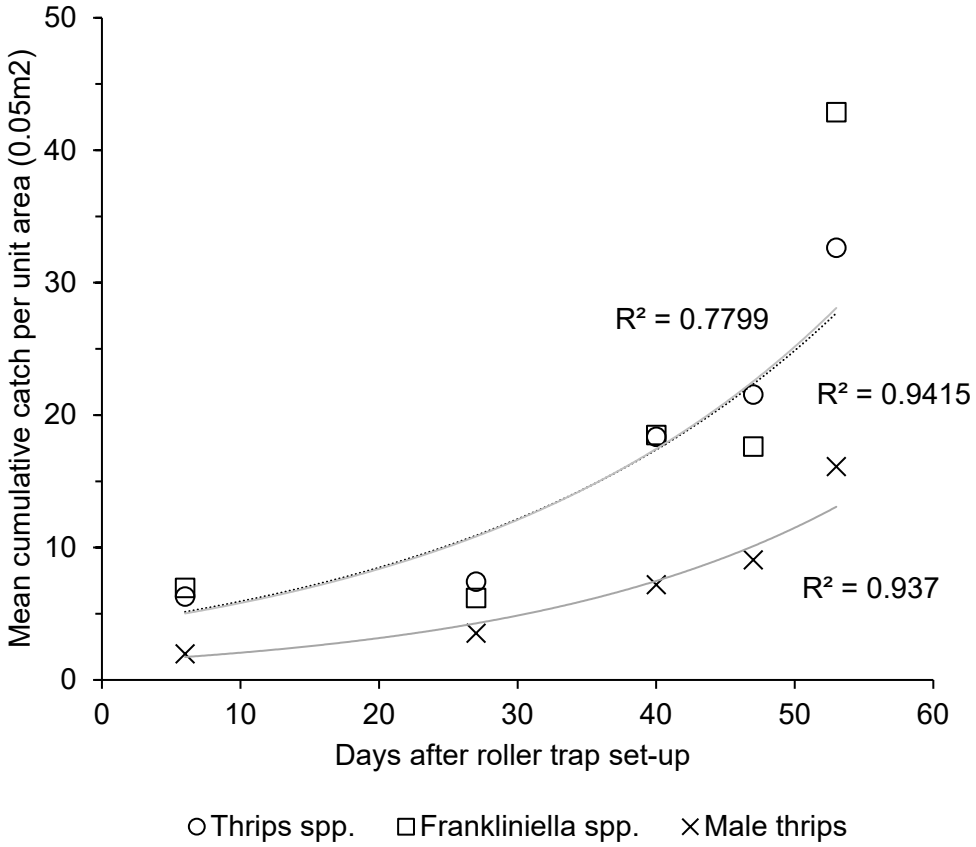



**Figure 4.11** Mean cumulative catch *Thrips* spp. and *Frankliniella* spp. females and male thrips at Site 2 per 0.05m$^2$ area of roller trap under a push-pull treatment regime. At this site, the *Thrips* spp. and *Frankliniella* spp. female and male thrips pressure seemed to increase on later assessments, being modelled well by exponential growth curves. The curves for *Thrips* spp. and *Frankliniella* spp. females were also found to markedly overlap.

*Semiochemical trial results*, Site 2

*Total pest thrips catch (Thrips spp. and Frankliniella spp. combined)*

When considering pest thrips species together (*Thrips* spp. and *Frankliniella* spp. females and male thrips), the different semiochemical treatments led to a significant difference in thrips trap catch per 0.05m$^2$ area of trap over the 2-week period (F(3,57)=98.45, P=<0.01). The lowest thrips catch was seen on untreated traps, with an average catch of 209.8 thrips per trap (Table 4.8; Figure 4.12). Where the Magipal treatment was used, thrips catch increased to an average of 233.0 per trap however this was not significantly higher than the trap alone (P>0.05). A significant increase (P<0.05) in catch relative to untreated traps however was given when the trap was combined with the Thripnok treatment, increasing mean catch to 276.4 (1.3x as many as on untreated traps). Lurem-TR in combination with blue traps however led to the highest mean thrips catch on traps averaging 582.6 – significantly more (P<0.05) than any other treatment with a mean of 2.8x as many as on untreated traps and 2.1x as many as on Thripnok traps (Table 4.8; Figure 4.12).

*Catch of Thrips spp. and Frankliniella spp. separately*

When considering thrips species females by genus (*Thrips* spp. and *Frankliniella* spp.) the different semiochemical treatments resulted in significant differences in *Thrips* spp. catch (F(3,57)=7.01, P=<0.01) and *Frankliniella* spp. catch (F(3,57)=112.69, P=<0.01).

For *Thrips* spp., no significant difference was noted in catch between untreated, Magipal and Thripnok treated traps which resulted in a catch of 67.7, 61.1 and 60.3 *Thrips* spp. per 0.05m$^2$ area of trap respectively. When traps were combined with a Lurem-TR treatment however an average of 86.1 *Thrips* spp. females per trap were caught, a significant increase (P<0.05) relative to all other evaluated treatments and a mean of 1.3x as many as on untreated traps (Table 4.8; Figure 4.13).

A mean of 87.40 *Frankliniella* spp. females per trap were caught on untreated traps, with no significant difference when traps were combined with Magipal which resulted in a mean of 102.9 *Frankliniella* spp. per trap. Where a Thripnok treatment was applied with the trap a mean of 131.8 *Frankliniella* spp. females were caught per trap, a significant increase compared with both untreated traps (1.5x as many) and traps combined with a Magipal treatment (P<0.05). The Lurem-TR treatment led to a further significant increase in *Frankliniella* spp. catch to 307.5, a significant increase over all other evaluated treatments (P<0.05) (Table 4.8; Figure 4.13) and a mean of 3.5x as many as on untreated traps.

Beneficials catch

*Predatory thrips*

No significant difference was observed in the mean numbers of predatory thrips (*Aeolothrips* spp.) between the semiochemical treatments, which ranged from 26.65-31.85 per 0.05m$^2$ area of trap (F(3,57)=0.94, P=0.428) (Table 4.8; Figure 4.15).

*Other beneficials: bees, hoverflies, ladybirds, lacewing, Orius spp. and other anthocorids*

Very few ladybirds, lacewing, *Orius* spp. and other anthocorids were recorded on any of the traps. Ladybirds per trap (0.05m$^2$) ranged from 0.05-0.15, with the highest numbers on Lurem-TR and Thripnok treated traps. Lacewing numbers per trap ranged from 0.25-1.1, with the lowest numbers seen on untreated traps and the highest on Thripnok and Lurem-TR treated traps respectively. *Orius* spp. catch numbers per trap ranged from 0.05-0.25, with the lowest numbers on untreated traps and the highest on Magipal treated traps. Other anthocorids catch numbers ranged from 0.4-1.05 per trap, with the lowest numbers on Magipal treated traps and the highest on untreated traps. Owing to the low catch numbers of these four beneficial insects, these data were not statistically analysed.

Notably higher numbers of bees and hoverflies were caught per trap, ranging from 1.15-4.7 and 1.4-3.1 respectively. Analysis revealed a significant difference in the number of bees caught on traps between the four evaluated treatments (F(3,57)=11.60, P=<0.01) but not the number of hoverflies caught (F(3,57)=1.59, P=0.203) (Table 4.8).

On untreated traps, a mean of 1.15 bees were caught per trap. On traps treated with Magipal and Lurem-TR, the catch of bees was significantly greater (P<0.05) – with means of 2.6 and 2.5 per trap respectively (2.3x and 2.2x as many as on untreated traps respectively). When traps were combined with the Thripnok treatment however a further significant increase (P<0.05) in bee catch was observed, with an average of 4.7 being caught per trap (4x as many as on untreated traps) (Table 4.8; Figure 4.14). For hoverflies, mean catches on untreated traps, trap treated with Magipal and Lurem-TR was 1.4, 1.4 and 1.8 respectively, with no significant differences between treatments. When traps were treated with Thripnok, the catch of hoverflies increased to 3.1 per trap; this increase however was not statistically significant (>0.05) (Table 4.8; Figure 4.14).

**Table 4.8** Mean number of thrips and beneficial insects found per trap at Site 2 (after a 2-week period) and analysis of variance results for each thrips or beneficials grouping. Columns sharing a letter are statistically similar. Values significantly different from those in the untreated controls indicated in bold and underlined.

| Treatment | | Thrips | | | Beneficials | | |
|---|---|---|---|---|---|---|---|
| | | ***Thrips* spp. and *Frankliniella* spp. (males and females)** | ***Thrips* spp. females** | ***Frankliniella* spp. females** | **Predatory thrips (*Aeolothrips* spp.)** | **Bees** | **Hoverflies** |
| Untreated | | 209.80 a | 67.70 a | 87.40 a | 26.65 | 1.15 a | 1.40 |
| Magipal | | 233.00 ab | 61.10 a | 102.90 a | 27.75 | **2.55 b** | 1.40 |
| Lurem | | **582.60 c** | **86.10 b** | **307.50 c** | 28.05 | **2.45 b** | 1.80 |
| Thripnok | | **276.40 b** | 60.30 a | **131.80 b** | 31.85 | **4.70 c** | 3.10 |
| One-way ANOVA | | | | | | | |
| Treatment | dof | **3,57** | **3,57** | **3,57** | 3,57 | **3,57** | 3,57 |
| | Test stat. (F) | **98.45** | **7.01** | **112.69** | 0.94 | **11.60** | 1.59 |
| | Prob (p) | **<0.01** | **<0.01** | **<0.01** | 0.428 | **<0.01** | 0.203 |

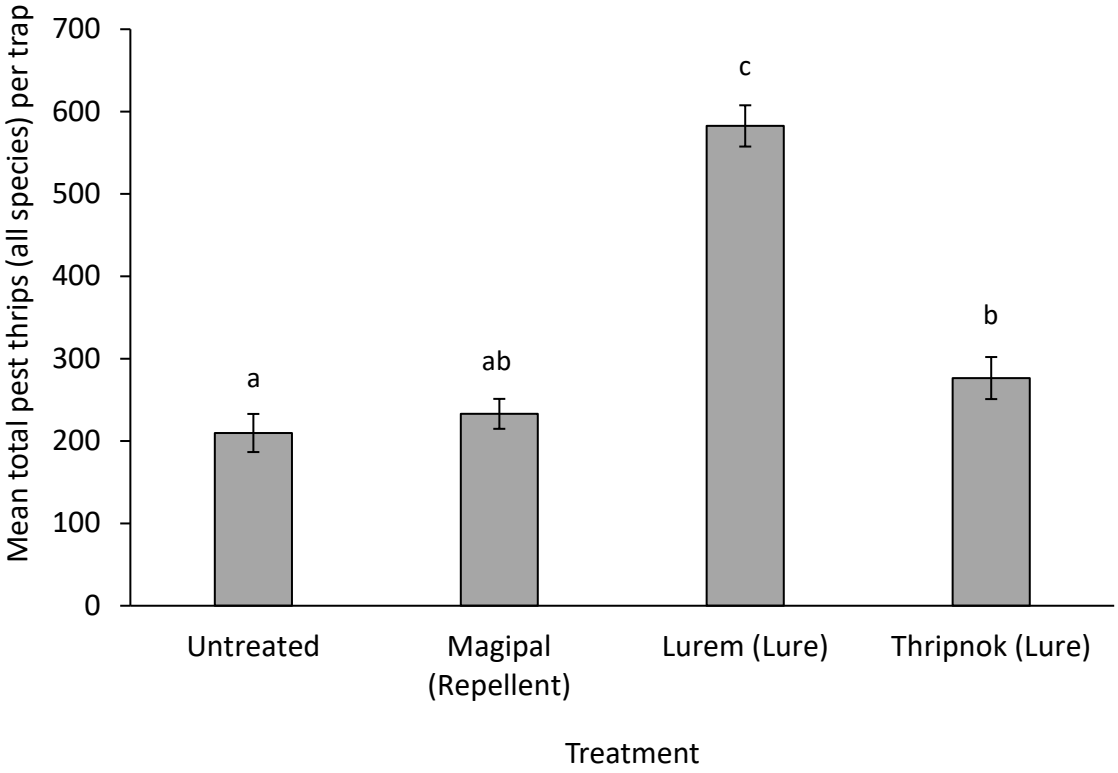



**Figure 4.12** Mean numbers of total thrips (*Thrips* spp., *Frankliniella* spp. and male thrips) per trap (both sides of a trap 10x25 cm, total of 0.05 $cm^2$) after a 2-week period, +/- standard error. Bars sharing a letter are statistically similar, those not sharing a letter are significantly different ($P<0.05$).

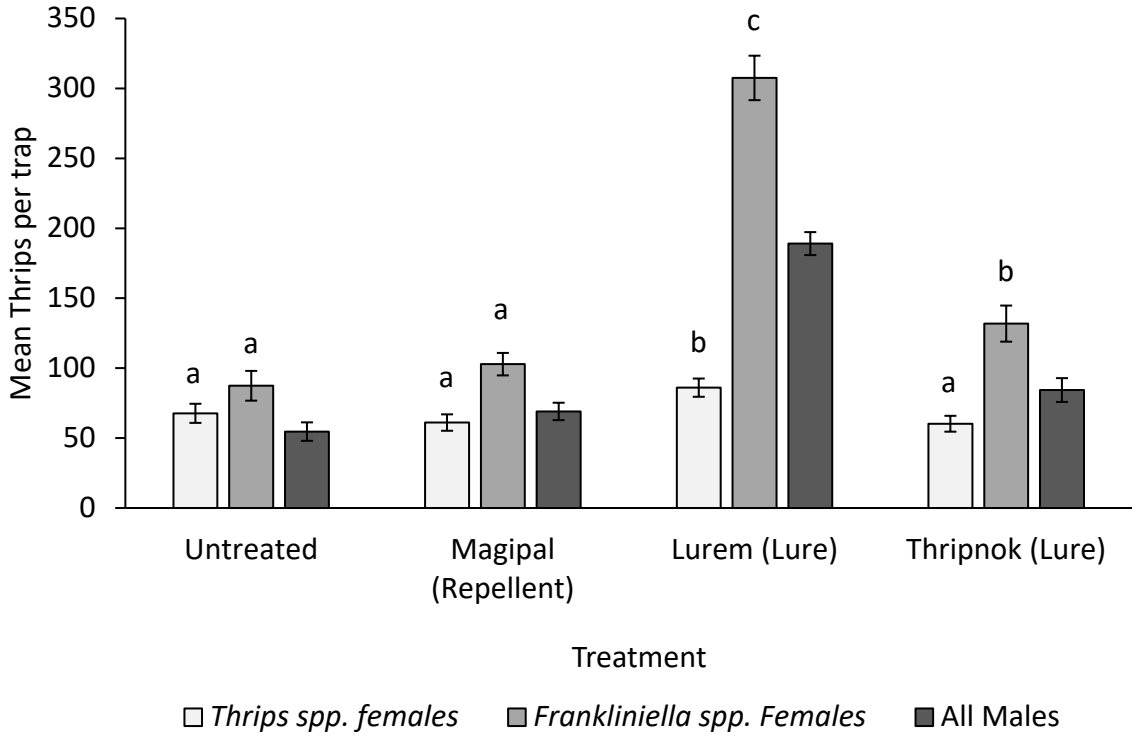



**Figure 4.13** Mean number of *Thrips* spp., *Frankliniella* spp. (females) and all species males per trap (both sides of a trap 10x25 cm, total of 0.05 $cm^2$) after a 2-week period, +/- standard error. Bars sharing a letter are statistically similar, those not sharing a letter are significantly different ($P<0.05$).

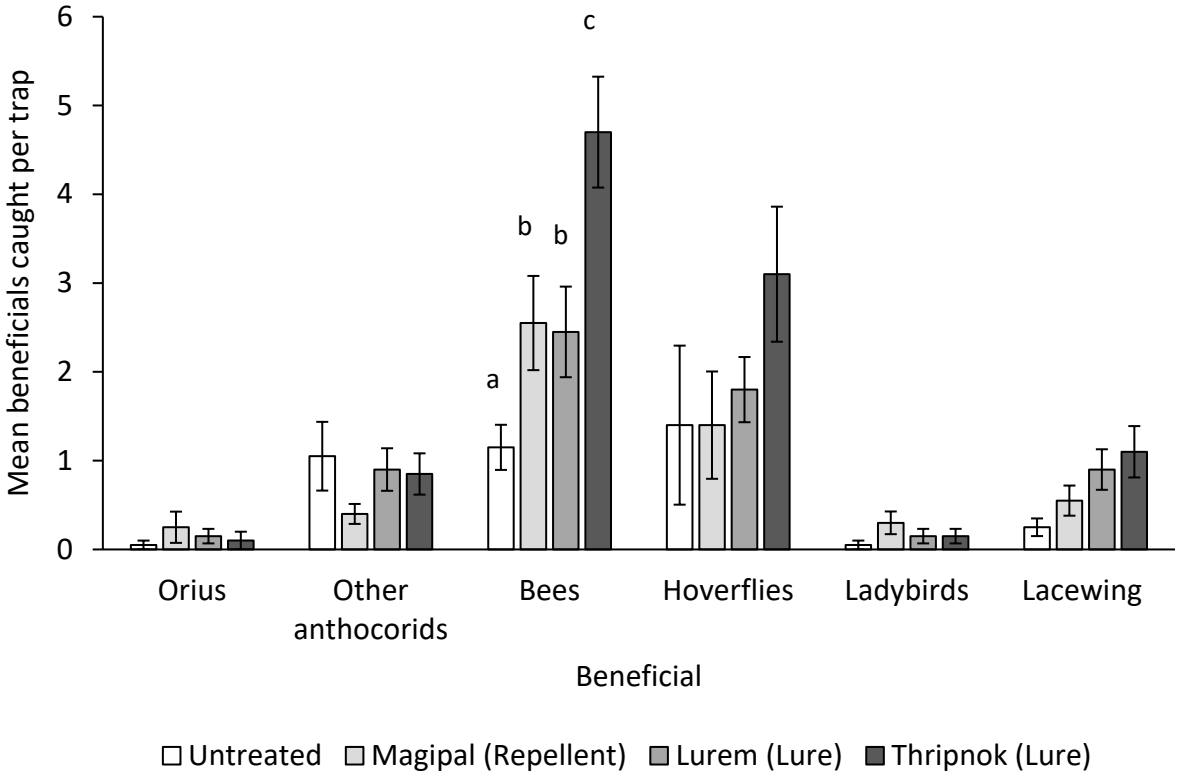



**Figure 4.14** Mean number of beneficial insects caught per trap (both sides of a trap 10x25 cm, total of 0.05 $cm^2$) after a 2-week period, +/- standard error. Significant differences in the mean catch of bees on traps with different semiochemical treatments but not hoverflies. Bars sharing a letter are statistically similar, those not sharing a letter are statistically different ($P<0.05$).

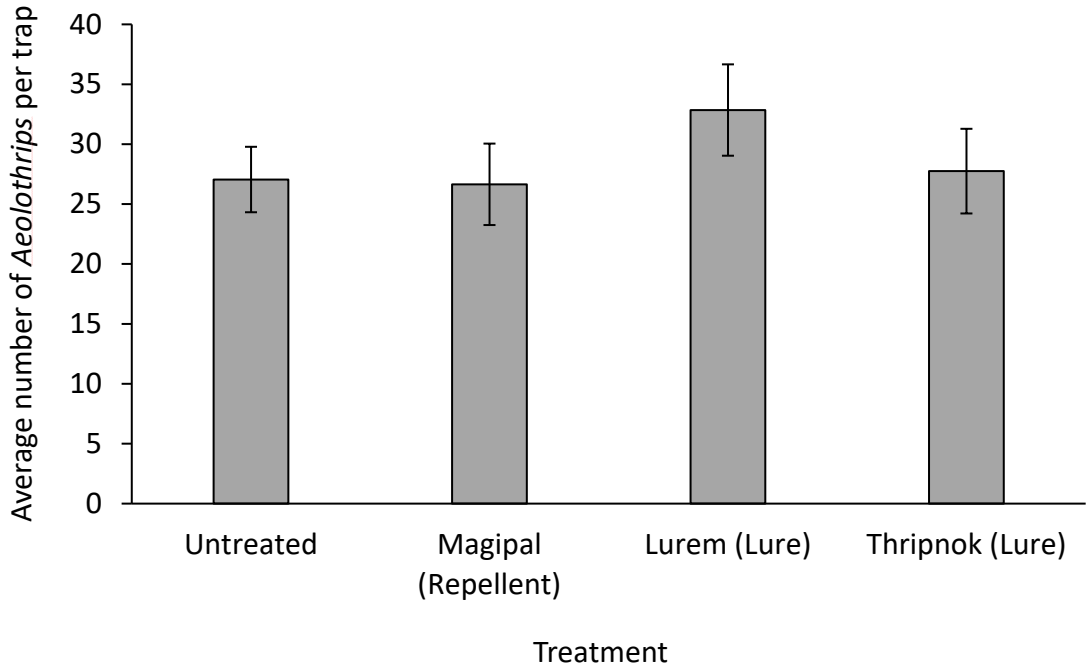



**Figure 4.15** Mean number of predatory thrips (*Aeolothrips* spp.) caught per trap (both sides of a trap 10x25 cm, total of 0.05 $cm^2$) after a 2-week period, +/- standard error. No significant differences in the mean catch of *Aeolothrips* spp. on traps with different semiochemical treatments.

***Semiochemical trial, thrips identification***

In total 62 thrips were removed from semiochemical trial traps, mounted on microscope slides and identified. Of these 13 were male and therefore could not be identified to species, 51 were *Thrips* spp. with the highest numbers being *Thrips fuscipennis* (18) and *Thrips tabaci* (14) (Table 4.9). Ten *Thrips* spp. specimens could not be identified to species level as the diagnostic features were not visible. A further eight *Thrips* specimens were male and thus could not be identified to species. Eight *Frankliniella* spp. were identified of which five were male and thus not identified to species. The remaining three *Frankliniella* were identified as *F. intonsa.* No *F. occidentalis* were recorded. Three *Limothrips cerealium* were also identified on traps but not included in the grand total.

Numbers of thrips species confirmed on each trap treatment were too low to analyse statistically. *Thrips fuscipennis* were recorded on all four treatments, *Frankliniella intonsa* was recorded on all treatments except for the untreated and the one *Thrips major* specimen was found on a Magipal trap (Table 4.9).

**Table 4.9** Thrips species identification after removal from sticky traps.

| | ***Thrips* spp.** | | | | | ***Frankliniella* spp.** | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Treatment** | *T. fuscipennis* | *T. major* | *T. tabaci* | *Thrips* spp. (unidentified) | *Thrips* spp. males | *F. occidentalis* (WFT) | *F. intonsa* | *Frankliniella* spp. males | **Total** |
| Untreated | 5 (41.7%) | 0 | 2 (16.7%) | 2 (16.7%) | 3 (23.1%) | 0 | 0 | 1 (7.7%) | 13 |
| Lurem-TR | 6 (28.6%) | 0 | 7 (33.3%) | 4 (19.0%) | 3 (14.3%) | 0 | 1 (4.8%) | 0 | 21 |
| Thripnok | 4 (30.8%) | 0 | 3 (23.1%) | 1 (7.7%) | 2 (15.4%) | 0 | 1 (7.7%) | 2 (15.4%) | 13 |
| MagiPal | 3 (25.0%) | 1 (8.3%) | 2 (16.7%) | 3 (25.0%) | 0 | 0 | 1 (8.3%) | 2 (16.7%) | 12 |
| All | 18 (30.5%) | 1 (1.7%) | 14 (23.7%) | 10 (16.9%) | 8 (13.6%) | 0 | 3 (5.1%) | 5 (8.5%) | 59 |

**Temperature and Humidity**

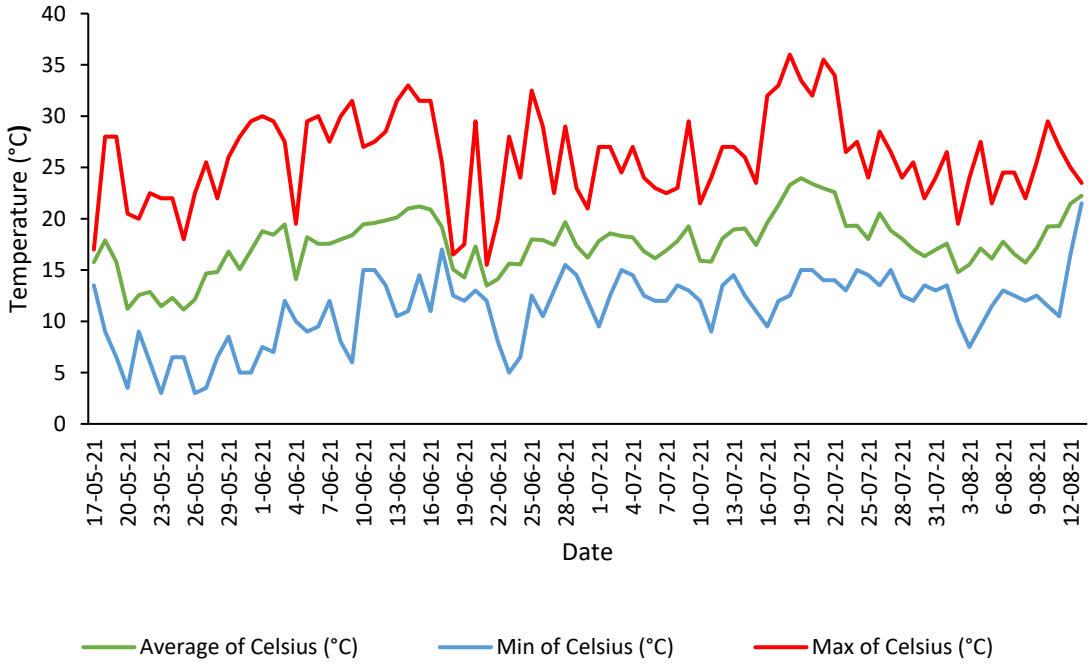



**Figure 4.16** Mean maximum, minimum and mean daily temperatures (°C) from data logger under the tabletops at site 1.

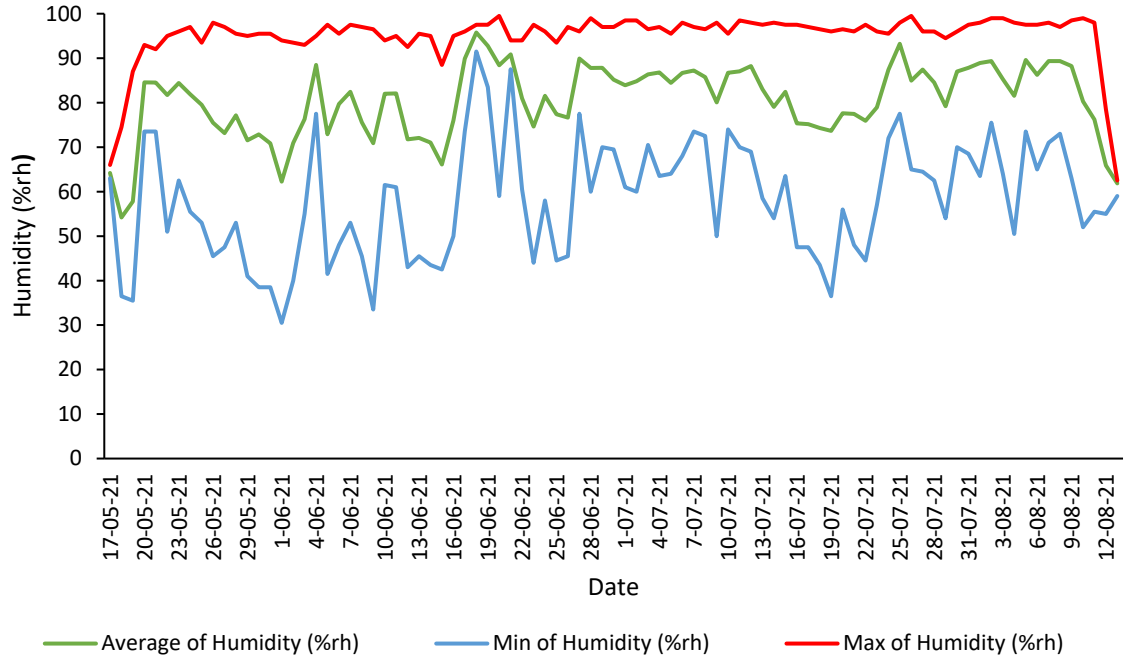



**Figure 4.17** Mean maximum, minimum and mean daily humidity (%rh) from data logger under the tabletops at site 1.

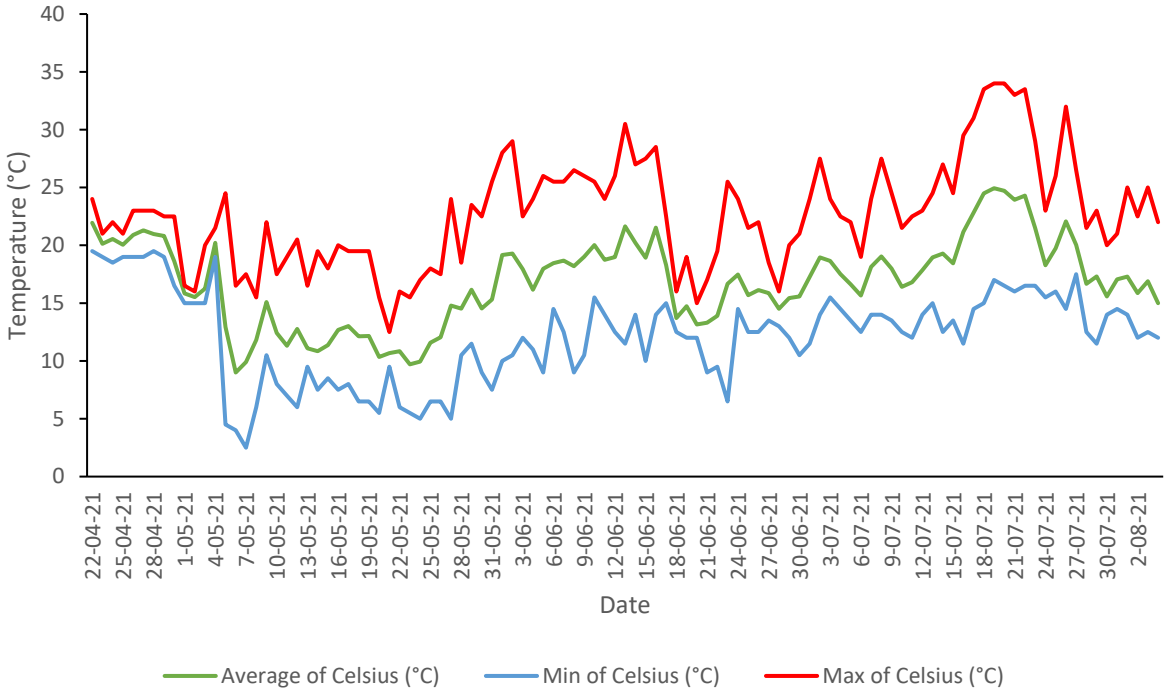



**Figure 4.18** Mean maximum, minimum and mean daily temperatures (°C) from data logger under the tabletops at site 2.

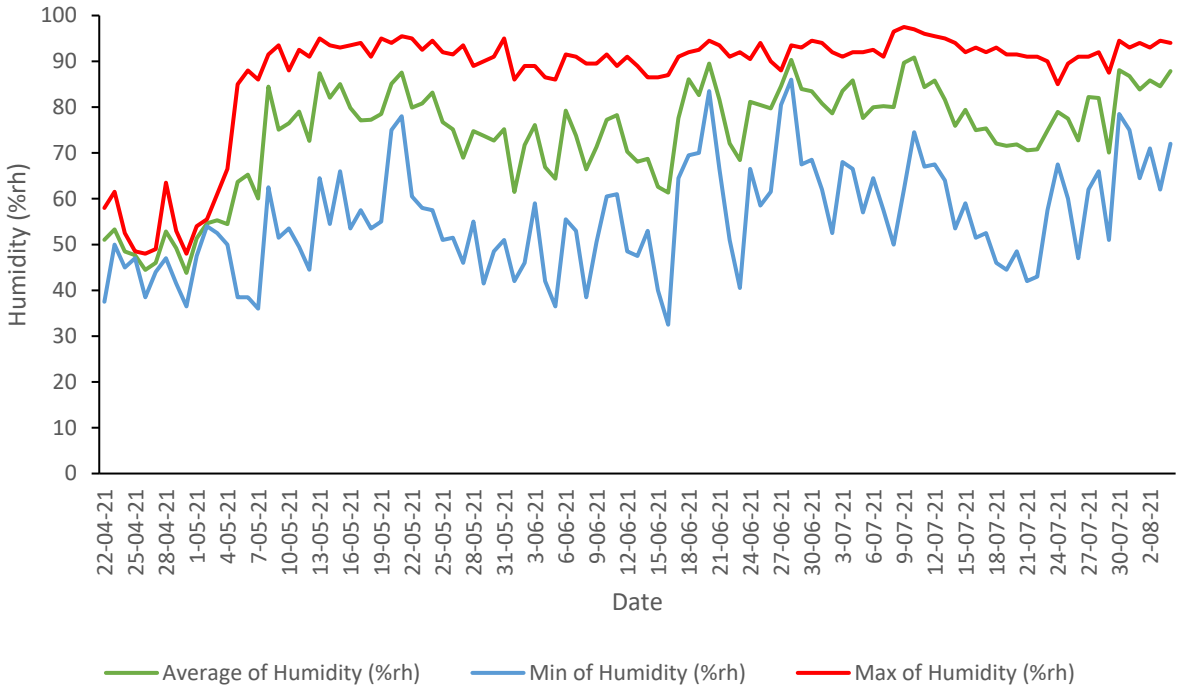



**Figure 4.19** Mean maximum, minimum and mean daily humidity (%rh) from data logger under the tabletops at site 2.

Grower IPM programmes

*Site 1*

Records of biological control and plant protection products used at Site 1 are unavailable, however it was noted that large numbers of empty *N. cucumeris* bottles were seen in the crop.

*Site 2*

**Table 4.10** Biological control agents released in both push-pull and semiochemical trial areas.

| Date | Biological control agent | Release rate |
|---|---|---|
| 15.5.21 | *Neoseiulus cucumeris* | 50/plant |
| 29.5.21 | *N. cucumeris* | 25/plant |
| 11.6.21 | *N. cucumeris* | 25/plant |
| 18.6.21 | *Phytoseiulus persimilis* | 2/plant |
| 26.6.21 | *N. cucumeris* | 25/plant |
| 1.7.21 | *P. persimilis* | 2/plant |
| 7.7.21 | *N. cucumeris* | 25/plant |
| 22.7.21 | *N. cucumeris* | 25/plant |
| 25 July | *P. persimilis* | 5/plant |

**Table 4.10** Plant protection products applied in both push-pull and semiochemical trial areas.

| Date | Active ingredient | Trade name |
|---|---|---|
| 23.3.21 | Spirotetramat<br>Silicon wetter | Batavia<br>SW7 |
| 12.5.21 | Pyrimethanil<br>Myclobutanil<br>Silicon wetter | Scala<br>Systhane<br>SW7 |
| 19.5.21 | Azoxystrobin<br>Fenhexamid<br>Silicon wetter<br>bifenazate | Amistar<br>Teldor<br>SW7<br>Floramite |
| 30.5.2 | Boscalid + pyraclostrobin<br>Silicon wetter | Signum<br>SW7 |
| 7.6.21 | Cyprodonil + fludioxonil<br>Myclobutanil<br>Silicon wetter | Switch<br>Systhane<br>SW7 |
| 9.6.21 | Potassium bicarbonate | |

| | | |
|---|---|---|
| | Silicon wetter | SW7 |
| 15.6.21 | Azoxystrobin<br>Mepanipyrim<br>Silicon wetter | Amistar<br>Frupica<br>SW7 |
| 23.6.21 | Boscalid + pyraclostrobin<br>Bupirimate<br>Silicon wetter | Signum<br>Nimrod<br>SW7 |
| 25.6.21 | Fatty acids C7-C20 | Flipper |
| 29.6.21 | Potassium bicarbonate<br>Silicon wetter | <br>SW7 |
| 3.7.21 | Azoxystrobin<br>Silicon wetter | Amistar<br>SW7 |
| 6.7.21 | Potassium bicarbonate<br>Silicon wetter | <br>SW7 |
| 10.7.21 | Bupirimate<br>Myclobutanil<br>Silicon wetter<br>bifenazate | Nimrod<br>Systhane<br>SW7<br>Floramite |
| 17.7.21 | Pyrimethanil<br>Cyflufenamid<br>Silicon wetter | Scala<br>Takumi<br>SW7 |
| 23.7.21 | Penconazole<br>Cyprodonil + fludioxonil<br>Silicon wetter | Topas<br>Switch<br>SW7 |
| 29.7.21 | Proquinazid<br>Silicon wetter | Talius<br>SW7 |

## Discussion

Thrips species in flowers

A mix of thrips species consistent with both previous studies at this site in 2020 in this project and at other sites in SF 156 and in other studies on strawberry (Brown & Bennison, 2017; Seymour, Bennison & Kirk, 2020; Nielsen *et al*, 2021) were identified from flower samples taken at sites 1 and 2. At both sites rose thrips, *T. fuscipennis* and rubus thrips, *T. major* were the two most prevalent species found in flower samples – as at the same sites in 2020. However, while *T. fuscipennis* was dominant in most assessments at site 2 as was seen in

2020, at site 1 *T. major* was found to be more prevalent in this study. Interestingly, during the first assessment at site 1, *T. minutissimus* was found to be dominant at the first assessment. This species has been confirmed in low numbers in strawberry flowers at other UK sites in previous studies. While *T. minutissimus* is reported to be common across Europe, most reports of this species to date have been on deciduous trees – primarily beech (*Fagus* spp.), hornbeam (*Carpinus* spp.) and oak (*Quercus* spp.) (Ulitzka and Funke, 1997; Alford, 2017, p. 30). *Thrips minutissimus* has however also been reported to show a preference for plants in the Rosaceae including apple, with previous reports of damage to apple blossom (*Malus domestica*) (Alford, 2017, p. 30). As strawberry (*Fragaria* x *anannessa*) is also in the Rosaceae with similar flower structure, it is possible that *T. minutissimus* may also be another thrips species to consider in the context of strawberry damage. However, so far it has only been confirmed in small numbers in UK strawberry crops.

Onion thrips, *T. tabaci*, occurred in very low numbers at Site 1 however at Site 2 the number of recorded *T. tabaci* increased over time, displacing *T. fuscipennis* and *T. major* as the dominant *Thrips* species at the final assessment. As very few larvae were found in the flowers at either site, it is likely that these fluctuations in relative abundance of adults were due to immigration of adult thrips into the crop rather than breeding in the crop.

No western flower thrips (WFT), *F. occidentalis* were recorded at Site 1 and only a single individual was identified at Site 2. As is standard practice, at both sites growers were using *Neoseiulus cucumeris* within their IPM programmes which is likely to have contributed to the virtual absence of WFT from the recorded thrips species. At Site 1, only a single individual adult of the flower thrips, *F. intonsa* was identified. At Site 2 however, notably more *F. intonsa* were identified particularly on the final assessment on 3 August, providing evidence in favour of the suggestion that *F. intonsa* is becoming more prevalent in protected UK crops, possibly due to climate change leading to higher summer temperatures (Brown and Bennison, 2017; Seymour, Bennison & Kirk, 2020). In Denmark, a study on tunnel-grown strawberry confirmed the main two thrips species occurring were *F. intonsa* followed by *T. tabaci* (Nielsen *et al*., 2021), although previous thrips samples from Danish strawberry crops have also included high numbers of *T. fuscipennis* (Bennison, unpublished data, 2018 & 2020).

While these findings provide a valuable insight into the dynamics of thrips species composition at these two sites, as in previous studies, the disparity in species composition between sites highlights the significant variability in thrips species pressure which can now arise following the development of reliable control of WFT within IPM. The factors affecting the different thrips species compositions at different sites remain unknown, however the surrounding environment and alternative/overwintering host plants, prevailing wind, season, temperature and rainfall may contribute (Nielsen *et al*, 2021). Grower practice such as

cultural, biological and chemical control methods are also likely to contribute to the species mixes in strawberry crops.

Push-pull trials - thrips numbers in flowers

*Adults*

At both sites the mean numbers of adult thrips per flower during all assessments was significantly below an average of one per flower. The successful use of *N. cucumeris* at both sites is likely to have contributed to the lack of WFT at site 1 and only one individual WFT being found at site 2. No records of plant protection products are available for site 1, but at site 2, only one insecticide, spirotetramat (Batavia) was applied to the crop, on 23 March before the push-pull trial was set up on 5 May. This product is recommended for the control of aphids and tarsonemid mites in protected strawberry but may give some incidental control of thrips. The persistence of spirotetramat against aphids is up to 25 days after treatment (Armand *et al*., 2021). The low numbers of thrips species other than WFT that infested the flowers may have been due to other factors including temperature, rainfall and surrounding alternative host plants affecting immigration from outdoors.

Where *Thrips* spp. and *Frankliniella* spp. were considered together, there was no effect at either site 1 or site 2 on thrips numbers in flowers between untreated and push-pull treated blocks. The result of the semiochemical trial at site 2 indicated that Magipal (used as the 'push') did not reduce numbers of thrips on traps, so it is possible that this semiochemical has no repellent effect on the thrips species occurring at these two sites. This result conflicts with promising results given in a pilot push-pull trial at a site where WFT was dominant, where Magipal was used together with blue roller traps and the WFT aggregation pheromone for WFT control within an IPM programme (Griffiths & Sampson, personal communication, 2020). In the semiochemical trial at site 2, Lurem-TR led to significantly higher numbers of thrips on traps over a 2-week period in late July/early August and much higher numbers of *Frankliniella* spp. were found on the traps than *Thrips* spp. This result may indicate that blue traps together with Lurem-TR may catch proportionally more *Frankliniella* spp. than *Thrips* spp. However, the semiochemical trial was set up adjacent to another strawberry crop that was pulled out during the 2-week trial and this may have led to high numbers of *Frankliniella* spp. adults flying from the old crop to the crop used for the semiochemical trial (Seymour, personal communication, 2021).

In the push-pull trial at site 2 that was done between May and early August in a different block of tunnels to that used for the semiochemical trial, any 'pull' effect of Lurem-TR used on blue roller traps was not reflected in the low thrips densities in flowers seen in both untreated and

push-pull plots. However, at both sites, *Thrips* spp. adults were much more prevalent in the flowers than *Frankliniella* spp. whereas on the roller traps, the proportion of *Frankliniella* spp. to *Thrips* spp. was higher than in the flowers. Thus, blue roller traps with Lurem-TR might be more effective at 'pulling' *Frankliniella spp.* thrips adults from the crop than *Thrips* spp.

At site 1 the highest numbers of thrips per flower were found during the final two assessments (30.06.21 and 15.07.21 respectively), with only *Thrips* spp. being present in flower samples on these dates while *Frankliniella* spp. were wholly absent during the monitored period. While site 1 results support previous findings in SF 156 that *T. fuscipennis* commonly peak in late June, at site 2 *T. fuscipennis* numbers in flowers peaked in late July (28.07.21). While this finding may be a result of the smaller sample size at Site 1, these results might also be accounted for by differences in environmental conditions both outdoors and in the polytunnels between sites, with data logger results indicating a pronounced dip in mean tunnel temperatures to ~15$^{o}$C at site 2 between 12.06.21 - 24.06.21. It is likely that ambient outdoor temperatures at site 2 were also cooler during this period, potentially delaying the expected *T. fuscipennis* peak immigration to the crop.

While *F. intonsa* along with *T. tabaci* were almost wholly absent during the five assessments at site 1, at site 2 *F. intonsa* and *T. tabaci* was found to be the two most abundant thrips species on the final assessment (03.08.21). In previous studies in SF 156, *F. intonsa* numbers were much higher than usually found in UK strawberry crops, peaking in the very hot weather in mid-late July at two sites in 2018 and at one site in 2019. *Frankliniella intonsa* was the main species occurring in in tunnel-grown strawberry crops in Denmark, when numbers also peaked in mid to late July (Nielsen *et al*. (2021). These results support the hypothesis that climate is an important factor for the incidence and geographical range of *F. intonsa*, with it possibly being more adapted to the more extreme climate of central Europe (Morison, 1957). This species may continue to become more common in the UK with climate change.

While in previous studies a potential relationship was noted between fewer mean flowers per plant and higher numbers of thrips per flower, no such relationship was noted in this study. This however may result from the overall lower numbers of thrips per flower at both sites, hinting that higher numbers of thrips may be necessary for this thrips per flower density effect to be observed.

*Larvae*

Across both sites in this study, very low numbers of thrips larvae were recorded in flowers. At site 1, thrips larvae were found on only one assessment (16.06.21) and it was not possible to identify these to species. At site 2 the incidence of thrips larvae was higher, being recorded

on four of the five assessments, however the number of larvae per flower was very low, peaking at 0.0056 larvae per flower in mid-July. Thrips larvae from flowers at site 2 were identifies as a single *T. tabaci* on 23 June and five *T. major* on 3 August. As in previous studies in this project and in SF 156, although larvae of *T. major*, *T. tabaci* and *F. intonsa* have been found in strawberry flowers, no larvae of *T. fuscipennis* were found in flowers despite this, together with *T. major* being the predominant *Thrips* species of adults in the flowers and despite strawberry being a recorded host plant for *T. fuscipennis* (Morison, 1957). It is possible that *T. fuscipennis* either do not breed on strawberry or are present elsewhere on the plant rather than in flowers. *Neoseiulus cucumeris* is known to feed on *T. tabaci* larvae as well as those of WFT (Brodsgaard & Hansen, 1992) but no published information is available on its predation of *T. major* or *F. intonsa*.

Push-pull trials - fruit bronzing incidence and percentage fruit bronzing

For assessments of fruit bronzing in this trial white fruit was used as it is easier to see bronzing on white fruit than ripe fruit, also the assessments could be done before the ripe fruit was picked. At site 1, mean thrips numbers per flower were consistently low, therefore both the incidence of bronzing and percentage fruit area damage were very low. Bronzing incidence at this site remained well below 1% until the sixth and final assessment when a mean incidence of 2.25% of assessed fruits being bronzed was recorded. This low incidence was reflected in the low percentage area bronzed on fruit at site 1, with a mean of 0.05% of fruit area being damaged. At site 2 the incidence of bronzing was notably higher, being greater than 1% during five of the six assessments and exceeding 10% on the final two assessments. Despite this higher incidence of bronzing however, the mean percentage of fruit area bronzed remained low at site 2, peaking at 3.26% on 28.07.21, significantly below the 10% threshold at which fruit is commonly downgraded. The thrips damage observed at both sites in this trial would therefore have not incurred economic losses for growers.

No significant difference was given in either the incidence of bronzing or percentage fruit area damaged between untreated blocks and those receiving a push-pull treatment regime, indicating that at the low thrips densities seen during these trials any effects from the push-pull treatment were not reflected in fruit bronzing.

Push-pull trials - thrips and beneficials on sticky roller traps under a push-pull treatment regime

*Beneficials on roller traps*

During this study, where a push-pull treatment regime was used, subsamples of roller traps were collected at each assessment and the numbers of thrips and beneficials caught counted.

Predatory thrips, *Aeolothrips* spp. were recorded in very low numbers on roller traps under the table tops at site 1 and not atall at site 2, although they were recorded on the traps just above the plants in the semiochemical trial in a different block of tunnels at site 2. It is possible that fewer predatory thrips are caught on traps below the table tops than on those just above the tops of the plants, or 'wet glue' roller traps may catch fewer predatory thrips than 'dry glue' traps. Blue traps were reported to be less attractive to *Aeolothrips* spp. than yellow traps in pea crops (Pobozniak *et al*., 2020).

At both sites 1 and 2, the bycatch of other beneficials i.e. bees, hoverflies, ladybirds, lacewings, *Orius* spp. and other anthocorids on roller traps was also notably low, even at the final assessment at both sites, after 56 and 53 days respectively. *Orius laevigatus* were not released by the grower at Site 2, so any *Orius* spp. found on the roller traps must have been naturally occurring. Although no biological control records are available for site 1, no *Orius* spp. were detected in the flowers.

*Thrips on roller traps*

At site 1, where thrips pressure was consistently low, roller traps caught a mixture of *Thrips* spp. and *Frankliniella* spp., with an approximate 3:2 ratio between the two. At site 2, where thrips were more numerous than at site 1 and where thrips pressure increased over time, the ratio of *Thrips* spp. and *Frankliniella* spp. on roller traps was more equal.

The ratios of *Thrips* spp. to *Frankliniella* spp. on roller traps contrasts with the recorded relative abundance of *Thrips* spp. and *Frankliniella* spp. in flowers. *Frankliniella occidentalis* (WFT) was absent at site 1 and only one individual was found in flowers at site 2. Only one individual *F. intonsa* was found in flowers at site 1 and although similar numbers of *F. intonsa* and *T. tabaci* were found at site 2 at the final assessment in early August, prior to that *Thrips fuscipennis and T. major* were the predominant species in flowers. This result may indicate that either the flower samples led to an under-representation of the *Frankliniella* spp. pressure or that the blue roller traps caught a disproportionately high proportion of *Frankliniella* spp. It is also possible that *N. cucumeris* may have predated *F. intonsa* larvae in flowers and this may have led to very low numbers of adults recorded in flowers, although there are no

published records of *N. cucumeris* predation of this species. There are many potential reasons why roller traps may have caught more *Frankliniella* relative to *Thrips* spp., including different responses to trap height, colour/wavelength and to Lurem-TR.

In these push-pull trials, roller traps were deployed as high as possible below the tabletops. Previous studies with *F. occidentalis* and *T. tabaci* have shown that the height of sticky traps can have a significant effect upon thrips catch, with the inference being that different species fly at different heights. The observed higher roller trap catch of *Frankliniella* spp. relative to those recorded in flowers might therefore indicate that traps were set up at a height more optimal for *Frankliniella* spp. flight relative to *Thrips* spp. (Gharekhani *et* al., 2014; Khavand *et al*., 2019). This result may also stem from differences in the attractiveness of blue traps (450-485nm) to different thrips genera and species. There is significant published evidence demonstrating the strong attraction of *F. occidentalis* (WFT) to blue traps (Roditakis *et al*., 2001; Chen *et al*., 2004; *Sampson et al*., 2012), Broughton & Harrison (2012). Significantly less research attention has focussed on the trap colour/wavelength attraction of other thrips species including *T. fuscipennis*, *T. tabaci* and *F. intonsa* relative to WFT therefore it is possible that blue traps (450-485nm) may be intrinsically more attractive to *Frankliniella* spp. than to these other thrips species.

Semiochemical trial

*Thrips*

During the semiochemical trial at site 2 thrips catches were notably higher than seen on roller traps in the push-pull trial at the same site, with a mean of 210 thrips per 25x10cm trap (front and back (i.e.0.05m$^2$ trap area) over the 2-week trial even with no semiochemical treatments. Although the ratio of *Thrips* spp. to *Frankliniella* spp. was equal on the roller traps baited with Lurem-TR in the push-pull trial at site 2, on the traps baited with Lurem-TR in the semiochemical trial more *Frankliniella* spp. than *Thrips* spp. were recorded. One potential reason underlying this difference was that the semiochemical trial was undertaken in a different block of tunnels to the push-pull trial, thus the thrips species mix may simply have differed locally across the farm. In addition, adjacent to the semiochemical trial, a 60-day crop was removed during the trial and left as a waste pile (Seymour, personal communication, 2021). The thrips adults from these older plants may have migrated into the semiochemical trial plots, altering the species mix and population density.

While only a relatively small number of thrips were identified to species level from the semiochemical sticky traps, these results further indicate a variation in species mix relative to that in the push-pull trial flower samples. On the semiochemical traps left in place between

15 July and 3 August, *T. fuscipennis* and *T. tabaci* were the most prevalent *Thrips* spp., only a single individual of *T. major* being identified and *F. intonsa* was the only *Frankliniella* spp. found. In the push-pull trial at the same site, the main species in the flowers were *T. fuscipennis* and *T. major* until the final assessment date on 3 August (the date the semiochemical trial traps were collected) when *T. tabaci* and *F. intonsa* were the predominant species. The accuracy of the species ratios on the semiochemical traps however is uncertain owing to the small sample size.

Of the three semiochemicals evaluated in combination with sticky traps in this trial, only the two kairomone lures Lurem-TR and Thripnok resulted in significant differences in thrips catch, with the reported thrips repellent Magipal resulting in no difference in catch relative to untreated traps. Thripnok resulted in a 49.9% (1.5x) increase in *Frankliniella* spp. catch but no significant improvement in *Thrips* spp. catch.

Lurem-TR resulted in a significant increase in both *Thrips* spp. and *Frankliniella* spp. catch, by 27.2% (1.3x) and 251.8% (3.5x) respectively. While both lures were therefore effective in improving thrips catch, Lurem-TR outperformed Thripnok and supported the findings of previous trials reporting the value of combining sticky traps with Lurem-TR (Teulon *et al.*, 2008a,b).

*Beneficials*

In common with the higher thrips catch on semiochemical trial sticky traps relative to push-pull roller traps, the catch of beneficials on semiochemical trial traps was also notably higher. Of the individually assessed beneficials, a significant difference in catch when different semiochemicals were used was seen only for bees. On untreated blue sticky traps there was a mean of 1.2 bees per trap however this increased to 2.6, 2.5 and 4.7 bees per trap with the addition of Magipal, Lurem-TR or Thripnok respectively, representing a 121.7% (2.2x), 113.0% (2.1x) and 308.7% (4.1x) increase in catch respectively. Previous research has demonstrated that blue sticky traps demonstrate intrinsic attractiveness to honeybees (*Apis* spp.) and bumblebees (*Bombus* spp.) however, relative to yellow and white traps, blue traps often lead to a significantly lower bee bycatch (Spears *et al*., 2021). The increased catch of bees on traps with Magipal is not surprising as it is marketed as an attractant to natural enemies. The increased catch of bees on traps with Lurem-TR and Thripnok is likely to be due to these two lures containing floral volatiles which may be attractive to bees as well as thrips. Although all three semiochemicals in this study led to an increased catch of bees, the traps used were ‘dry glue’ traps which tend to catch more insects including bees than ‘wet glue traps’ such as roller traps as large insects such as bees can escape from the wet glue

(Sampson, personal communication, 2022). Thus, the use of either Lurem-TR or Thripnok with roller traps should be less of a risk to bees than if high numbers of dry glue traps were used. UK growers currently using blue roller traps unbaited with either Lurem-TR or Thripnok have not experienced pollination problems (Clare Sampson, personal communication, 2020).

*Aeolothrips* spp. are naturally occurring predatory thrips commonly found in strawberry flowers where IPM is used where they feed on pollen and small invertebrates including pest species of thrips (Seymour, Bennison & Kirk, 2020). They are recorded as feeding on thrips larvae, but it is not known whether they also feed on thrips adults. The impact of *Aeolothrips* spp. on pest species of thrips in strawberry is unknown and justifies research. While no significant difference was seen in predatory thrips, *Aeolothrips* spp. catch with different semiochemical treatments, the catch of these beneficials was notably higher than for all other evaluated beneficials, averaging 28.6 per trap. However, at the same site (site 2) in the push-pull trial, no *Aeolothrips* spp. were recorded on roller trap sections beneath the table tops throughout the trial period and very few were recorded on roller traps at site 1. It is possible that *Aeolothrips* spp. were more active near the tops of the plants and thus higher numbers were caught on the semiochemical traps just above the plants than on roller traps beneath the tabletops. Another potential reason for fewer *Aeolothrips* spp. being caught on the roller traps was that they might escape from the wet glue, as previously discussed regarding bees. Previous studies have demonstrated that blue traps above pea plants are less attractive to predatory thrips than other coloured traps such as yellow (Pobozniak *et al.*, 2020), however our result indicates that a potential bycatch of predatory thrips when using dry glue blue monitoring traps. In a sweet pepper crop, more *Aeolothrips* spp. were caught on yellow than blue traps (Sampson *et al.*, 2012). However, numbers of *Aeolothrips* in the sweet pepper crop itself were not recorded and further work would be needed to estimate the potential impact of traps on their populations and on thrips control.

## Conclusions

*Push-pull trial*

- As in previous work in this project and in SF 156, the results showed that several species of thrips adults can invade everbearer strawberry crops. Species composition is likely to vary with site, season and weather but unless WFT is present, there seems to be very little breeding in the flowers.
- Thrips adult and larvae numbers per flower across both sites was low, with fewer than one thrips being found per flower across all assessments.

- At both sites, push-pull treatment did not result in any significant differences in the mean number of either *Thrips* spp. or *Frankliniella* spp. per flower.
- At both sites, *T. fuscipennis* and *T. major* were the most prevalent species in flowers. *Thrips minutissimus* was dominant on the first assessment date at site 1 but owing to the small sample size this result might be spurious. This species was found only on the first assessment date at site 1 and not at site 2.
- At the final assessment at Site 2 a markedly different thrips species mix was seen in the flowers, with *T. tabaci* and *F. intonsa* dominating.
- Only a single individual of *F. occidentalis* (WFT) was identified across both sites throughout the trials, demonstrating the continuing efficacy of WFT control within IPM.
- Very low numbers of larvae were recorded in the flowers, and were more numerous at site 2, where they were identified as *Thrips major* and *Thrips tabaci.*
- At Site 1, fruit bronzing incidence and percentage area was minimal, with well below a mean of 1% fruit area damaged. At Site 2, fruit bronzing incidence and percentage area was notably higher, significantly increasing in later assessments relative to earlier assessments, reaching a mean of almost 5% fruit area damaged.
- No significant differences were seen in fruit bronzing incidence and percentage damage between untreated and push-pull treated blocks at either site.
- The proportion of *Thrips* spp. to *Frankliniella* spp. was 3:2 on roller traps at site 1 and approximately 1:1 at site 2. However, this was not reflected in the proportions of thrips species found in the flowers. At site 1, *Frankliniella* species were absent in flowers except for very low numbers on the first assessment date. At site 2, most thrips found in flowers were *Thrips* species until the final assessment date when the proportion of *Thrips* spp. to *Frankliniella* spp. was approximately 1:1, with all the *Frankliniella* spp. identified being *F. intonsa*. These results indicated that the proportions of thrips species on roller traps under the tabletops are not necessarily the same as those in the flowers; the roller traps may catch relatively more *Frankliniella* spp.
- Numbers of bees and other beneficials on the roller traps were very low.

*Semiochemical trial*

- Traps with either a Lurem-TR or Thripnok lure caught significantly more (2.8x and 1.3x respectively) adult pest thrips (*Thrips* spp. females, *Frankliniella* spp. females and males) than untreated traps.
- Traps with a Lurem-TR lure caught significantly more (2.1x) adult pest thrips (*Thrips* spp. females, *Frankliniella* spp. females and males) than traps with a Thripnok lure.

- Lurem-TR significantly increased trap catch of both *Thrips* spp. and *Frankliniella* spp. relative to untreated traps and traps combined with a Thripnok or Magipal lure.
- Thripnok increased mean numbers of *Frankliniella* spp. adults per trap compared to untreated traps, but was significantly outperformed by Lurem-TR. Thripnok did not increase mean numbers of *Thrips* spp. per trap.
- Magipal did not affect mean numbers of thrips adults per trap compared with those on the untreated control traps.
- Of the thrips females identified to species, all the *Frankliniella* spp. on the traps in the semiochemical trial were *F. intonsa* (flower thrips) and the *Thrips* spp. were a mix of *T. fuscipennis* (rose thrips), *T. major* (rubus thrips), and *T. tabaci* (onion thrips).
- Thripnok resulted in a significantly increased catch of bees (4x as many as on untreated traps), however 'dry glue' traps were used in the semiochemical trial which are known to catch more bees than the 'wet glue' used on roller traps.
- Lurem-TR and Magipal also increased mean numbers of bees caught on traps (2x as many as on untreated traps), but significantly less so than Thripnok.
- None of the semiochemicals affected the number of predatory thrips, *Aeolothrips* spp. on the traps.

# Objective 6. To investigate the efficacy of a pheromone-based push-pull strategy for control of first-generation raspberry cane midge and blackberry leaf midge in raspberry. (ADAS and NIAB EMR)

## Introduction

The raspberry cane midge *Resseliella theobaldi* (Barnes) (RCM) and blackberry leaf midge D*asineura plicatrix* (Loew) (BLM) are major pests in UK raspberry production. RCM damages raspberry canes which can lead to secondary pathogen outbreaks (cane blight). BLM damages the growing shoot tips, causing poor growth and lowering the photosynthetic capacity of the plant and thus yield. Flower development is damaged causing a direct reduction in fruit production. Recent changes in approves means broad-spectrum pyrethroids, lambda-cyhalothrin (current EAMU for use on outdoor raspberry) and deltamethrin (currently approved for use on raspberry) may be the only potential chemical options for control and these disrupt predatory mites used for the control of spider mite. Use of tunnels for raspberry production has increased the number of generations per year of these pests and subsequently the damage they cause. Pyrethroids are contact acting and are only likely to kill adult midges due to the larvae of RCM being protected by the cane epidermis and to those of BLM being protected by the unfolded leaves. In addition, efficacy of contact pesticides tends to be low in raspberry production due to the dense canopy. It can be difficult to target the timing of pesticides against the adult midges due to their short lifespan and long emergence period. New and novel approaches to control RCM and BLM have been investigated within SCEPTREplus CP165 SP38. However, of the foliar applications made, only two coded products were able to reduce BLM damage in young raspberry leaves and there was no impact on RCM. With the loss of thiacloprid and the importance of biological control for mites in raspberry production, novel nonchemical IPM strategies are required for control of these pests. This requires growers to use investigate alternative control methods.

The aim of this objective is to test the efficacy of a push-pull strategy against RCM and BLM in commercial raspberry which would be compatible with IPM for other pests. Push-pull approaches are widely used in agriculture and application in horticulture is increasing. These systems ‘push’ pests away from a crop and ‘pull’ them towards an alternative location. These systems can be based on plant material or semiochemicals from synthetic sources. Semiochemicals have been successfully used in IPM programmes to improve control of other

pest species in other crops. The sex pheromones of both RCM and BLM have been successfully identified and commercialised (Hall et al., 2009, Hall et al., 2012) and used for many years in conjunction with monitoring traps. Monitoring traps are effectively employed to assess pest presence in crops and generally used to time PPP applications once the trap threshold has been reached (10 male midges per trap per week). The combination of the sex pheromone of both these species, combined with large white sticky roller traps, account for the 'pull' element of this push-pull approach.

For the 'push' element, MagiPal™ sachets containing methyl salicylate, a signal molecule for systemic acquired resistance (SAR) in plants were deployed in raspberry crops. Methyl salicylate, the active component of "MagiPal", is an established Russell IPM product used to attract beneficial insects into a crop and has been associated with low pest numbers when deployed in crops. In an initial Russell IPM push-pull trial against the blueberry gall midge (BGM) *Dasineura oxycoccana* in blueberry, using the BGM specific pheromone, promising results have been obtained when combined with sticky roller traps and MagiPal. Within this field trial, the efficacy of this approach will be assessed on its ability to reduce BLM and RCM damage and numbers of larvae in comparison to an untreated control.

## Methods

Two sites were established for this trial one in Kent and one in Norfolk. Key information and dates of importance from both sites are displayed in Table 6.1.

**Table 6.1.** Site information for both Kent and Norfolk field sites including location, crop details and key dates in trial deployment.

| Site | Kent | Norfolk |
|---|---|---|
| Crop | Raspberry 'Kweli' | Classified commercial variety |
| Substrate | Soil | Soil |
| Planting date | 2019 | April 2018 |
| Monitoring traps deployed | 24/02/2021 | 02/03/2021 |
| Tunnels skinned | 25/03/2021 | 7/04/2021 |
| Push-pull deployed | 31/03/2021 | 9/04/2021 |

For both Norfolk (Figure 6.1) and Kent (Figure 6.2) sites, six replicate blocks, each containing one control plot (untreated) and one push-pull plot (treated) were established. Sizes of the plots were 18 m x 24 m and 20 m x 20 m in Kent and Norfolk respectively. A buffer zone of 8 m wide between each plot was maintained.

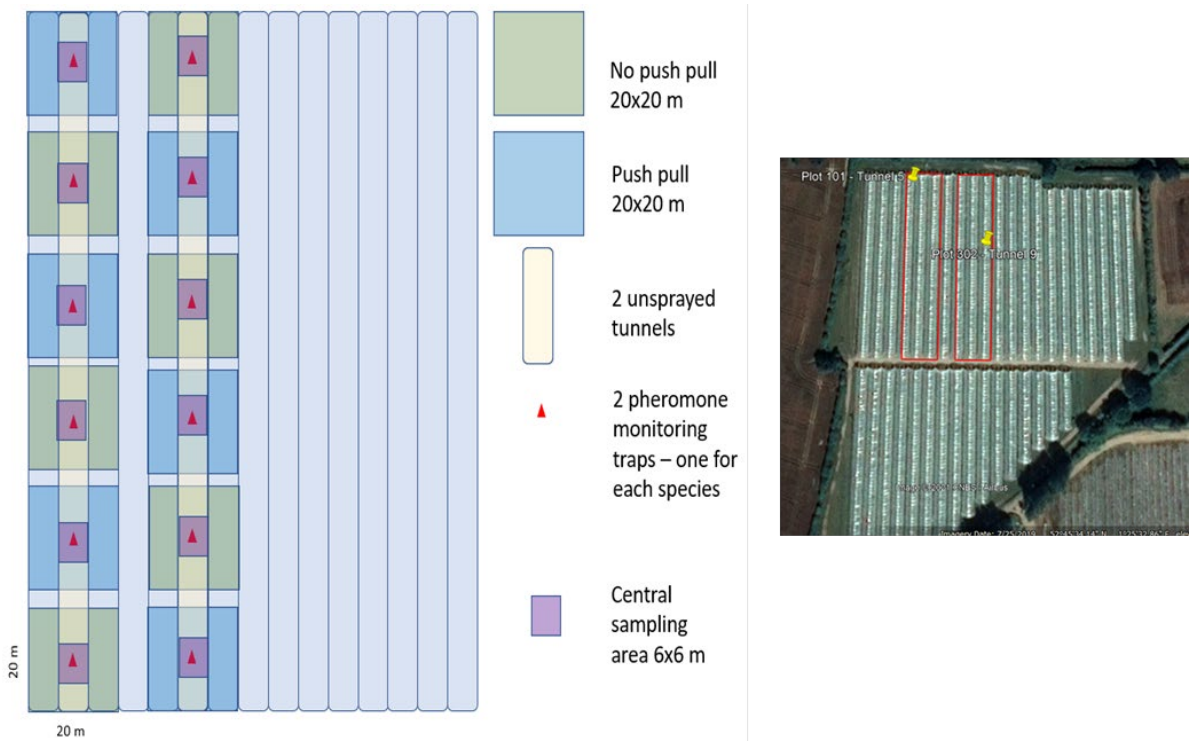



**Figure 6.1.** Norfolk site overview. Left image shows a visualization of the trial layout. Green and blue boxes show the locations of push-pull treated and control plots respectively. Right image displays location of tunnels to be used in trial in reference to field location outlined in red.

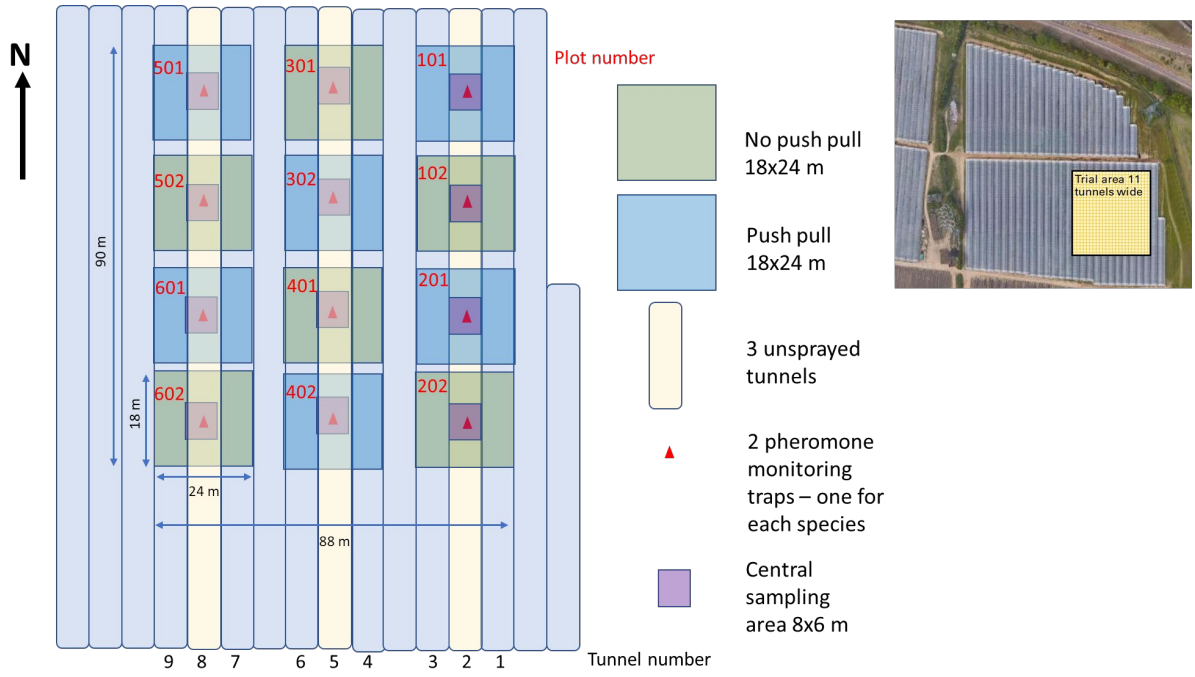
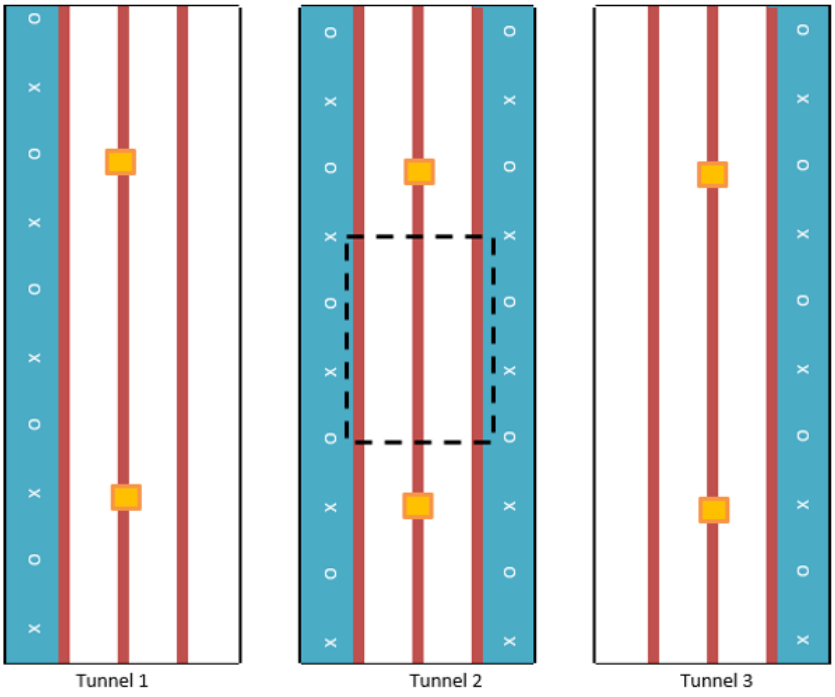



**Figure 6.2.** Kent site overview. Left image shows a visualization of the trial layout. Green and blue boxes show the locations of push-pull treated and control plots respectively. Right image displays location of tunnels to be used in trial in reference to field location in yellow box.

Treated plots included both MagiPal sachets and white roller sticky traps (Figure 6.3). Treatments were deployed in advance of monitoring traps detecting midges in the crop. The MagiPal™ repellent sachets (Figure 6.3 Left) were deployed with two sachets (10m apart) hung on central canes in the middle row of each tunnel within the plot (i.e. three treated rows with six sachets applied per treated plot, see Figure 6.4). Sachets were hung 0.5 m up from the ground. In Norfolk, leg rows were strimmed or treated with herbicide prior to roller trap deployment. In Kent, leg rows were covered with Mypex and so did not require vegetation removal. White roller traps were deployed in four leg rows per plot (Figure 6.4) at 18 m length (Kent), 20m length (Norfolk) and 20 cm above the ground (Figure 6.3 Right). Holes were punched in the roller traps every 2.2 m in Kent and every 2m in Norfolk. The RCM and BLM sex pheromone rubber septa lures were placed alternately in the holes e.g. five pheromone lures per species, per section of sticky roll (Figure 6.4). The growers were asked not to apply plant protection products (PPP), including herbicides to the central tunnel of trial plots once the trial has been deployed and throughout the assessment period.

**Figure 6.3.** Left- MagiPal sachets hung on support structure in crop. Right- white roller sticky trap deployed within the leg row of tunnel.




| KEY | |
|---|---|
| X | Roller trap with RCM pheromone in leg row |
| O | Roller trap with BLM pheromone in leg row |
| | Raspberry row |
| | MagiPal™ sachet |
| | BLM and RCM assessment area |

**Figure 6.4.** Overview of treated plot layout including deployment position of MagiPal sachets (orange boxes), roller traps (blue bands), pheromone lure placement (o's and x's) and sampling area (black dashed box).

Pheromone monitoring traps were deployed within two blocks towards the end of February (Table 6.1). Two red delta traps with white sticky bases containing either RCM or BLM pheromone lures were hung 0.5 m above the ground in both treated and untreated areas. Traps were placed in pairs, one for each species, spaced approximately 5 m apart, in the two outer raspberry rows. Initially four monitoring traps were used to monitor for midge presence and to indicate when further monitoring traps should be deployed. After reaching the threshold midge catch (10 midges per trap per week) (Table 6.2) the number of monitoring traps increased to 12 for each species. All 12 traps were monitored three time per week in Kent. The four original traps were monitored twice weekly by the grower in Norfolk and all 12 traps were monitored on assessments one - four (on 13/05/21, 24/05/21, 02/06/21, 14/06/21). The bases were changed once a week until numbers caught in the Kent traps escalated and at this point, bases were changed every visit. Traps were monitored by NIAB EMR and ADAS

staff or by the grower's farm staff. Farm staff were asked to circulate photos of trap catches for identification by NIAB EMR and ADAS research personnel for confirmation.

**Table 6.2.** General information regarding dates of importance related to midge trapping, treatment implementation and assessment at both Kent and Norfolk sites.

| | **Kent** | **Norfolk** |
|---|---|---|
| Traps deployed | 24/02/21 | 02/03/2021 |
| **BLM** | | |
| Frist BLM caught | 12/04/2021 | 07/05//21 |
| BLM threshold reached | 30/04/2021 | Not reached |
| 1st BLM assessment | 10/05/2021 | 24/05/21 |
| 2nd BLM assessment | 20/05/2021 | 01/06/21 |
| 3rd BLM assessment | 01/06/2021 | 14/06/21 |
| **RCM** | | |
| First RCM caught | 12/04/2021 | 26/04/21 |
| RCM threshold reached | 19/04/2021 | 29/04/21 |
| 1st cane splits made | 21/04/2021 | 04/05/21 |
| 1st cane assessments | 30/04/2021 | 13/05/21 |
| 2nd cane splits made | 30/04/2021 | 24/05/21 |
| 2nd cane assessments | 10/05/2021 | 24/05/21 |
| 3rd cane splits made | 10/05/2021 | n/a |
| 3rd cane assessments | 20/05/2021 | 01/06/21 |
| 4$^{th}$ cane splits made | | n/a |
| 4$^{th}$ cane assessment | | 14/06/21 |

Once midge trap threshold (10 midges per trap per week or a sharp increase in catches) had been reached in the monitoring traps, cane splits and assessments commenced (Table 6.2).

For RCM assessment splits were made in canes after trap threshold had been reached in the monitoring traps. Splits were made by inserting a mounted needle beneath the outer layer of cane and scoring a 10 cm vertical line at the base of young raspberry spawn on one side. Splits were made in raspberries in the three rows at the centre of each plot. Splits were marked with coloured tape to ensure recovery for assessments. Ten split canes per plot were collected from the field by cutting the canes from the plant 10 days post splits being made. Canes from each plot were collected in labelled plastic bags to prevent any movement of larvae between plots. Canes were assessed in the laboratory under a microscope and the number of eggs and larvae (Figure 6.5) were counted and the length of the split was recorded. Three RCM assessments were performed at the Kent site and four were performed at the Norfolk site.

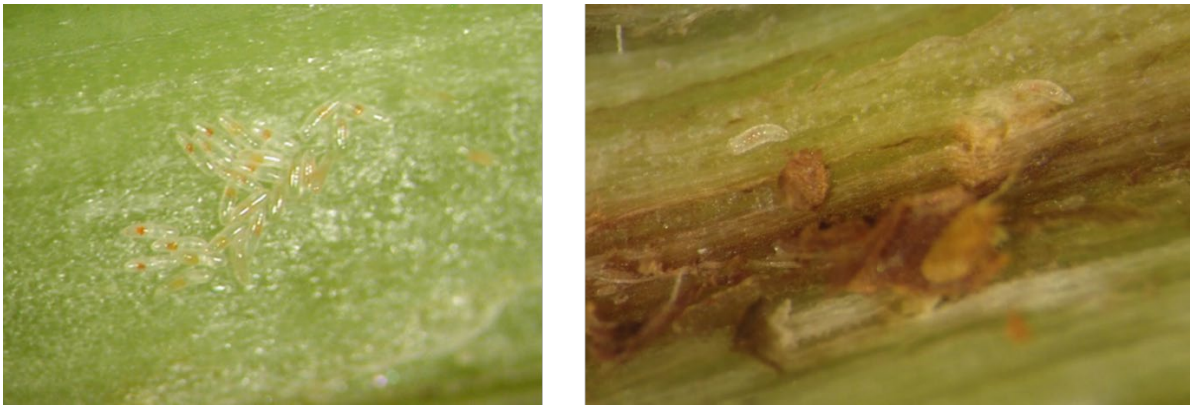


**Figure 6.5.** RCM eggs (left) and larvae (right) from cane splits made within raspberry canes.

For BLM, leaf damage assessments were performed on foliage of raspberry canes in the three rows at the centre of each plot. Assessments were carried out 10 days post trap threshold. Fifty randomly selected shoots were assessed for visible damage. Assessments recorded the number of BLM damaged shoots (characteristic twisting and distortion of leaf veins (Figure 6.6) and the total number of leaves damaged in each of the damaged shoots. Three assessments were performed for BLM damage.


**Figure 6.6.** Raspberry shoots displaying characteristic twisting and distortion of the leaves and shoots as the result of BLM (top left and bottom) in comparison to undamaged shoots (top right).

Roller trap assessments were performed to count the number of BLM and RCM caught in various locations on the trap. Three 5 cm x 5 cm sections of white roller trap were removed per plot and the number of RCM and BLM were counted. One of the sections was collected close to a RCM lure, one section collected close to a BLM lure and one taken from between the two lures. Both species were counts on each section.

At each assessment, the crop was examined for the presence of phytotoxic effects of the MagiPal sachets on a scale of 1 – 10, where 1 represents no crop damage and 10 represents complete crop kill. These were performed within 1 m proximity to the sachets. Photographs of any damage was taken and % leaf cover of damage estimated.

*Norfolk*

The raspberry cane midge threshold was reached after a sudden increase in caught midges.

Thirty-six cane splits per plot were made on 4/05/21. However, no larvae or eggs were found on the first laboratory assessment, 10 days after the cane splits were made. Therefore, more cane splits were made upon returning to the site on 24/05/21 to ensure that there were 'fresh' splits available for any emerging females. However, when the canes that were split on 24/05/21 were assessed on the third assessment (02/06/21) no eggs or larvae were found. A small sample of canes split on 04/05/21 were also collected on 02/06/21 and these canes contained larvae. Therefore, it was not necessary to make any further splits. All splits were made in green primocane spawn.

The only plant protection product applied to the crop during the trial was the fungicide cyprodinil + fludioxonil (Switch) at a rate of 0.5L / ha on 20/04/2021. This was not applied to the central tunnels of each plot.

Air temperature and relative humidity data loggers were placed 5m inside the North entrance of one of the trial tunnels and another logger was placed in the centre of a central plot of one of the trial tunnels. Two soil temperature data loggers were placed in the same locations and buried to a depth of 10cm.

*Natural split assessment*

Fifty randomly selected canes were assessed for presence and length of any natural cane splits, measured with a ruler.

*Kent*

For the Kent site, cane splits were made two days following reaching trap threshold for the RCM assessments. There was a lack of green spawn for cane splits to be made into so splits were made in both woody and green canes. Three cane split assessment were performed with splits made and collected every 10 days. By the second set of splits, there was enough green growth for subsequent assessments to be executed on green growth alone.

*Statistical analysis*

Data from the Kent site was analysed with analysis of variance (ANOVA). Data from the Norfolk site was analysed with omnibus tests (ANOVA) and post hoc tests.

## Results and Discussion

*Norfolk*

BLM trap threshold was not reached on any date, the mean number of BLM caught remained below 10 per trap and there was no sudden increase in midge numbers. The first BLM assessment was carried out on 24/05/21, 17 days after the first BLM were found on 7/05/21. The number of BLM caught peaked on 01/06/21 with a mean of 2.7 midges per trap caught (Figure 6.7). There was no significant difference on any of the analysed dates between numbers of BLM caught in the treated plots and the control plots (Table 6.1). Data from 14/06/21 was excluded from statistical analysis due to low numbers.

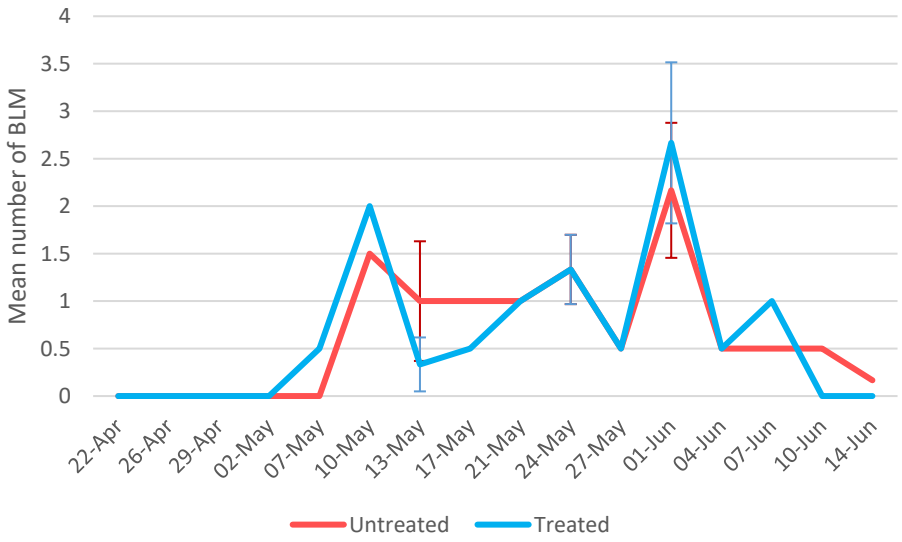



**Figure 6.7.** Mean number of blackberry leaf midge caught per monitoring trap. Bars represent standard error on statistically analysed assessment dates. No significant difference between treatments (P<0.05).

**Table 6.3**. Post hoc analysis of blackberry leaf midge trap catches.

| **Assessment date** | **13/05/2021** | **24/05/2021** | **01/06/2021** |
|---|---|---|---|
| z.ratio | 1.053 | 0 | -0.454 |
| P-value | 0.2925 | 1 | 0.6495 |

*RCM threshold*

The RCM threshold was reached on 29/04/21, three days after the first midges were caught, when a sudden increase from zero to eight midges in one trap was recorded. There were significantly more RCM midges caught in the traps in the untreated plots compared with those in the treated plots on 24/05/2021 (P=0.0092) (Table 6.4). There was no significant difference between treatments on 13/05/21 and 01/06/21. Trap catch results from 14/06/21 were excluded from statistical analysis due to low numbers. Peak numbers of RCM reached an average of 34.5 in the untreated plots on 24/05/21 (Figure 6.8).

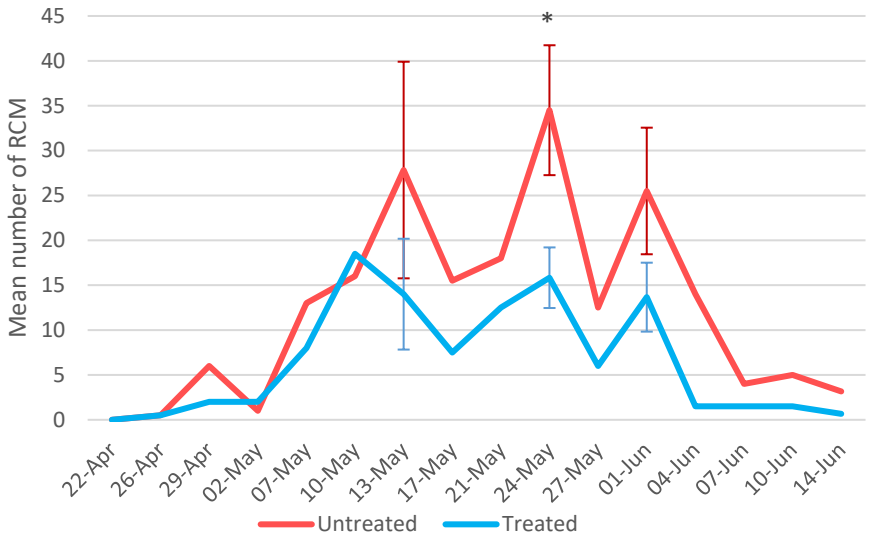



**Figure 6.8.** Mean number of raspberry cane midge caught in monitoring traps. Bars represent standard error on statistically analysed assessment dates. * indicates significant difference between untreated and treated plots on 24/05/21 (P<0.01).

**Table 6.4** Post hoc analysis of raspberry cane midge trap catches.

| Assessment date | 13/05/2021 | 24/05/2021 | 01/06/2021 |
|---|---|---|---|
| z.ratio | 1.111 | 2.604 | 1.582 |
| P-value | 0.2665 | 0.0092 | 0.1137 |

*RCM cane split assessment*

Mean numbers of RCM eggs are shown in Figure 6.9. There was no significant difference between treatments. There were only three eggs found in one untreated plot on 14.06.21, results were not statistically analysed.

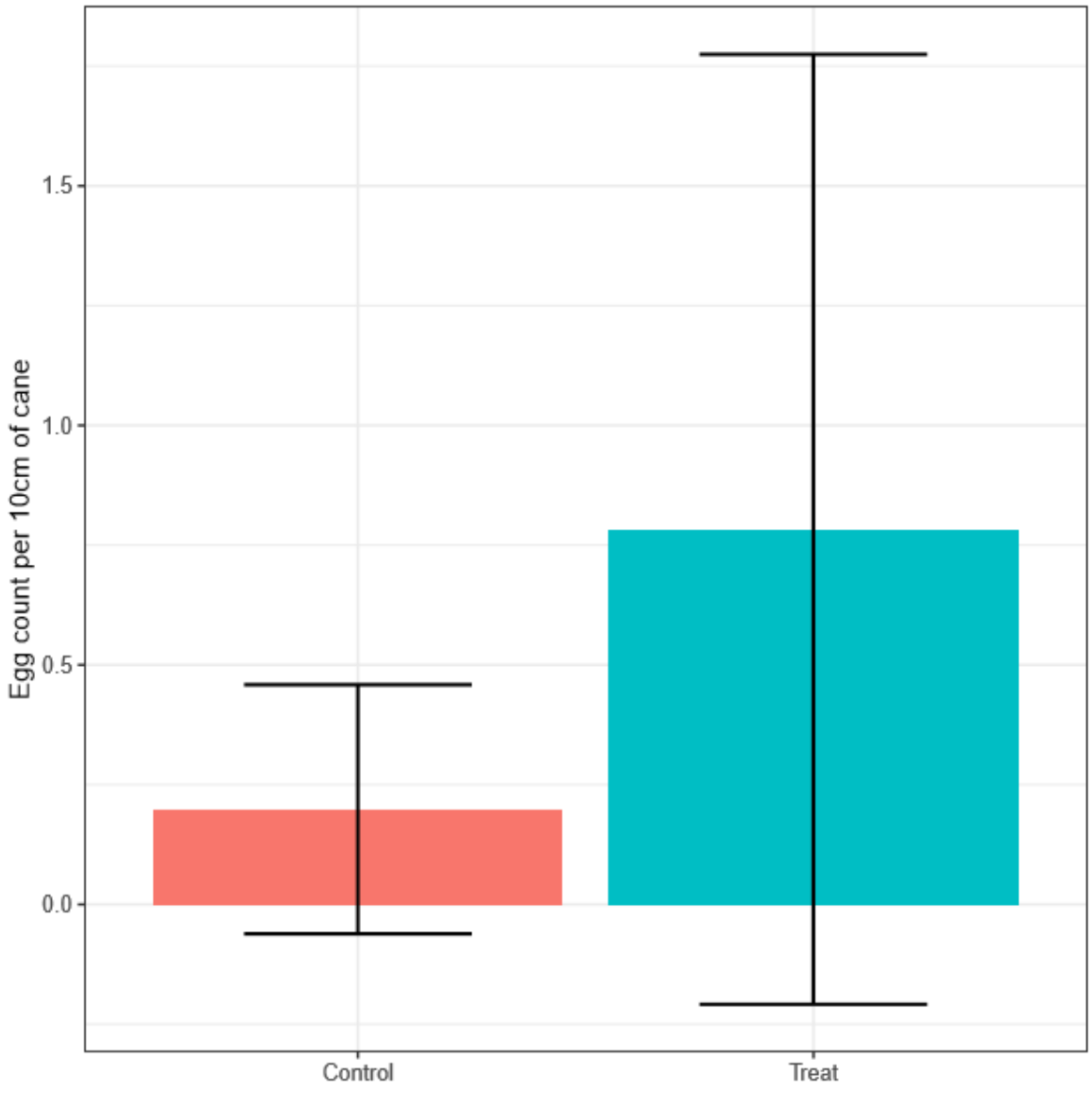



**Figure 6.9.** Mean numbers of eggs found on 24.05.21 in control (pink) and treated (blue) plots. Bars represent standard error.

No eggs or larvae were recorded on 13/05/21, 10 days after the canes were artificially split. Figure 6.10 shows that there were significantly less larvae recorded per cm of split cane in the untreated control compared with the treated plots on 25/05/21 (P=0.0416). No eggs or larvae were recorded on 02/06/21 from the canes that were split on 13/05/21. A small number of canes that were split on 04/06/21 contained larvae but these canes were not collected evenly between the plots, therefore data was not analysed. Larvae were present in the canes split on 04/05/21 and collected on 14/06/21; there was no significant difference between treatments (Table 6.5).

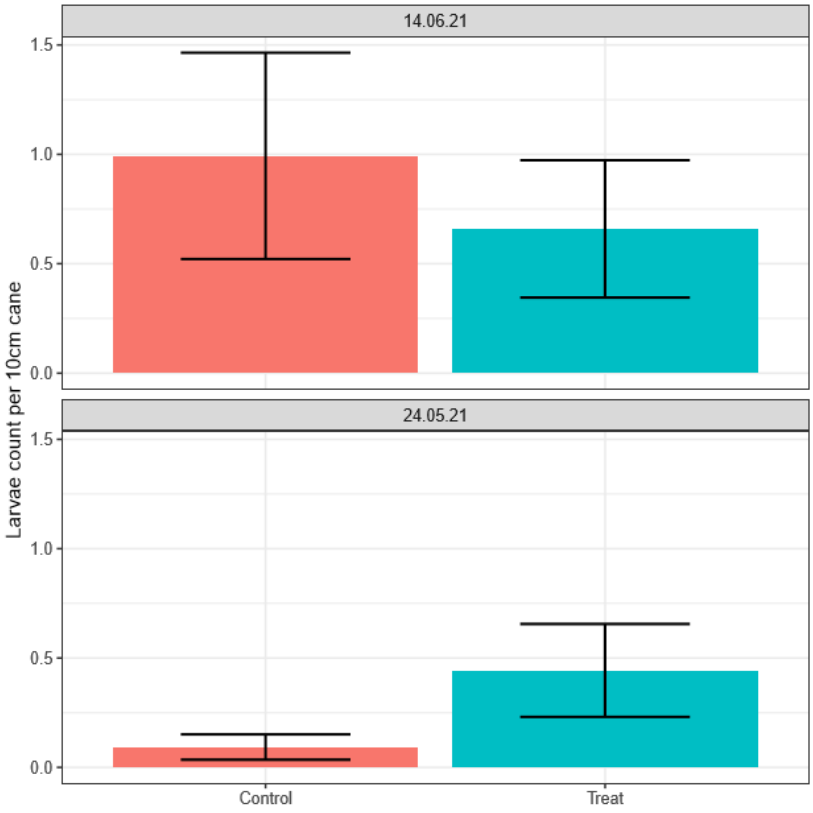



**Figure 6.10.** Mean number of RCM larvae recorded on 24/05/21 (bottom) and 14/06/21 (top) in control (pink) and push-pull treated (blue) plots. * indicated significant difference, bars represent standard error. *

**Table 6.5**. Post hoc analysis of raspberry cane midge larvae found on two assessments.

| Assessment date | 24/05/2021 | 14/06/2021 |
|---|---|---|
| t.ratio | -2.049 | 0.630 |
| P-value | 0.0416 | 0.5295 |

*Blackberry leaf midge*

The first symptoms of BLM damage were recorded on 25/05/21, 17 days after the first BLM was caught in a monitoring trap. Mean numbers of damaged shoots and leaves were very low on 24/05/21 (Figure 6.11). The number of damaged shoots and leaves increased between assessment dates (Figure 6.12 and Figure 6.13). There were no significant differences between treatments on any assessment date in numbers of damaged shoots or damaged leaves (P= 0.2797).

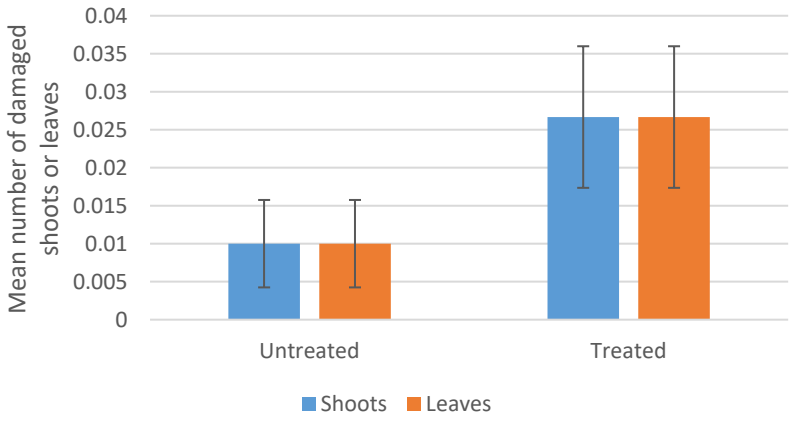



**Figure 6.11.** Mean number of damaged shoots or leaves per 300 canes assessed on 24/05/21. Bars represent standard error.

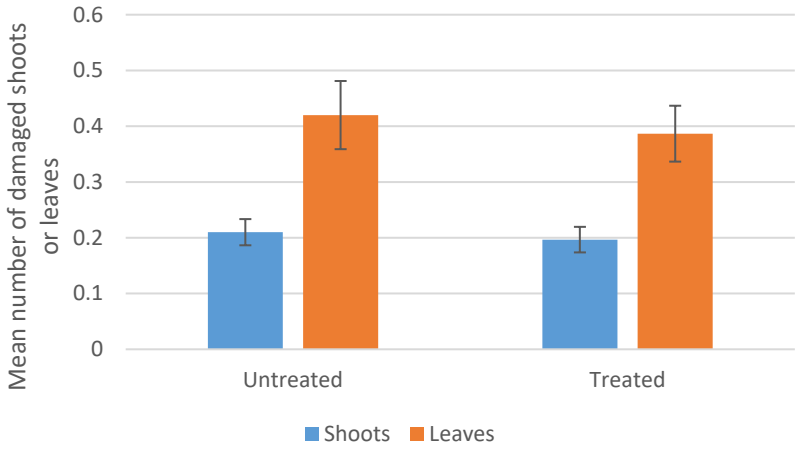



**Figure 6.12.** Mean number of damaged shoots or leaves per 300 canes assessed on 01/06/21. Bars represent standard error.

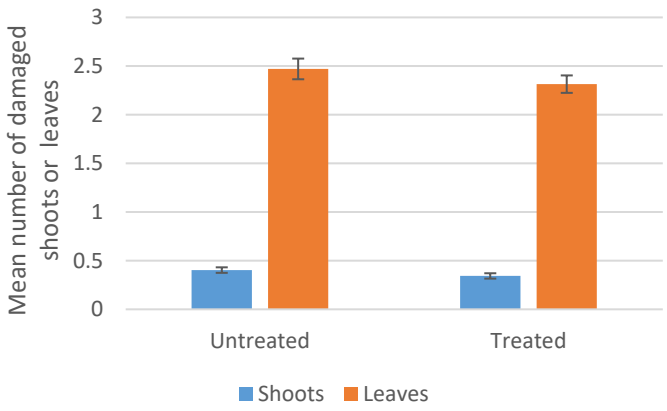



**Figure 6.13.** Mean number of damaged shoots or leaves per 300 canes assessed on 14/06/21. Bars represent standard error.

**Table 6.6.** ANOVA of shoot damage and leaf damage caused by blackberry leaf midge.

| Assessment | Shoot damage | Leaf damage |
|---|---|---|
| Df | 1 | 5 |
| Chisq | 1.1684 | 8.5895 |
| P value | 0.2797 | 0.3804 |

*Roller trap catches*

Sample size of roller trap catches was too low for statistical analysis; however, results were recorded to indicate whether the midges could be flying towards the lures. Results show that both raspberry cane midge and blackberry leaf midge were most frequently caught in the centre, between the RCM and the BLM lures (Figure 6.14, 6.15). More RCM were caught next to the RCM lures rather than next to the BLM lures on all dates. More BLM were caught next to the BLM lures rather than next to the RCM lures on all dates, except for 02/06/21.

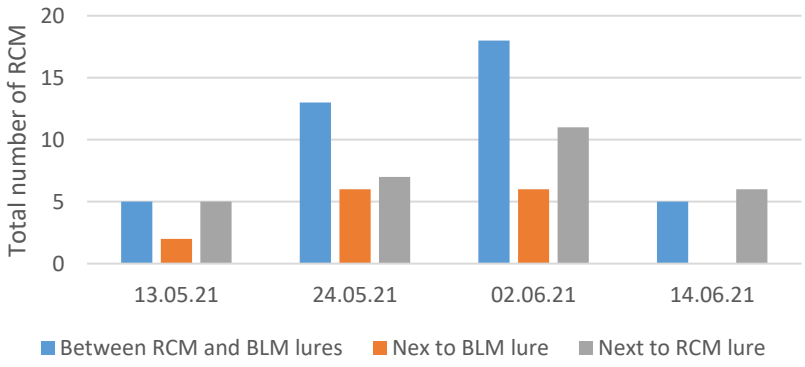



**Figure 6.14.** Total number of RCM caught on six 5cm x 5cm squares of roller trap between 13.05.21 and 14.06.21.

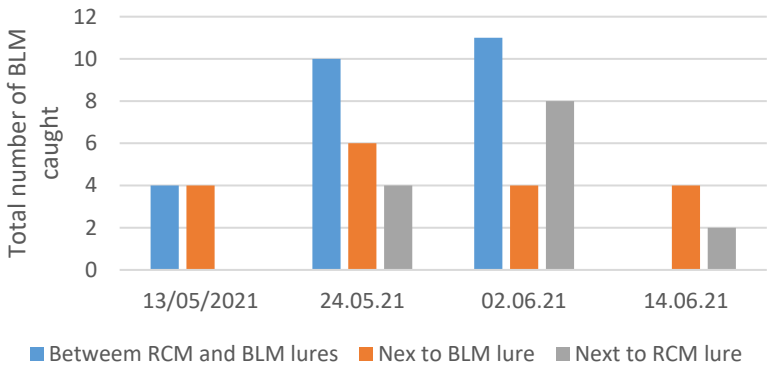



**Figure 6.15.** Total number of BLM caught on six 5cm x 5cm squares of roller trap between 13.05.21 and 14.06.21.

*Natural split assessment*

Natural splits were present in the crop on each assessment date; 24/05/21, 02/06/21, and 14/06/21 (Table 6.7). Damage to the cane epidermis was recorded as a 'split', the majority of 'splits' were caused by slug damage, not necessarily true cane splitting. RCM larvae were found in slug damaged cane during the laboratory assessments. The number of splits per

cane decreased on each assessment in both treatments and the mean split length increased, suggesting that splits had merged. Results were not subject to statistical analysis.

**Table 6.7.** Mean number of naturally formed splits and mean length of split on three assessment dates.

| Assessment date | 24/05/21 | | 02/06/21 | | 14/06/21 | |
|---|---|---|---|---|---|---|
| Parameter | Mean splits per cane | Mean length (cm) | Mean splits per cane | Mean length (cm) | Mean splits per cane | Mean length (cm) |
| Untreated | 0.3 | 3.69 | 0.17 | 8.47 | 0.17 | 8.76 |
| Treated | 0.22 | 4.16 | 0.20 | 5.85 | 0.17 | 8.26 |

*Meteorological data*

Air temperature, humidity, and soil temperature were collected from the tunnel entrance and from the centre of one of the tunnels. Average relative humidity remained relatively consistent throughout the trial, ranging between 62.0% and 90.2% (Figure 6.16). Average air temperature increased throughout the trial, with an early peak in maximum temperature of 25.5ºC on 31 March, but the last frost was seen on 6 May at -0.5ºC.

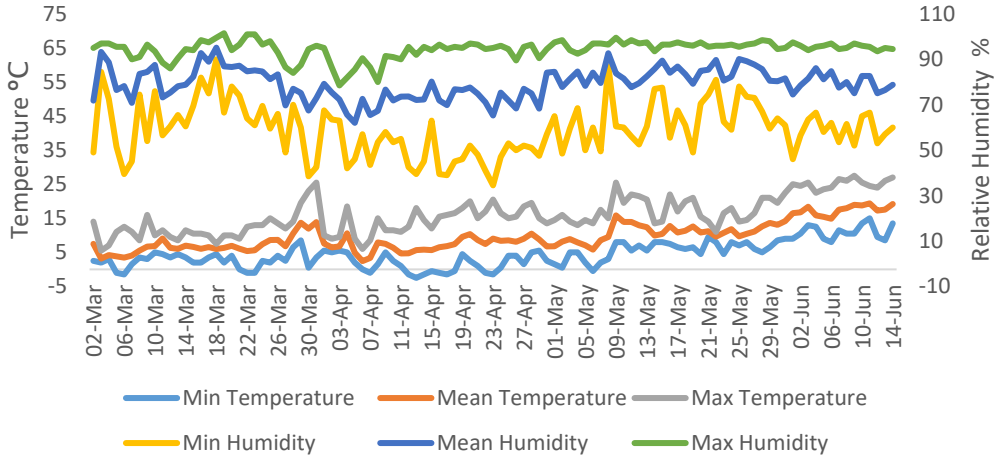



**Figure 6.16.** Minimum, mean and maximum air temperature and relative humidity recorded from 02/03/21 to 14/06/21.

Average soil temperature at 10cm depth was 11.2ºC when the first midges were caught on 26 April and when the midge threshold was reached on 29 April (Figure 6.17). Average soil temperature was 9.2ºC at the start of the trial, accumulated temperature was 457ºC by 26 April, when the first midges were caught and was 798ºC when the first RCM eggs were discovered, above a base temperature of 4ºC from the start of the trial. Gordon *et al*., (1989) found a mean accumulated average soil temperature of 339ºC above a base of 4ºC before RCM eggs were detected with a model based on calculated soil temperature from air temperature data using local meteorological stations. Although the model could accurately predict oviposition dates it may need updating for tunnel-based systems and on-farm soil temperature data. It appears that the tunnel system accumulates more temperature before oviposition, indicating that other factors may be more important in determining oviposition dates, such as soil moisture.

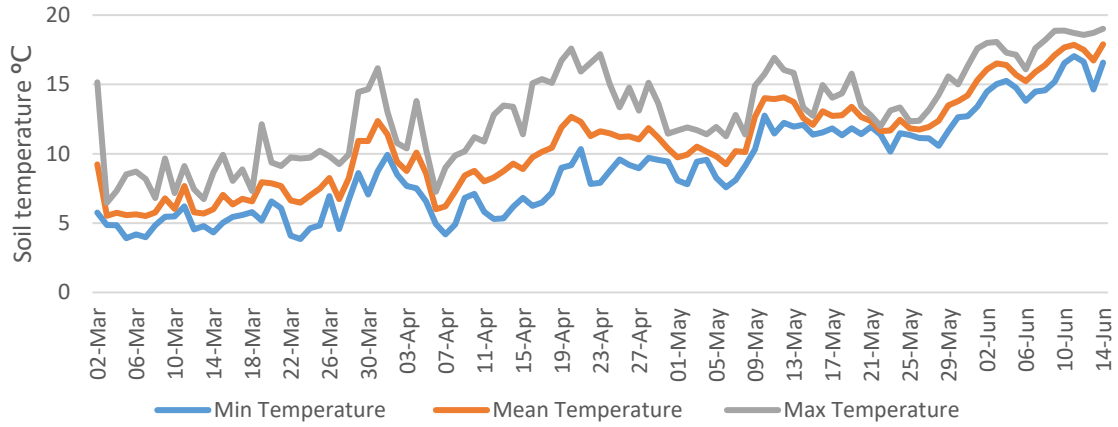



**Figure 6.17.** Minimum, mean and maximum soil temperature at 10 cm depth recorded from 5 m inside the North entrance of one of the trial tunnels.

There was no difference in air temperature or humidity between the tunnel entrance and the centre of the tunnel. Cumulatively over the 104 days of the trial the average soil temperature in the middle of the tunnel was 2.92ºC colder than at the tunnel entrance (Figure 6.18).

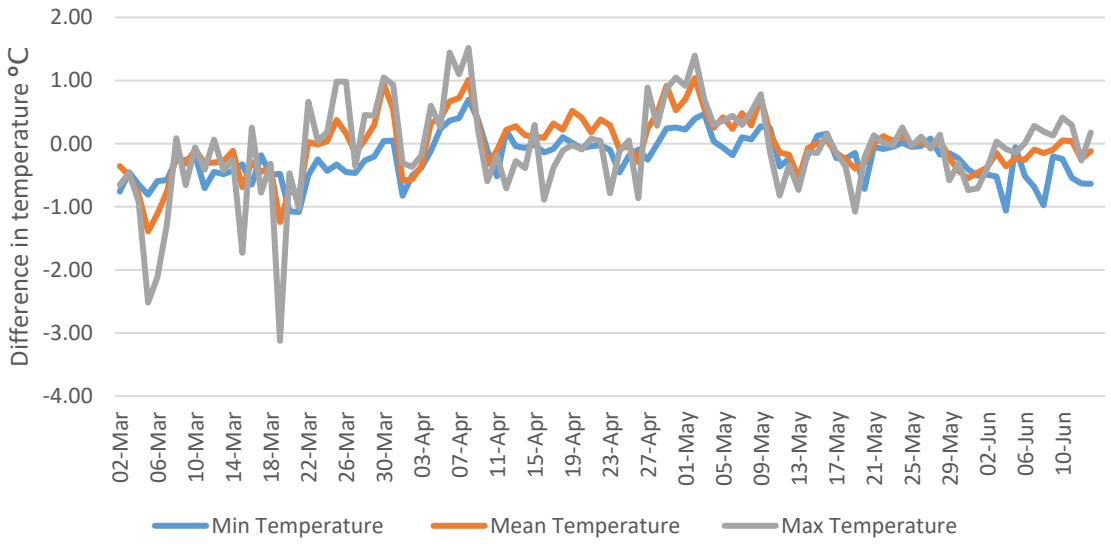



**Figure 6.18.** Difference in mean, minimum and maximum soil temperature between the tunnel entrance and the tunnel centre, where values less than zero show that the centre of the tunnel was colder than the entrance and values greater than zero show that the centre of the tunnel was warmer than the entrance.

In Norfolk the crop was irrigated from the end of March, when soil moisture was declining (Figure 6.19). Soil water content was maintained between 50mm and 70mm for most of the trial, greater fluctuations were seen in June.

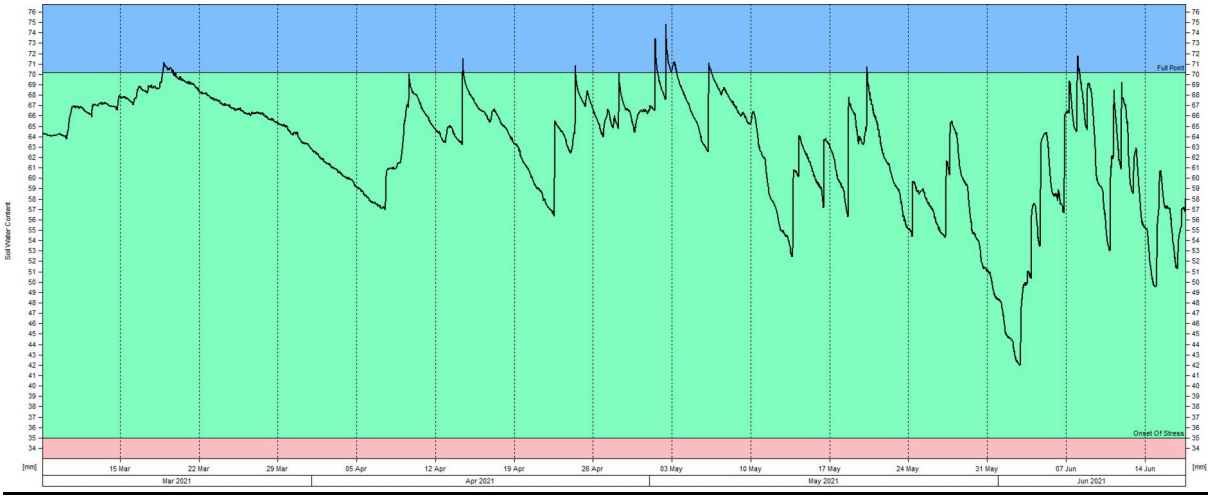



Figure 6.19. Soil moisture content (mm) data from one of the trial tunnels, close to the dripper line in the top 30cm of soil. Graph taken from Enviroscan software.

*Kent*

BLM trap threshold was reached on 30/04/21, 18 days after the first BLM were caught. Peak monitoring trap catch reached an average of 113 BLM per trap per week in the control plots and 100 in the push-pull treated plots on 07/05/21. There were significantly more BLM caught in the control plots between 23/04/21 and 07/05/21 (23/04/21 P= 0.018, 30/04/21 P= 0.016, 07/05/21 P= 0.001) (Figure 6.20 Top).

RCM trap threshold was reached on 19/04/21, 7 days after the first RCM were caught. Peak monitoring trap catch reached an average of 1221 RCM per trap per week in the control plots and 509 in the push-pull treated plots on 07/05/21. There were significantly more RCM caught in the control plots between 23/04/21 and 07/05/21 (All dates P= <0.001) (Figure 6. 20 Bottom).

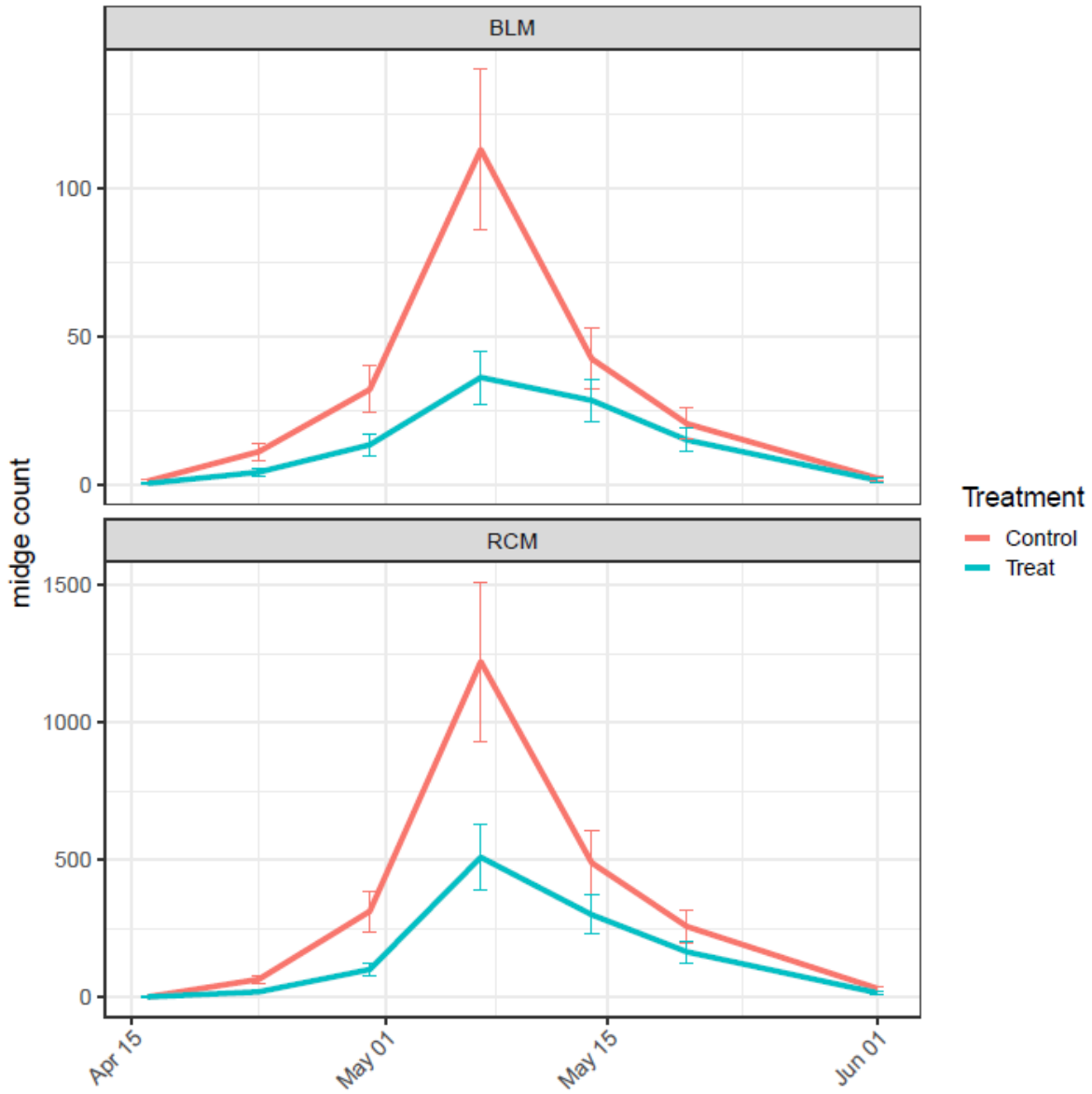


**Figure 6.20.** Average number of midges per week per trap for BLM (Top) and RCM (Bottom). For both species, count of midges were significantly higher in the control plots compared to the treated plots between 23/04/21 and 07/05/21 in Kent trial.

For RCM cane split assessments there was a significant difference in the number of eggs in green shoot growth over woody growth in the first assessment of the Kent site in the push-pull treated plots only (P= <0.001) (Figure 6.21). There was no overall significant difference between the number of eggs or larvae per cm of cane in any assessment (figures not shown).

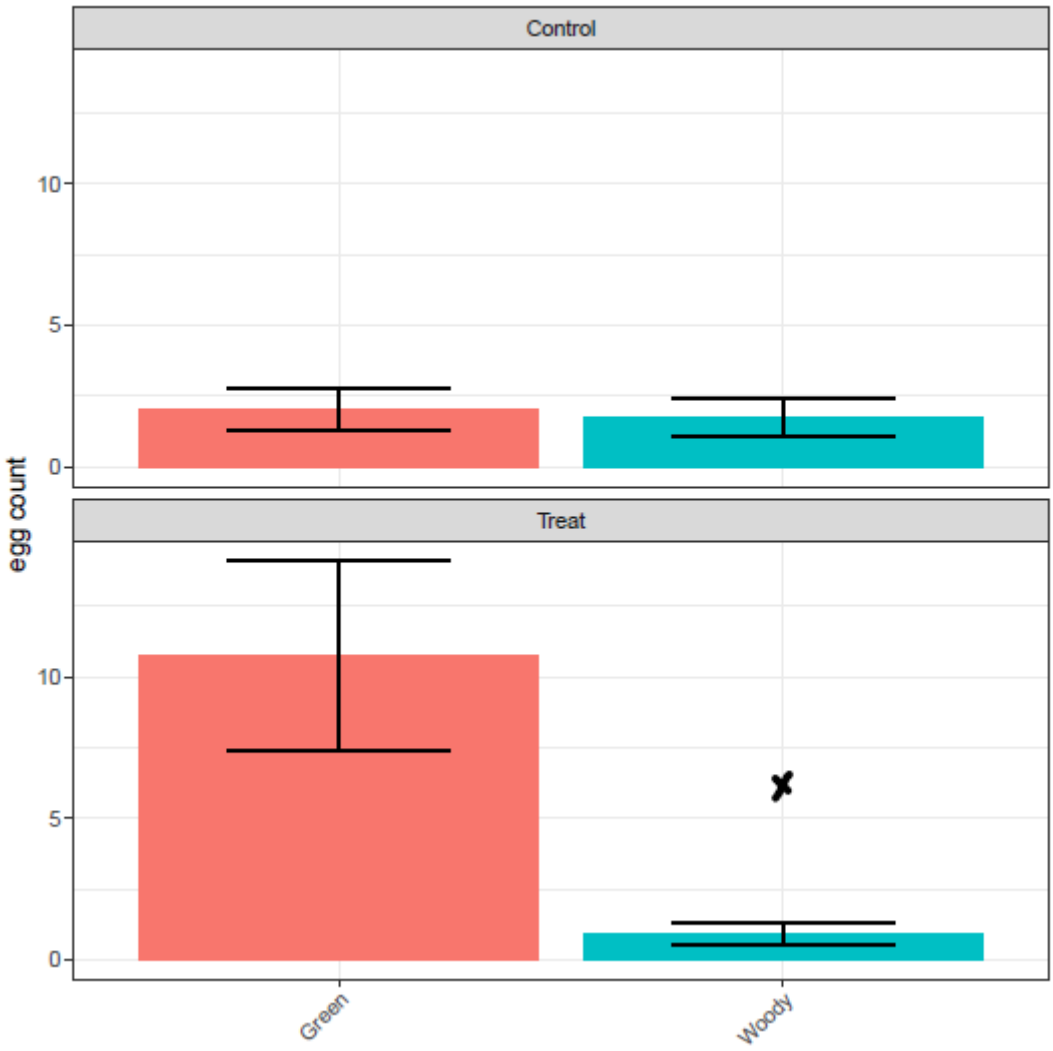



**Figure 6.21.** Number of RCM eggs in green (pink) or woody (blue) canes in control (top) and push-pull treated (bottom) plots in Kent trial. * indicated significant difference.

For BLM there was significantly higher numbers of leaves (Figure 6.22) and number of shoots (Figure 6.23) that displayed damage in control plots in the first two assessments (leaf damage

1st assessment P= <0.001, 2nd assessment P= 0.004; shoot damage 1st assessment P= 0.007, 2nd assessment P= 0.022). There was no significant difference in damage between treatments in the third and final assessment.

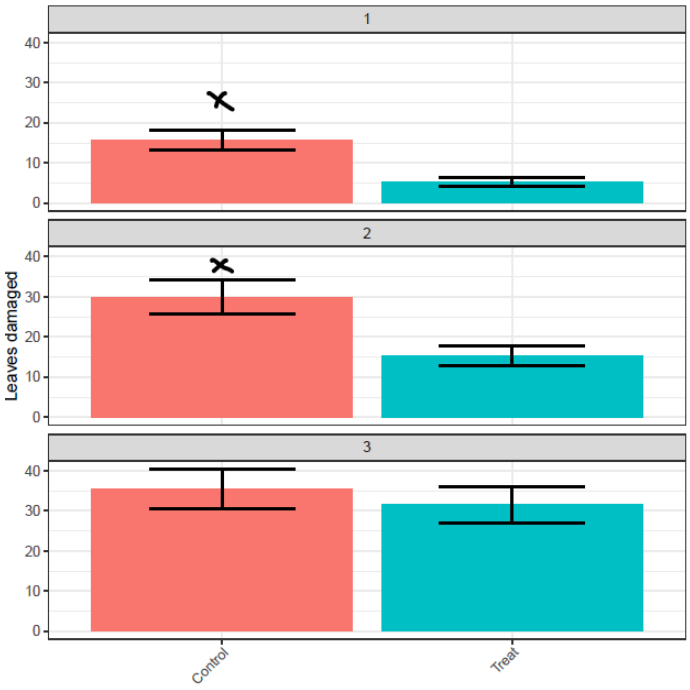



**Figure 6.22.** Average number of leaves that displayed BLM damage in each assessment in control (pink) and push-pull treated (blue) plots in Kent trial. * indicate significant differences.

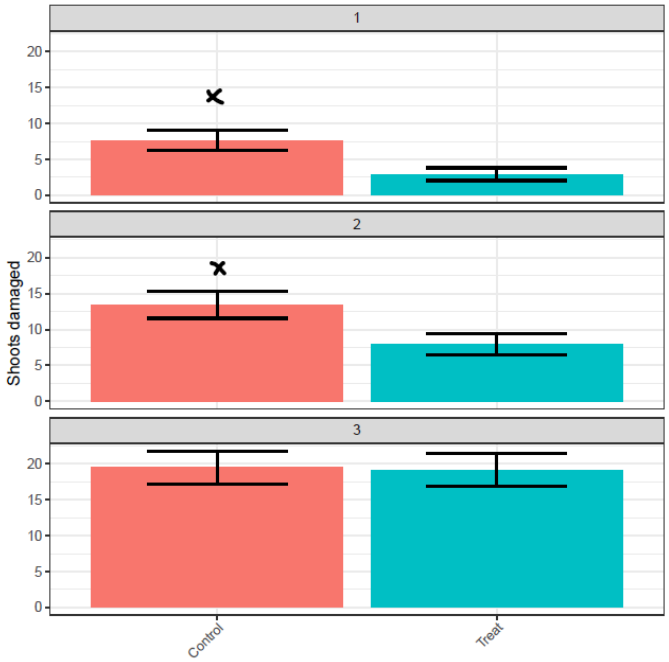



**Figure 6.23.** Average number of shoots that displayed BLM damage in each assessment in control (pink) and push-pull treated (blue) plots in Kent trial. * indicate significant differences.

There was no significant difference in the numbers of BLM midge caught on the white roller sticky traps based on proximity to lures on any assessment date (Figure 6.24 top). Significantly more RCM were caught in proximity to the RCM lure on the final assessment (1/06/21) (Figure 6.24 bottom). There were no counts for RCM in proximity to the BLM lure at the first assessment due to human error.

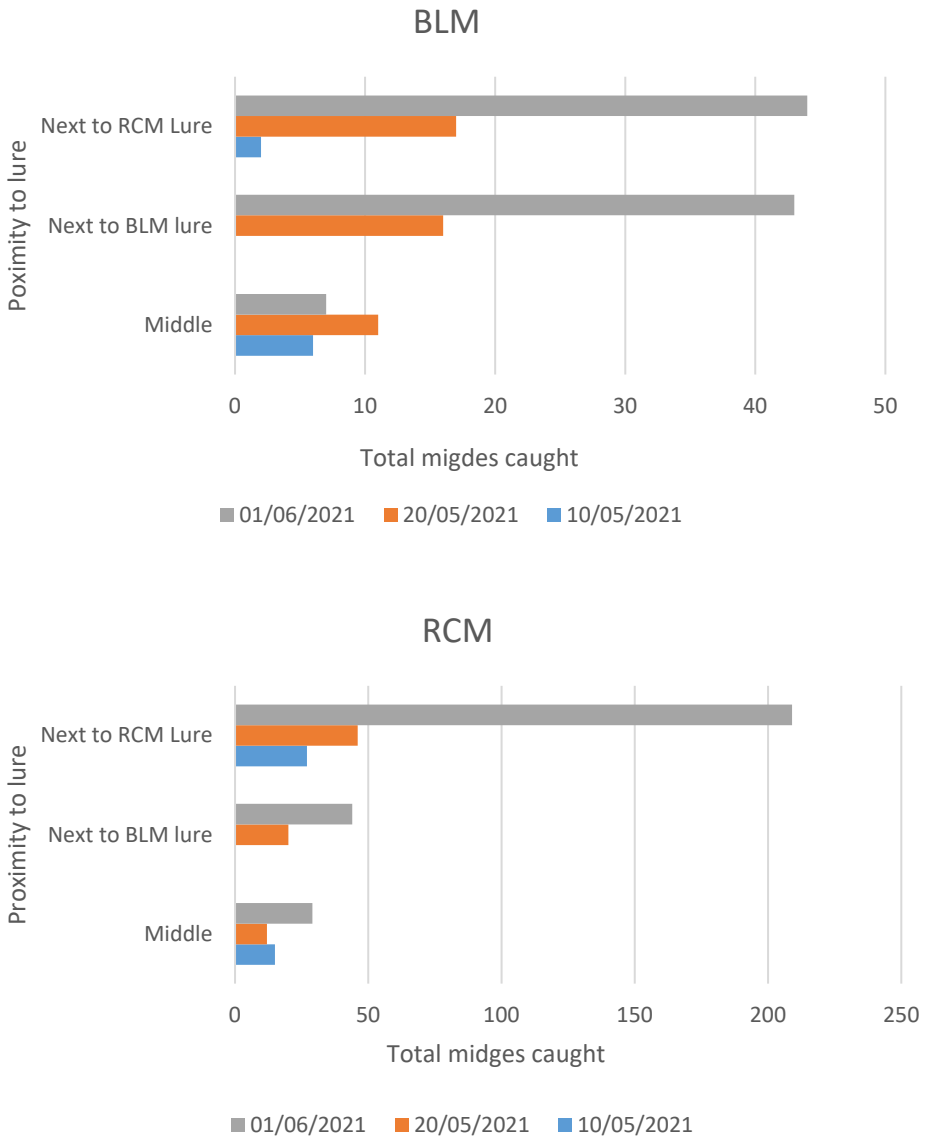



**Figure 6.24.** Total number of BLM (top) and RCM (bottom) caught over each assessment date in proximity to pheromone lure in Kent trial.

There were also no incidences of phytotoxicity damage as the result of the MagiPal lures at either the Kent site or the Norfolk site.

*Meteorological data*

Air temperature and humidity were collected from the centre of one of the tunnels (Figure 6.25). Average temperatures were consistent however maximum and minimum fluctuated greatly from the end of March to the end of the data collection period. Peak temperature was recorded on 30th of March with a maximum of 33.5 ºC. The last frost was seen on 30 April at -0.5ºC. Relative humidity fluctuated throughout the trial, ranging between 31% and 100%.

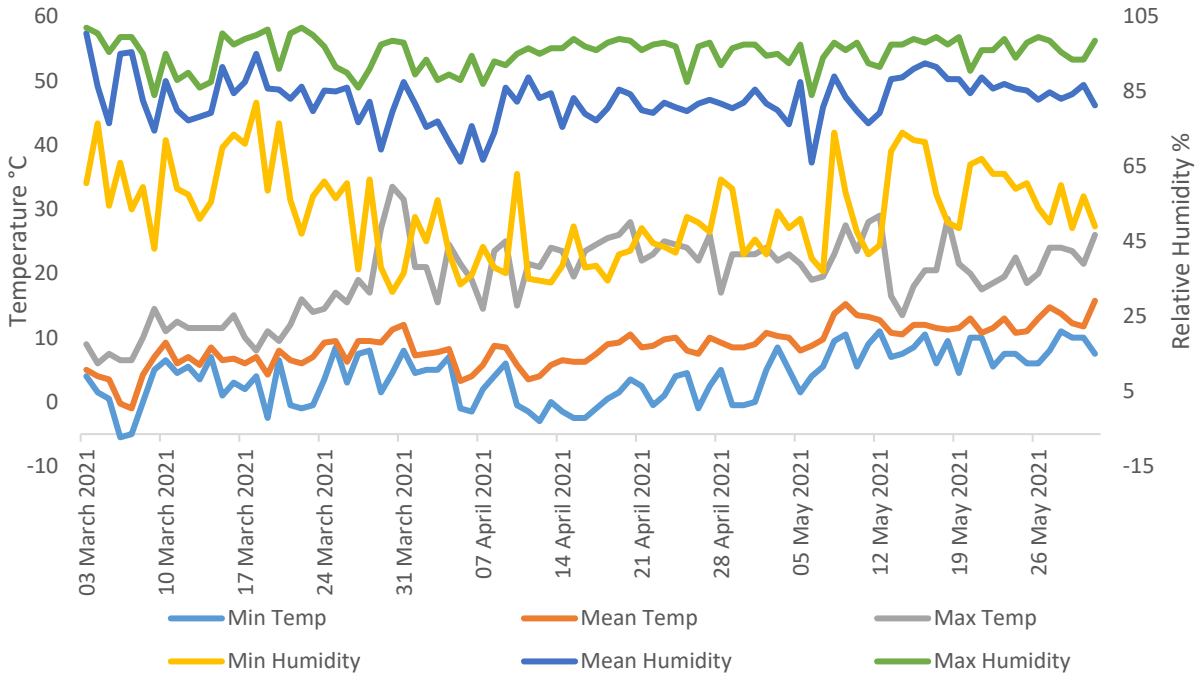



**Figure 6.25.** Minimum, mean and maximum air temperature and relative humidity recorded from 03/03/21 to 1/06/21 in Kent trial.

## Conclusions

The pest pressure in the Kent site was extremely high in 2021 in comparison to the Norfolk site. For Kent, there was no overall reduction in RCM eggs and larvae between the treated and control plots which may have been the result of these high trap catches. However, there was a significant reduction in monitoring trap catches in treated plots by > 60% at trap catch peak. For BLM, there was a significant reduction in the amount of visible damage in the push-pull treated areas compared to the control in the first two assessments. There was also a significant reduction in monitoring trap catch in the treated areas.

In the Kent site, there was a significant difference in the amount of RCM eggs found in green shoot growth indicating the pest's preference for younger growth as an egg laying site.

Growers frequently remove the green spawn growth from the crop and this result supports that action.

In Norfolk there was no significant difference in the monitoring trap catches of BLM, however significantly more RCM midges caught in the monitoring traps in the control plots compared with the push-pull treated plots on 24 May 2021. There was no significant difference in BLM damage to shoots or leaves between the control and treated plots. This could be because the BLM population was too low to be significantly affected. The peak number of BLM caught at the Norfolk site was a mean of 2.7 midges, compared with a peak mean of 113 midges caught at the Kent site, where treatments were significantly effective.

In Norfolk RCM larvae and eggs were only found in splits made on 04/05/21, no larvae or eggs were found in splits made on 24/05/21 and only three individual eggs were found on 14/06/21. This suggests that there was a short window of up to four weeks for the majority of egg laying between the capture of the first males on 26/05/21 and the second cane splitting on 24/05/21. A few individuals will have continued to oviposit until 14/06/21 and potentially after this date.

In Norfolk there were significantly fewer RCM larvae found in control plots compared with push-pull treated plots on the second assessment (24 May 2021). This could suggest that the push-pull treatment facilitated mating of RCM when numbers of emerged midges were low by attracting males to the push-pull treated plots. On the same date there were significantly more midges caught in monitoring traps in the control plots suggesting that male midges were more abundant in the control plots. It is difficult to draw conclusions on the efficacy of the trial based on this result as the numbers of larvae recorded were very low. No RCM larvae were found on the first and third assessments and there was no significant difference between treatments on the fourth assessment. More research is required to determine whether a semiochemical push-pull technique can reduce or increase damage caused by raspberry cane midge larvae.

The roller trap assessments recorded the most RCM and BLM landing between the RCM and BLM lure, i.e. one metre from the lures instead of adjacent to them. This could suggest that the midges are caught on the traps when attracted near to their pheromone lures rather than directly on top of them. Therefore, it is likely to be beneficial to use a large trap for this purpose, such as a roller trap instead of a small trap such as a hanging sticky trap. The roller trap assessments were not statistically analysed and more work is required to draw further conclusions.

## Knowledge and Technology Transfer

2020

AHDB Soft Fruit Day, Technical Webinar on Soft Fruit Research, Thursday 18 November 202

- The use of floral margins to support natural enemies in strawberry, (Celine Silva, NIAB EMR)
- A novel push/pull approach to capsid control in strawberry (Adam Walker, NIAB EMR)
- Novel approaches to thrips control in strawberry (Peter Seymour, ADAS)

Fountain - 30 Jan 20 Herefordshire Hop Discussion Group, Plough Inn, Stoke Lacy, Herefordshire TTSM, floral interventions, capsid control

Fountain - 06 Feb 20 HSE Chemicals Regulation Division (CRD) to NIAB EMR

Overview of R&D on novel crop protection products

Fountain - 29 Jul 20 Katrina Hayer's visit BBSRC – Entomology research at NIAB EMR

Fountain - 9 Sep 20 Fruit Focus – Enhancing beneficial insect in orchards

2021

Mozūraitis R, Hall D, Trandem N, Ralle B, Sigsgaard L, Baroffio C, Fountain MT, Cross JV, Wibe A, Borg-Karlson A-K (2021) Composition of Strawberry Floral Volatiles and their Effects on Behavior of Strawberry Blossom Weevil, Anthonomus rubi. Journal of Chemical Ecology, 46:1069–1081.

Fountain MT, Deakin G, Farman D, Hall D, Jay C, Shaw B, Walker A (2021) An effective “push-pull” control strategy for European tarnished plant bug, Lygus rugulipennis (Heteroptera: Miridae), in strawberry using synthetic semiochemicals. Pest Management Science. DOI 10.1002/ps.6303

Fountain, M.T. Impacts of Wildflower Interventions on Beneficial Insects in Fruit Crops: A Review. Insects 2022, 13, 304.

NIAB EMR Soft Fruit Day - Technical Webinar on Soft Fruit Research, Tuesday 16 November 2021

- The use of Orius as a predator for capsid bugs (Michelle Fountain, NIAB EMR)
- Push/pull strategies for midge control in cane fruit (Elysia Bartel, ADAS)
- A push/pull approach to control of thrips in strawberry (Peter Seymour, ADAS)
- The use of floral margins to harbour predators of thrips and other pests (Celine Silva, NIAB EMR)
- New approaches to aphid control (Ross George, Harper Adams University)

Jude Bennison gave a presentation on the aims and preliminary results of the thrips trials at the International Symposium on Thysanoptera in 2021 and the Nordic Berry Conference in January 2022.

Fountain 07 Apr 21 Worshipful Company of Fruiterers - Innovations in fruit pest control and how WCoF kick-started recent pollination research at NIAB EMR

Fountain, Raffle 29 Apr 21 AHDB Horticulture - New IPM approaches to aphid and capsid control in strawberry

Fountain 1-5 May 21 IX International Strawberry Symposium Rimini (Italy) - Synthetic push-pull strategy for controlling capsids in commercial strawberry

Fountain 26 May 21 BIFGA Cryals Farm, Matfield, Kent TN12 7HN - Pollinator Identification Guides and Records plus How to Successfully Establish Perennial Wildflower Areas

Fountain, Silva Jul 21 Fruit Focus – Follow the Bees

## Acknowledgements

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## Appendix 2.2.1.

Grower spray record for the blocks where the capsid repellent trial took place, summer 2021.

Block1:

| | | |
|---|---|---|
| **Potassium hydrogen carbonate** | 1.00 ha | 7.000 kg/ha |
| **Wetcit** | 1.00 ha | 1.000 L/ha |

Reference: Plan 00082 Hill Farm Fung + Foliar Job 5 Issued by: Kate (09/06/2021)
Job reason: Mildew prevention/control
Botrytis prevention/control
Nutrition
Target growth stage: 89: Most fruits coloured
Job Harvest Interval: 03 Days 00 Hours
**Finish: 12/06/2021 15:30**
*Implement: HOP 1, Volume rate: 1000.000 L*

| | | |
|---|---|---|
| **Stroby WG (17316)** | 1.00 ha | 0.300 kg/ha |

MAPP:17316, Harvest interval:03 Days 00 Hours, Active Ingredients:Kresoxim-methyl, Manufacturer:BASF plc., Expires:30/06/2027

| | | |
|---|---|---|
| **Serifel (19236)** | 1.00 ha | 0.500 kg/ha |

MAPP:19236, Active Ingredients:Bacillus amyloliquefaciens strain MBI 600, Manufacturer:BASF plc., Expires:10/10/2023

| | | |
|---|---|---|
| **Maxicrop Concentrate** | 1.00 ha | 1.300 L/ha |
| **Biochel CA** | 1.00 ha | 1.500 L/ha |

Reference: Plan 00087 Murano Mildew Control Job 7 Issued by: Kate (11/06/2021)
Job reason: Mildew prevention/control
Target growth stage: Harvest
**Finish: 13/06/2021 07:00**
*Implement: HOP 1, Volume rate: 1000.000 L*

| | | |
|---|---|---|
| **Potassium hydrogen carbonate** | 1.00 ha | 7.000 kg/ha |
| **Wetcit** | 1.00 ha | 1.000 L/ha |

Reference: Plan 00098 Hill farm Fung + Foliar Job 5 Issued by: Kate (17/06/2021)
Job reason: Mildew prevention/control
Botrytis prevention/control
Nutrition
Target growth stage: 89: Most fruits coloured
Job Harvest Interval: 03 Days 00 Hours
**Finish: 20/06/2021 12:00**
*Implement: HOP 1, Volume rate: 1000.000 L*

| | | |
|---|---|---|
| **Justice (12835)** | 1.00 ha | 0.190 L/ha |

MAPP:12835, Harvest interval:03 Days 00 Hours, Active Ingredients:Proquinazid, Manufacturer:DuPont (UK) Ltd., EAMU:2436/17, Expires:31/01/2025

| | | |
|---|---|---|
| **Amylo X WG (17978)** | 1.00 ha | 2.500 kg/ha |

MAPP:17978, Active Ingredients:Bacillus amyloliquefaciens subsp. plantarum strain, Manufacturer:Certis, EAMU:0469/18, Expires:30/09/2027

| | | |
|---|---|---|
| **Maxicrop Concentrate** | 1.00 ha | 1.300 L/ha |
| **Biochel CA** | 1.00 ha | 1.500 L/ha |

Reference: Plan 00092 Murano Mildew control Job 7 Issued by: Kate (15/06/2021)
Job reason: Mildew prevention/control
Target growth stage: Harvest
**Finish: 21/06/2021 08:00**
*Implement: HOP 1, Volume rate: 1000.000 L*

| | | |
|---|---|---|
| **Potassium hydrogen carbonate** | 1.00 ha | 7.000 kg/ha |
| **Wetcit** | 1.00 ha | 1.000 L/ha |

Reference: Plan 00102 Murano Mildew Control Job 15 Issued by: Kate (21/06/2021)
Job reason: Mildew prevention/control
Target growth stage: Harvest
**Finish: 25/06/2021 09:00**
*Implement: HOP 1, Volume rate: 1000.000 L*

| | | |
|---|---|---|
| **Potassium hydrogen carbonate** | 1.00 ha | 7.000 kg/ha |
| **Wetcit** | 1.00 ha | 1.000 L/ha |

Reference: Plan 00109 Hill Farm Fung + Foliar Job 5 Issued by: Kate (23/06/2021)
Job reason: Mildew prevention/control
Botrytis prevention/control
Nutrition
Target growth stage: 87: Fruit ready to pick

 

Job Harvest Interval: 01 Days 00 Hours

**Finish: 28/06/2021 17:30**

*Implement: HOP 1, Volume rate: 1000.000 L*

| | | |
|---|---|---|
| **Luna Sensation (15793)** | 1.00 ha | 0.800 L/ha |

MAPP:15793, Harvest interval:01 Days 00 Hours, Active Ingredients:Fluopyram, Trifloxystrobin, Manufacturer:Bayer CropScience Limited

| | | |
|---|---|---|
| **Serenade ASO (16139)** | 1.00 ha | 5.000 L/ha |

MAPP:16139, Active Ingredients:Bacillus subtilis strain QST 713, Manufacturer:Bayer CropScience Limited, Expires:31/10/2024

| | | |
|---|---|---|
| **Maxicrop Concentrate** | 1.00 ha | 1.300 L/ha |
| **Biochel CA** | 1.00 ha | 1.500 L/ha |

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Reference: Plan 00114 Murano Mildew Control Job 3 Issued by: Kate (28/06/2021)

Job reason: Mildew prevention/control

Target growth stage: Harvest

**Finish: 29/06/2021 10:00**

*Implement: HOP 1, Volume rate: 1000.000 L*

| | | |
|---|---|---|
| **Potassium hydrogen carbonate** | 1.00 ha | 10.000 kg/ha |
| **Wetcit** | 1.00 ha | 1.000 L/ha |

---

Reference: Plan 00124 Murano Mildew Control Job 9 Issued by: Kate (30/06/2021)

Job reason: Mildew prevention/control

Target growth stage: Harvest

**Finish: 02/07/2021 07:00**

*Implement: HOP 1, Volume rate: 1000.000 L*

| | | |
|---|---|---|
| **Potassium hydrogen carbonate** | 1.00 ha | 10.000 kg/ha |
| **Wetcit** | 1.00 ha | 1.000 L/ha |

---

Reference: Plan 00123 Hill Farm Fung + Foliar Job 5 Issued by: Kate (02/07/2021)

Job reason: Mildew prevention/control
Botrytis prevention/control
Nutrition

Target growth stage: 89: Most fruits coloured

Job Harvest Interval: 01 Days 00 Hours

**Finish: 07/07/2021 11:00**

*Implement: HOP 1, Volume rate: 1000.000 L*

| | | |
|---|---|---|
| **Charm (18396)** | 1.00 ha | 0.600 L/ha |

MAPP:18396, Harvest interval:01 Days 00 Hours, Active Ingredients:Fluxapyroxad, Difenoconazole, Manufacturer:BASF plc., Expires:30/06/2025

| | | |
|---|---|---|
| **Serifel (19236)** | 1.00 ha | 0.500 kg/ha |

MAPP:19236, Active Ingredients:Bacillus amyloliquefaciens strain MBI 600, Manufacturer:BASF plc., Expires:10/10/2023

| | | |
|---|---|---|
| **Maxicrop Concentrate** | 1.00 ha | 1.300 L/ha |
| **Biochel CA** | 1.00 ha | 1.500 L/ha |

---

Reference: Plan 00133 Murano Mildew Control Job 4 Issued by: Kate (07/07/2021)

Job reason: Mildew prevention/control

Target growth stage: Harvest

**Finish: 10/07/2021 15:00**

*Implement: HOP 1, Volume rate: 1000.000 L*

| | | |
|---|---|---|
| **Potassium hydrogen carbonate** | 1.00 ha | 10.000 kg/ha |
| **Wetcit** | 1.00 ha | 1.000 L/ha |

---

Reference: Plan 00137 Hill Farm Fung + Foliar Job 5 Issued by: Kate (08/07/2021)

Job reason: Mildew prevention/control
Botrytis prevention/control
Nutrition

Target growth stage: 89: Most fruits coloured

Job Harvest Interval: 03 Days 00 Hours

**Finish: 14/07/2021 09:55**

*Implement: HOP 1, Volume rate: 1000.000 L*

| | | |
|---|---|---|
| **Systhane 20 EW (19160)** | 1.00 ha | 0.300 L/ha |

MAPP:19160, Harvest interval:03 Days 00 Hours, Active Ingredients:Myclobutanil, Manufacturer:Landseer Ltd., Expires:30/11/2022

| | | |
|---|---|---|
| **Amylo X WG (17978)** | 1.00 ha | 2.500 kg/ha |

MAPP:17978, Active Ingredients:Bacillus amyloliquefaciens subsp. plantarum strain, Manufacturer:Certis, EAMU:0469/18, Expires:30/09/2027

 

| | | |
|---|---|---|
| **Maxicrop Concentrate** | 1.00 ha | 1.300 L/ha |
| **Biochel CA** | 1.00 ha | 1.500 L/ha |

Reference: Plan 00139 Murano Mildew Control Job 4 Issued by: Kate (12/07/2021)
Job reason: Mildew prevention/control
Target growth stage: Harvest
**Finish: 15/07/2021 13:20**
*Implement: HOP 1, Volume rate: 1000.000 L*

| | | |
|---|---|---|
| **Potassium hydrogen carbonate** | 1.00 ha | 10.000 kg/ha |
| **Wetcit** | 1.00 ha | 1.000 L/ha |

Reference: Plan 00149 Murano Mildew Control Job 3 Issued by: Kate (16/07/2021)
Job reason: Mildew prevention/control
Target growth stage: Harvest
**Finish: 20/07/2021 06:15**
*Implement: HOP 1, Volume rate: 1000.000 L*

| | | |
|---|---|---|
| **Potassium hydrogen carbonate** | 1.00 ha | 10.000 kg/ha |
| **Wetcit** | 1.00 ha | 1.000 L/ha |

Reference: Plan 00150 Hill Farm Fung + Foliar Job 5 Issued by: Kate (19/07/2021)
Job reason: Mildew prevention/control
Botrytis prevention/control
Nutrition
Target growth stage: Harvest
Job Harvest Interval: 03 Days 00 Hours
**Finish: 22/07/2021 15:00**
*Implement: HOP 1, Volume rate: 1000.000 L*

| | | |
|---|---|---|
| **Pan Penco (18180)** | 1.00 ha | 0.500 L/ha |

MAPP:18180, Harvest interval:03 Days 00 Hours, Active Ingredients:Penconazole, Manufacturer:Pan Agriculture Ltd., Expires:30/06/2024

| | | |
|---|---|---|
| **Teldor (11229)** | 1.00 ha | 1.000 kg/ha |

MAPP:11229, Harvest interval:01 Days 00 Hours, Active Ingredients:Fenhexamid, Manufacturer:Bayer CropScience Limited

| | | |
|---|---|---|
| **Maxicrop Concentrate** | 1.00 ha | 1.300 L/ha |
| **Biochel CA** | 1.00 ha | 1.500 L/ha |

Reference: Plan 00152 Murano Mildew Control Job 3 Issued by: Kate (20/07/2021)
Job reason: Mildew prevention/control
Target growth stage: Harvest
**Finish: 23/07/2021 17:10**
*Implement: HOP 1, Volume rate: 1000.000 L*

| | | |
|---|---|---|
| **Potassium hydrogen carbonate** | 1.00 ha | 10.000 kg/ha |
| **Wetcit** | 1.00 ha | 1.000 L/ha |

Reference: Plan 00160 Hill Farm Fung + Foliar Job 5 Issued by: Kate (27/07/2021)
Job reason: Mildew prevention/control
Botrytis prevention/control
Nutrition
Target growth stage: 87: Fruit ready to pick
Job Harvest Interval: 03 Days 00 Hours
**Finish: 30/07/2021 16:20**
*Implement: HOP 1, Volume rate: 1000.000 L*

| | | |
|---|---|---|
| **Azoxystar (17407)** | 1.00 ha | 1.000 L/ha |

MAPP:17407, Harvest interval:03 Days 00 Hours, Active Ingredients:Azoxystrobin, Manufacturer:Life Scientific Limited, Expires:30/06/2027

| | | |
|---|---|---|
| **Serenade ASO (16139)** | 1.00 ha | 5.000 L/ha |

MAPP:16139, Active Ingredients:Bacillus subtilis strain QST 713, Manufacturer:Bayer CropScience Limited, Expires:31/10/2024

| | | |
|---|---|---|
| **Maxicrop Concentrate** | 1.00 ha | 1.300 L/ha |
| **Biochel CA** | 1.00 ha | 1.500 L/ha |

Reference: Plan 00170 Hill Farm Insect + Fung + Foliar Job 5 Issued by: Kate (03/08/2021)
Job reason: SWD control
Mildew prevention/control
Botrytis prevention/control
Nutrition
Target growth stage: 89: Most fruits coloured

 

Block 2:

| 1<br>Recommendation number | 2<br>Product | 3<br>Date and time *chemical/plant protection product application finished* | 4<br>Harvest interval (days) | 5<br>First Available harvest date and time | 6<br>Actual harvest date and time |
|---|---|---|---|---|---|
| AK Spray No 11 | AMISTAR TOP | 20.05.2021 11:10-12:45 | 3 | 23.05.2021 - 12:46 | 24.05.2021 - 05:30 |
| AK Spray No 11 | NORTRACE PITSTOP | 20.05.2021 11:10-12:45 | 0 | 20.05.2021 - 12:46 | 24.05.2021 - 05:30 |
| AK Spray No 12 | LUNA SENSATION | 25.05.2021 12:25-14:00 | 1 | 26.05.2021 - 14:01 | 27.05.2021 - 05:30 |
| AK Spray No 13 | AMYLO X WG | 03.06.2021 06:00-07:35 | 0 | 03.06.2021 - 07:36 | 05.06.2021 - 05:00 |
| AK Spray No 13 | NORTRACE PITSTOP | 03.06.2021 06:00-07:35 | 0 | 03.06.2021 - 07:36 | 05.06.2021 - 05:00 |
| AK Spray No 14 | CHARM | 09.06.2021 06:00-07:35 | 1 | 10.06.2021 - 07:36 | 11.06.2021 - 05:00 |
| AK Spray No 14 | NORTRACE PITSTOP | 09.06.2021 06:00-07:35 | 0 | 09.06.2021 - 07:36 | 11.06.2021 - 05:00 |
| AK Spray No 15 | AMYLO X WG | 16.06.2021 07:35-09:10 | 0 | 16.06.2021 - 09:11 | 17.06.2021 - 05:00 |
| AK Spray No 16 | LUNA SENSATION | 21.06.2021 06:10-07:45 | 1 | 22.06.2021 - 07:46 | 23.06.2021 - 05:00 |
| AK Spray No 17 | CHARM | 01.07.2021 05:00-06:35 | 1 | 02.07.2021 - 06:36 | 03.07.2021 - 05:00 |
| AK Spray No 18 | CHARM | 07.07.2021 07:00-08:35 | 1 | 08.07.2021 - 08:36 | 09.07.2021 - 05:00 |
| AK Spray No 19 | ROBIN | 13.07.2021 12:25-14:05 | 1 | 14.07.2021 - 14:06 | 15.07.2021 - 05:00 |
| AK Spray No 20 | NATURALIS-L | 18.07.2021 17:00-18:40 | 0 | 18.07.2021 - 18:41 | 18.07.2021 - 05:00 |
| AK Spray No 20 | AMYLO X WG | 22.07.2021 05:00-06:40 | 0 | 22.07.2021 - 06:41 | 24.07.2021 - 05:30 |
| AK Spray No 23 | COMBI-PROTECT | 31.07.2021 06:00-07:35 | 0 | 31.07.2021 - 07:36 | 02.08.2021 - 05:30 |
| AK Spray No 23 | BENEVIA 10OD | 31.07.2021 06:00-07:35 | 1 | 01.08.2021 - 07:36 | 02.08.2021 - 05:30 |

| 1<br>Recommendation number | 2<br>Product | 3<br>Date and time *chemical/plant protection product application finished* | 4<br>Harvest interval (days) | 5<br>First Available harvest date and time | 6<br>Actual harvest date and time |
|---|---|---|---|---|---|
| AK Spray No 24 | AMYLO X WG | 04.08.2021 09:30-11:05 | 0 | 04.08.2021 - 11:06 | 05.08.2021 - 05:30 |
| AK Spray No 25 | AMYLO X WG | 12.08.2021 08:30-10:05 | 0 | 12.08.2021 - 10:06 | 14.08.2021 - 05:30 |
| AK Spray No 27 | AMYLO X WG | 18.08.2021 07:35-09:10 | 0 | 18.08.2021 - 09:11 | 20.08.2021 - 05:30 |
| AK Spray No 27 | OMEX CALMAX ULTRA | 18.08.2021 07:35-09:10 | 0 | 18.08.2021 - 09:11 | 20.08.2021 - 05:30 |
| AK Spray No 29 | TELDOR | 24.08.2021 10:40-12:15 | 1 | 25.08.2021 - 12:16 | 26.08.2021 - 05:30 |
| AK Spray No 29 | NORTRACE PITSTOP | 24.08.2021 10:40-12:15 | 0 | 24.08.2021 - 12:16 | 26.08.2021 - 05:30 |

 

Block 3:

| 1<br>Recommendation number | 2<br>Product | 3<br>Date and time *chemical/plant protection product application finished* | 4<br>Harvest interval (days) | 5<br>First Available harvest date and time | 6<br>Actual harvest date and time |
|---|---|---|---|---|---|
| AK Spray No 11 | AMISTAR TOP | 21.05.2021 06:00-06:50 | 3 | 24.05.2021 - 06:51 | 10.06.2021 - 05:00 |
| AK Spray No 11 | NORTRACE PITSTOP | 21.05.2021 06:00-06:50 | 0 | 21.05.2021 - 06:51 | 10.06.2021 - 05:00 |
| AK Spray No 12 | LUNA SENSATION | 26.05.2021 13:00-13:50 | 1 | 27.05.2021 - 13:51 | 10.06.2021 - 05:00 |
| AK Spray No 13 | AMYLO X WG | 03.06.2021 07:40-08:30 | 0 | 03.06.2021 - 08:31 | 10.06.2021 - 05:00 |
| AK Spray No 13 | NORTRACE PITSTOP | 03.06.2021 07:40-08:30 | 0 | 03.06.2021 - 08:31 | 10.06.2021 - 05:00 |
| AK Spray No 14 | CHARM | 11.06.2021 08:30-09:20 | 1 | 12.06.2021 - 09:21 | 13.06.2021 - 05:00 |
| AK Spray No 14 | NORTRACE PITSTOP | 11.06.2021 08:30-09:20 | 0 | 11.06.2021 - 09:21 | 13.06.2021 - 05:00 |
| AK Spray No 15 | AMYLO X WG | 17.06.2021 07:30-08:20 | 0 | 17.06.2021 - 08:21 | 19.06.2021 - 05:00 |
| AK Spray No 16 | LUNA SENSATION | 20.06.2021 07:40-08:30 | 1 | 21.06.2021 - 08:31 | 22.06.2021 - 05:00 |
| AK Spray No 17 | CHARM | 29.06.2021 11:10-12:00 | 1 | 30.06.2021 - 12:01 | 02.07.2021 - 05:00 |
| AK Spray No 18 | CHARM | 09.07.2021 07:30-08:20 | 1 | 10.07.2021 - 08:21 | 11.07.2021 - 05:00 |
| AK Spray No 19 | ROBIN | 15.07.2021 07:25-08:15 | 1 | 16.07.2021 - 08:16 | 17.07.2021 - 05:00 |
| AK Spray No 20 | AMYLO X WG | 21.07.2021 07:25-08:15 | 0 | 21.07.2021 - 08:16 | 23.07.2021 - 05:00 |
| AK Spray No 23 | COMBI-PROTECT | 02.08.2021 08:35-09:25 | 0 | 02.08.2021 - 09:26 | 04.08.2021 - 05:30 |
| AK Spray No 23 | BENEVIA 10OD | 02.08.2021 08:35-09:25 | 1 | 03.08.2021 - 09:26 | 04.08.2021 - 05:30 |
| AK Spray No 24 | AMYLO X WG | 05.08.2021 07:00-07:50 | 0 | 05.08.2021 - 07:51 | 07.08.2021 - 05:30 |

| 1<br>Recommendation number | 2<br>Product | 3<br>Date and time *chemical/plant protection product application finished* | 4<br>Harvest interval (days) | 5<br>First Available harvest date and time | 6<br>Actual harvest date and time |
|---|---|---|---|---|---|
| AK Spray No 25 | AMYLO X WG | 12.08.2021 13:30-14:20 | 0 | 12.08.2021 - 14:21 | 13.08.2021 - 05:30 |
| AK Spray No 27 | AMYLO X WG | 18.08.2021 06:00-06:50 | 0 | 18.08.2021 - 06:51 | 19.08.2021 - 05:30 |
| AK Spray No 27 | OMEX CALMAX ULTRA | 18.08.2021 06:00-06:50 | 0 | 18.08.2021 - 06:51 | 19.08.2021 - 05:30 |
| AK Spray No 29 | TELDOR | 26.08.2021 08:30-09:20 | 1 | 27.08.2021 - 09:21 | 28.08.2021 - 05:30 |
| AK Spray No 29 | NORTRACE PITSTOP | 26.08.2021 08:30-09:20 | 0 | 26.08.2021 - 09:21 | 28.08.2021 - 05:30 |

 

| 1<br>Recommendation number | 2<br>Product | 3<br>Date and time *chemical/plant protection product application finished* | 4<br>Harvest interval (days) | 5<br>First Available harvest date and time | 6<br>Actual harvest date and time |
|---|---|---|---|---|---|
| AK Spray No 11 | AMISTAR TOP | 21.05.2021 07:35-08:25 | 3 | 24.05.2021 - 08:26 | 09.06.2021 - 05:00 |
| AK Spray No 11 | NORTRACE PITSTOP | 21.05.2021 07:35-08:25 | 0 | 21.05.2021 - 08:26 | 09.06.2021 - 05:00 |
| AK Spray No 12 | LUNA SENSATION | 26.05.2021 14:35-15:30 | 1 | 27.05.2021 - 15:31 | 09.06.2021 - 05:00 |
| AK Spray No 13 | AMYLO X WG | 03.06.2021 09:15-09:55 | 0 | 03.06.2021 - 09:56 | 09.06.2021 - 05:00 |
| AK Spray No 13 | NORTRACE PITSTOP | 03.06.2021 09:15-09:55 | 0 | 03.06.2021 - 09:56 | 09.06.2021 - 05:00 |
| AK Spray No 14 | CHARM | 10.06.2021 09:40-10:30 | 1 | 11.06.2021 - 10:31 | 12.06.2021 - 05:00 |
| AK Spray No 14 | NORTRACE PITSTOP | 10.06.2021 09:40-10:30 | 0 | 10.06.2021 - 10:31 | 12.06.2021 - 05:00 |
| AK Spray No 15 | AMYLO X WG | 17.06.2021 09:00-09:50 | 0 | 17.06.2021 - 09:51 | 18.06.2021 - 05:00 |
| AK Spray No 16 | LUNA SENSATION | 21.06.2021 14:30-15:15 | 1 | 22.06.2021 - 15:16 | 21.06.2021 - 05:00 |
| AK Spray No 17 | CHARM | 29.06.2021 12:45-13:35 | 1 | 30.06.2021 - 13:36 | 01.07.2021 - 05:00 |
| AK Spray No 18 | CHARM | 08.07.2021 08:40-09:30 | 1 | 09.07.2021 - 09:31 | 10.07.2021 - 05:00 |
| AK Spray No 19 | ROBIN | 14.07.2021 08:35-09:25 | 1 | 15.07.2021 - 09:26 | 16.07.2021 - 05:00 |
| AK Spray No 20 | AMYLO X WG | 20.07.2021 13:35-14:25 | 0 | 20.07.2021 - 14:26 | 22.07.2021 - 05:00 |
| AK Spray No 23 | COMBI-PROTECT | 01.08.2021 09:45-10:35 | 0 | 02.08.2021 - 10:36 | 03.05.2021 - 05:30 |
| AK Spray No 23 | BENEVIA 10OD | 01.08.2021 09:45-10:35 | 1 | 02.08.2021 - 10:36 | 03.05.2021 - 05:30 |
| AK Spray No 24 | AMYLO X WG | 05.08.2021 08:35-09:25 | 0 | 05.08.2021 - 09:26 | 09.05.2021 - 05:30 |

| 1<br>Recommendation number | 2<br>Product | 3<br>Date and time *chemical/plant protection product application finished* | 4<br>Harvest interval (days) | 5<br>First Available harvest date and time | 6<br>Actual harvest date and time |
|---|---|---|---|---|---|
| AK Spray No 25 | AMYLO X WG | 11.08.2021 12:45-13:35 | 0 | 11.08.2021 - 13:36 | 12.05.2021 - 05:30 |
| AK Spray No 27 | AMYLO X WG | 17.08.2021 15:10-16:00 | 0 | 17.08.2021 - 16:01 | 18.05.2021 - 05:30 |
| AK Spray No 27 | OMEX CALMAX ULTRA | 17.08.2021 15:10-16:00 | 0 | 17.08.2021 - 16:01 | 18.05.2021 - 05:30 |
| AK Spray No 29 | TELDOR | 25.08.2021 09:40-10:30 | 1 | 26.08.2021 - 10:31 | 27.05.2021 - 05:30 |
| AK Spray No 29 | NORTRACE PITSTOP | 25.08.2021 09:40-10:30 | 0 | 25.08.2021 - 10:31 | 27.05.2021 - 05:30 |

 

Block 4:

| 1<br>Recommendation number | 2<br>Product | 3<br>Date and time *chemical/plant protection product application finished* | | 4<br>Harvest interval (days) | 5<br>First Available harvest date and time | 6<br>Actual harvest date and time |
|---|---|---|---|---|---|---|
| AK Spray No 11 | AMISTAR TOP | 19.05.2021 | 11:40-12:50 | 3 | 22.05.2021 - 12:51 | 25.05.2021 - 05:30 |
| AK Spray No 11 | NORTRACE PITSTOP | 19.05.2021 | 11:40-12:50 | 0 | 19.05.2021 - 12:51 | 25.05.2021 - 05:30 |
| AK Spray No 12 | LUNA SENSATION | 26.05.2021 | 07:20-08:35 | 1 | 27.05.2021 - 08:36 | 28.05.2021 - 05:30 |
| AK Spray No 13 | AMYLO X WG | 02.06.2021 | 08:40-09:55 | 0 | 02.06.2021 - 09:56 | 03.06.2021 -05:00 |
| AK Spray No 13 | NORTRACE PITSTOP | 02.06.2021 | 08:40-09:55 | 0 | 02.06.2021 - 09:56 | 03.06.2021 -05:00 |
| AK Spray No 14 | CHARM | 10.06.2021 | 07:20-08:35 | 1 | 11.06.2021 - 08:36 | 12.06.2021 -05:00 |
| AK Spray No 14 | NORTRACE PITSTOP | 10.06.2021 | 07:20-08:35 | 0 | 10.06.2021 - 08:36 | 12.06.2021 -05:00 |
| AK Spray No 15 | AMYLO X WG | 16.06.2021 | 06:20-07:35 | 0 | 16.06.2021 - 07:36 | 18.06.2021 -05:00 |
| AK Spray No 16 | LUNA SENSATION | 21.06.2021 | 12:00-13:15 | 1 | 22.06.2021 - 13:16 | 21.06.2021 - 05:00 |
| AK Spray No 17 | CHARM | 29.06.2021 | 07:40-08:55 | 1 | 30.06.2021 - 08:56 | 01.07.2021 - 05:00 |
| AK Spray No 18 | CHARM | 08.07.2021 | 06:20-07:35 | 1 | 09.07.2021 - 07:36 | 10.07.2021 - 05:00 |
| AK Spray No 19 | ROBIN | 14.07.2021 | 06:20-07:30 | 1 | 15.07.2021 - 07:31 | 16.07.2021 - 05:00 |
| AK Spray No 20 | AMYLO X WG | 20.07.2021 | 12:20-13:30 | 0 | 20.07.2021 - 13:31 | 22.07.2021 - 05:00 |
| AK Spray No 23 | COMBI-PROTECT | 01.08.2021 | 07:20-08:35 | 0 | 01.08.2021 - 08:36 | 03.08.2021 - 05:30 |
| AK Spray No 23 | BENEVIA 10OD | 01.08.2021 | 07:20-08:35 | 1 | 02.08.2021 - 08:36 | 03.08.2021 - 05:30 |
| AK Spray No 24 | AMYLO X WG | 05.08.2021 | 12:10-13:25 | 0 | 05.08.2021 - 13:26 | 06.08.2021 - 05:30 |

| 1<br>Recommendation number | 2<br>Product | 3<br>Date and time *chemical/plant protection product application finished* | | 4<br>Harvest interval (days) | 5<br>First Available harvest date and time | 6<br>Actual harvest date and time |
|---|---|---|---|---|---|---|
| AK Spray No 25 | AMYLO X WG | 11.08.2021 | 10:30-11:45 | 0 | 11.08.2021 - 11:46 | 12.08.2021 - 05:30 |
| AK Spray No 27 | AMYLO X WG | 17.08.2021 | 11:45-12:55 | 0 | 17.08.2021 - 12:56 | 18.08.2021 - 05:30 |
| AK Spray No 27 | OMEX CALMAX ULTRA | 17.08.2021 | 11:45-12:55 | 0 | 17.08.2021 - 12:56 | 18.08.2021 - 05:30 |
| AK Spray No 29 | TELDOR | 25.08.2021 | 07:20-08:35 | 1 | 26.08.2021 - 08:36 | 27.08.2021 - 05:30 |
| AK Spray No 29 | NORTRACE PITSTOP | 25.08.2021 | 07:20-08:35 | 0 | 25.08.2021 - 08:36 | 27.08.2021 - 05:30 |

 

| 1<br>Recommendation number | 2<br>Product | 3<br>Date and time *chemical/plant protection product application finished* | | 4<br>Harvest interval (days) | 5<br>First Available harvest date and time | 6<br>Actual harvest date and time |
|---|---|---|---|---|---|---|
| AK Spray No 11 | AMISTAR TOP | 17.05.2021 | 06:00-07:05 | 3 | 20.05.2021 - 07:06 | 21.05.2021 - 05:30 |
| AK Spray No 11 | NORTRACE PITSTOP | 17.05.2021 | 06:00-07:05 | 0 | 17.05.2021 - 07:06 | 21.05.2021 - 05:30 |
| AK Spray No 12 | LUNA SENSATION | 27.05.2021 | 07:15-08:20 | 1 | 28.05.2021 - 08:21 | 29.05.2021 - 05:30 |
| AK Spray No 13 | AMYLO X WG | 02.06.2021 | 10:00-11:05 | 0 | 02.06.2021 - 11:06 | 04.06.2021 - 05:00 |
| AK Spray No 13 | NORTRACE PITSTOP | 02.06.2021 | 10:00-11:05 | 0 | 02.06.2021 - 11:06 | 04.06.2021 - 05:00 |
| AK Spray No 14 | CHARM | 11.06.2021 | 07:20-08:25 | 1 | 12.06.2021 - 08:26 | 13.06.2021 - 05:00 |
| AK Spray No 14 | NORTRACE PITSTOP | 11.06.2021 | 07:20-08:25 | 0 | 11.06.2021 - 08:26 | 13.06.2021 - 05:00 |
| AK Spray No 15 | AMYLO X WG | 17.06.2021 | 06:20-07:25 | 0 | 17.06.2021 - 07:26 | 19.06.2021 - 05:00 |
| AK Spray No 16 | LUNA SENSATION | 21.06.2021 | 13:20-14:25 | 1 | 22.06.2021 - 14:26 | 21.06.2021 - 05:00 |
| AK Spray No 17 | CHARM | 29.06.2021 | 09:00-10:05 | 1 | 30.06.2021 - 10:06 | 02.06.2021 - 05:00 |
| AK Spray No 18 | CHARM | 09.07.2021 | 06:20-07:25 | 1 | 10.07.2021 - 07:26 | 11.07.2021 - 05:00 |
| AK Spray No 19 | ROBIN | 15.07.2021 | 06:15-07:20 | 1 | 16.07.2021 - 07:21 | 17.07.2021 - 05:00 |
| AK Spray No 20 | AMYLO X WG | 21.07.2021 | 06:15-07:20 | 0 | 21.07.2021 - 07:21 | 23.07.2021 - 05:00 |
| AK Spray No 23 | COMBI-PROTECT | 02.08.2021 | 07:20-08:30 | 0 | 02.08.2021 - 08:31 | 04.08.2021 - 05:30 |
| AK Spray No 23 | BENEVIA 10OD | 02.08.2021 | 07:20-08:30 | 1 | 03.08.2021 - 08:31 | 04.08.2021 - 05:30 |
| AK Spray No 24 | AMYLO X WG | 05.08.2021 | 13:30-14:35 | 0 | 05.08.2021 - 14:36 | 07.08.2021 - 05:30 |

| 1<br>Recommendation number | 2<br>Product | 3<br>Date and time *chemical/plant protection product application finished* | | 4<br>Harvest interval (days) | 5<br>First Available harvest date and time | 6<br>Actual harvest date and time |
|---|---|---|---|---|---|---|
| AK Spray No 25 | AMYLO X WG | 12.08.2021 | 07:20-08:25 | 0 | 12.08.2021 - 08:26 | 13.08.2021 - 05:30 |
| AK Spray No 27 | AMYLO X WG | 17.08.2021 | 13:00-14:05 | 0 | 17.08.2021 - 14:06 | 19.08.2021 - 05:30 |
| AK Spray No 27 | OMEX CALMAX ULTRA | 17.08.2021 | 13:00-14:05 | 0 | 17.08.2021 - 14:06 | 19.08.2021 - 05:30 |
| AK Spray No 29 | TELDOR | 26.08.2021 | 07:20-08:25 | 1 | 27.08.2021 - 08:26 | 28.08.2021 - 05:30 |
| AK Spray No 29 | NORTRACE PITSTOP | 26.08.2021 | 07:20-08:25 | 0 | 26.08.2021 - 08:26 | 28.08.2021 - 05:30 |

 

Block 5:

Job Harvest Interval: 03 Days 00 Hours

**Finish: 07/08/2021 14:00**

*Implement: HOP 1, Volume rate: 800.000 L*

| | | |
|---|---|---|
| **Benevia 10OD (99992)** | 1.00 ha | 0.750 L/ha |

MAPP:99992, Harvest interval:01 Days 00 Hours, Active Ingredients:Cyantraniliprole, Manufacturer:FMC Agro Limited, EAMU:1230/21, Expires:30/09/2021

| | | |
|---|---|---|
| **Takumi SC (16000)** | 1.00 ha | 0.150 L/ha |

MAPP:16000, Harvest interval:03 Days 00 Hours, Active Ingredients:Cyflufenamid, Manufacturer:Certis, EAMU:2055/16, Expires:30/09/2025

| | | |
|---|---|---|
| **Serifel (19236)** | 1.00 ha | 0.500 kg/ha |

MAPP:19236, Active Ingredients:Bacillus amyloliquefaciens strain MBI 600, Manufacturer:BASF plc., Expires:10/10/2023

| | | |
|---|---|---|
| **Maxicrop Concentrate** | 1.00 ha | 2.000 L/ha |
| **Biochel CA** | 1.00 ha | 1.500 L/ha |

Reference: Plan 00179 Hill Farm Insect + Fung + Foliar Job 5 Issued by: Kate (10/08/2021)

Job reason: SWD control
Mildew prevention/control
Botrytis prevention/control
Nutrition

Target growth stage: 89: Most fruits coloured

Job Harvest Interval: 01 Days 00 Hours

**Finish: 15/08/2021 13:50**

*Implement: HOP 1, Volume rate: 1000.000 L*

| | | |
|---|---|---|
| **Tracer (12438)** | 1.00 ha | 0.150 L/ha |

MAPP:12438, Harvest interval:01 Days 00 Hours, Active Ingredients:Spinosad, Manufacturer:Landseer Ltd., Expires:31/10/2024

| | | |
|---|---|---|
| **Amylo X WG (17978)** | 1.00 ha | 2.500 kg/ha |

MAPP:17978, Active Ingredients:Bacillus amyloliquefaciens subsp. plantarum strain, Manufacturer:Certis, EAMU:0469/18, Expires:30/09/2027

| | | |
|---|---|---|
| **Maxicrop Concentrate** | 1.00 ha | 1.300 L/ha |
| **Biochel CA** | 1.00 ha | 1.500 L/ha |

Reference: Plan 00187 Hill Farm Insect + Fung + Foliar Job 5 Issued by: Kate (19/08/2021)

Job reason: SWD control
Mildew prevention/control
Nutrition

Target growth stage: 89: Most fruits coloured

Job Harvest Interval: 03 Days 00 Hours

**Finish: 23/08/2021 13:40**

*Implement: HOP 1, Volume rate: 800.000 L*

| | | |
|---|---|---|
| **Benevia 10OD (99992)** | 1.00 ha | 0.750 L/ha |

MAPP:99992, Harvest interval:01 Days 00 Hours, Active Ingredients:Cyantraniliprole, Manufacturer:FMC Agro Limited, EAMU:1230/21, Expires:30/09/2021

| | | |
|---|---|---|
| **Nimrod (18522)** | 1.00 ha | 1.000 L/ha |

MAPP:18522, Harvest interval:03 Days 00 Hours, Active Ingredients:Bupirimate, Manufacturer:Adama Agricultural Solutions UK Ltd, Expires:28/02/2027

| | | |
|---|---|---|
| **Maxicrop Concentrate** | 1.00 ha | 1.300 L/ha |
| **Biochel CA** | 1.00 ha | 1.500 L/ha |

Reference: Plan 00196 Hill Farm Insect + Fung + Foliar Job 5 Issued by: Kate (27/08/2021)

Job reason: SWD control
Mildew prevention/control
Nutrition

Target growth stage: 89: Most fruits coloured

Inspected growth stage: 67: Late Flower, majority of petals fallen

Job Harvest Interval: 03 Days 00 Hours

**Finish: 31/08/2021 14:30**

*Implement: HOP 1, Volume rate: 1000.000 L*

| | | |
|---|---|---|
| **Tracer (12438)** | 1.00 ha | 0.150 L/ha |

MAPP:12438, Harvest interval:01 Days 00 Hours, Active Ingredients:Spinosad, Manufacturer:Landseer Ltd., Expires:31/10/2024

| | | |
|---|---|---|
| **Stroby WG (17316)** | 1.00 ha | 0.300 kg/ha |

MAPP:17316, Harvest interval:03 Days 00 Hours, Active Ingredients:Kresoxim-methyl, Manufacturer:BASF plc., Expires:30/06/2027

| | | |
|---|---|---|
| **Maxicrop Concentrate** | 1.00 ha | 1.300 L/ha |
| **Biochel CA** | 1.00 ha | 1.500 L/ha |

Reference: Plan 00204 Hill Farm Fung + Foliar Job 5 Issued by: Kate (02/09/2021)

 

Nutrition

Target growth stage: 67: Late Flower, majority of petals fallen

Job Harvest Interval: 03 Days 00 Hours

**Finish: 26/05/2021 13:45**

*Implement: HOP 1, Volume rate: 1000.000 L*

| | | |
|---|---|---|
| **Frupica SC (12067)** | 1.55 ha | 0.680 L/ha |
| MAPP:12067, Harvest interval:03 Days 00 Hours, Active Ingredients:Mepanipyrim, Manufacturer:Certis, Expires:31/10/2024 | | |
| **Maxicrop Concentrate** | 1.55 ha | 2.000 L/ha |
| **Headland complex** | 1.55 ha | 2.500 kg/ha |
| **Biochel CA** | 1.55 ha | 1.500 L/ha |

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Reference: Plan 00073 Arnold Farm Majestic Fung + Foliar Job 3 Issued by: Kate (03/06/2021)

Job reason: Mildew prevention/control
Botrytis prevention/control
Nutrition

Target growth stage: 89: Most fruits coloured

**Finish: 06/06/2021 15:00**

*Implement: HOP 1, Volume rate: 1000.000 L*

| | | |
|---|---|---|
| **Amylo X WG (17978)** | 1.55 ha | 2.500 kg/ha |
| MAPP:17978, Active Ingredients:Bacillus amyloliquefaciens subsp. plantarum strain, Manufacturer:Certis, EAMU:0469/18, Expires:30/09/2027 | | |
| **Maxicrop Concentrate** | 1.55 ha | 2.000 L/ha |
| **Biochel CA** | 1.55 ha | 1.500 L/ha |

---

Reference: Plan 00088 Arnold Majestic Fung + Foliar Job 3 Issued by: Kate (14/06/2021)

Job reason: Mildew prevention/control
Botrytis prevention/control
Nutrition

Target growth stage: 89: Most fruits coloured

Job Harvest Interval: 01 Days 00 Hours

**Finish: 17/06/2021 17:45**

*Implement: HOP 1, Volume rate: 1000.000 L*

| | | |
|---|---|---|
| **Luna Sensation (15793)** | 1.55 ha | 0.800 L/ha |
| MAPP:15793, Harvest interval:01 Days 00 Hours, Active Ingredients:Fluopyram, Trifloxystrobin, Manufacturer:Bayer CropScience Limited | | |
| **Serifel (19236)** | 1.55 ha | 0.500 kg/ha |
| MAPP:19236, Active Ingredients:Bacillus amyloliquefaciens strain MBI 600, Manufacturer:BASF plc., Expires:10/10/2023 | | |
| **Maxicrop Concentrate** | 1.55 ha | 1.300 L/ha |
| **Biochel CA** | 1.55 ha | 1.500 L/ha |

---

Reference: Plan 00100 Majestic Mildew Control Job 3 Issued by: Kate (17/06/2021)

Job reason: Mildew prevention/control

Target growth stage: Harvest

**Finish: 19/06/2021 13:45**

*Implement: HOP 1, Volume rate: 1000.000 L*

| | | |
|---|---|---|
| **Potassium hydrogen carbonate** | 1.55 ha | 7.000 kg/ha |
| **Wetcit** | 1.55 ha | 1.000 L/ha |
| **Maxicrop Concentrate** | 1.55 ha | 1.300 L/ha |

---

Reference: Plan 00103 Arnold Farm Majestic Fung + Foliar Job 3 Issued by: Kate (21/06/2021)

Job reason: Mildew prevention/control
Botrytis prevention/control
Nutrition

Target growth stage: 87: Fruit ready to pick

Job Harvest Interval: 03 Days 00 Hours

**Finish: 25/06/2021 13:15**

*Implement: HOP 1, Volume rate: 1000.000 L*

| | | |
|---|---|---|
| **Takumi SC (16000)** | 1.55 ha | 0.150 L/ha |
| MAPP:16000, Harvest interval:03 Days 00 Hours, Active Ingredients:Cyflufenamid, Manufacturer:Certis, EAMU:2055/16, Expires:30/09/2025 | | |
| **Serenade ASO (16139)** | 1.55 ha | 5.000 L/ha |
| MAPP:16139, Active Ingredients:Bacillus subtilis strain QST 713, Manufacturer:Bayer CropScience Limited, Expires:31/10/2024 | | |
| **Maxicrop Concentrate** | 1.55 ha | 1.300 L/ha |
| **Biochel CA** | 1.55 ha | 1.500 L/ha |

Reference: Plan 00105 Majestic Mildew Control Job 3 Issued by: Kate (22/06/2021)
Job reason: Mildew prevention/control
Target growth stage: Harvest
**Finish: 26/06/2021 09:15**
*Implement: HOP 1, Volume rate: 1000.000 L*

| | | |
|---|---|---|
| **Potassium hydrogen carbonate** | 1.55 ha | 7.000 kg/ha |
| **Wetcit** | 1.55 ha | 1.000 L/ha |
| **Maxicrop Concentrate** | 1.55 ha | 1.300 L/ha |

Reference: Plan 00112 Majestic Mildew Control Job 3 Issued by: Kate (23/06/2021)
Job reason: Mildew prevention/control
Target growth stage: Harvest
**Finish: 29/06/2021 12:00**
*Implement: HOP 1, Volume rate: 1000.000 L*

| | | |
|---|---|---|
| **Potassium hydrogen carbonate** | 1.55 ha | 10.000 kg/ha |
| **Wetcit** | 1.55 ha | 1.000 L/ha |
| **Maxicrop Concentrate** | 1.55 ha | 1.300 L/ha |

Reference: Plan 00115 Arnold Farm Majestic Fung + Foliar Job 3 Issued by: Kate (29/06/2021)
Job reason: Mildew prevention/control
Botrytis prevention/control
Nutrition
Target growth stage: 89: Most fruits coloured
Job Harvest Interval: 03 Days 00 Hours
**Finish: 03/07/2021 12:30**
*Implement: HOP 1, Volume rate: 1000.000 L*

| | | |
|---|---|---|
| **Justice (12835)** | 1.55 ha | 0.190 L/ha |

MAPP:12835, Harvest interval:03 Days 00 Hours, Active Ingredients:Proquinazid, Manufacturer:DuPont (UK) Ltd., EAMU:2436/17, Expires:31/01/2025

| | | |
|---|---|---|
| **Amylo X WG (17978)** | 1.55 ha | 2.500 kg/ha |

MAPP:17978, Active Ingredients:Bacillus amyloliquefaciens subsp. plantarum strain, Manufacturer:Certis, EAMU:0469/18, Expires:30/09/2027

| | | |
|---|---|---|
| **Maxicrop Concentrate** | 1.55 ha | 1.300 L/ha |
| **Biochel CA** | 1.55 ha | 1.500 L/ha |

Reference: Plan 00125 Majestic Mildew Control Job 3 Issued by: Kate (02/07/2021)
Job reason: Mildew prevention/control
Target growth stage: Harvest
Inspected growth stage: 67: Late Flower, majority of petals fallen
**Finish: 08/07/2021 07:00**
*Implement: HOP 1, Volume rate: 1000.000 L*

| | | |
|---|---|---|
| **Potassium hydrogen carbonate** | 1.55 ha | 10.000 kg/ha |
| **Wetcit** | 1.55 ha | 1.000 L/ha |
| **Maxicrop Concentrate** | 1.55 ha | 1.300 L/ha |

Reference: Plan 00130 Arnold Majestic Fung + Foliar Job 3 Issued by: Kate (06/07/2021)
Job reason: Mildew prevention/control
Botrytis prevention/control
Nutrition
Target growth stage: 89: Most fruits coloured
Job Harvest Interval: 03 Days 00 Hours
**Finish: 11/07/2021 16:20**
*Implement: HOP 1, Volume rate: 1000.000 L*

| | | |
|---|---|---|
| **Systhane 20 EW (19160)** | 1.55 ha | 0.300 L/ha |

MAPP:19160, Harvest interval:03 Days 00 Hours, Active Ingredients:Myclobutanil, Manufacturer:Landseer Ltd., Expires:30/11/2022

| | | |
|---|---|---|
| **Serifel (19236)** | 1.55 ha | 0.500 kg/ha |

MAPP:19236, Active Ingredients:Bacillus amyloliquefaciens strain MBI 600, Manufacturer:BASF plc., Expires:10/10/2023

| | | |
|---|---|---|
| **Maxicrop Concentrate** | 1.55 ha | 1.300 L/ha |
| **Biochel CA** | 1.55 ha | 1.500 L/ha |

Reference: Plan 00141 Majestic Mildew Control Job 3 Issued by: Kate (13/07/2021)
Job reason: Mildew prevention/control
Target growth stage: Harvest

**Finish: 16/07/2021 07:30**

*Implement: HOP 1, Volume rate: 1000.000 L*

| | | |
|---|---|---|
| **Potassium hydrogen carbonate** | 1.55 ha | 7.000 kg/ha |
| **Wetcit** | 1.55 ha | 1.000 L/ha |
| **Maxicrop Concentrate** | 1.55 ha | 1.300 L/ha |

Reference: Plan 00143 Arnold Majestic Fung + Foliar Job 3 Issued by: Kate (14/07/2021)
Job reason: Mildew prevention/control
Botrytis prevention/control
Nutrition
Target growth stage: Harvest
Job Harvest Interval: 01 Days 00 Hours

**Finish: 18/07/2021 10:30**

*Implement: HOP 1, Volume rate: 1000.000 L*

| | | |
|---|---|---|
| **Sonata (19161)** | 1.55 ha | 10.000 L/ha |

MAPP:19161, Harvest interval:01 Days 00 Hours, Active Ingredients:Bacillus Pumilus QST2808, Manufacturer:Bayer CropScience Limited, Expires:17/10/2023

| | | |
|---|---|---|
| **Teldor (11229)** | 1.55 ha | 1.000 kg/ha |

MAPP:11229, Harvest interval:01 Days 00 Hours, Active Ingredients:Fenhexamid, Manufacturer:Bayer CropScience Limited

| | | |
|---|---|---|
| **Maxicrop Concentrate** | 1.55 ha | 1.300 L/ha |
| **Biochel CA** | 1.55 ha | 1.500 L/ha |

Reference: Plan 00155 Arnold Majestic Fung + Foliar Job 3 Issued by: Kate (22/07/2021)
Job reason: Mildew prevention/control
Botrytis prevention/control
Nutrition
Target growth stage: 87: Fruit ready to pick
Job Harvest Interval: 01 Days 00 Hours

**Finish: 27/07/2021 10:30**

*Implement: HOP 1, Volume rate: 1000.000 L*

| | | |
|---|---|---|
| **Charm (18396)** | 1.55 ha | 0.600 L/ha |

MAPP:18396, Harvest interval:01 Days 00 Hours, Active Ingredients:Fluxapyroxad, Difenoconazole, Manufacturer:BASF plc., Expires:30/06/2024

| | | |
|---|---|---|
| **Serenade ASO (16139)** | 1.55 ha | 5.000 L/ha |

MAPP:16139, Active Ingredients:Bacillus subtilis strain QST 713, Manufacturer:Bayer CropScience Limited, Expires:31/10/2024

| | | |
|---|---|---|
| **Maxicrop Concentrate** | 1.55 ha | 1.300 L/ha |
| **Biochel CA** | 1.55 ha | 1.500 L/ha |

Reference: Plan 00167 Arnold Farm Majestic Insect + Fung + Foliar Job 3 Issued by: Kate (02/08/2021)
Job reason: SWD control
Mildew prevention/control
Botrytis prevention/control
Nutrition
Target growth stage: 89: Most fruits coloured
Job Harvest Interval: 01 Days 00 Hours

**Finish: 05/08/2021 09:50**

*Implement: HOP 1, Volume rate: 800.000 L*

| | | |
|---|---|---|
| **Benevia 10OD (99992)** | 1.55 ha | 0.750 L/ha |

MAPP:99992, Harvest interval:01 Days 00 Hours, Active Ingredients:Cyantraniliprole, Manufacturer:FMC Agro Limited, EAMU:1230/21, Expires:30/09/2021

| | | |
|---|---|---|
| **Amylo X WG (17978)** | 1.55 ha | 2.500 kg/ha |

MAPP:17978, Active Ingredients:Bacillus amyloliquefaciens subsp. plantarum strain, Manufacturer:Certis, EAMU:0469/18, Expires:30/09/2027

| | | |
|---|---|---|
| **Maxicrop Concentrate** | 1.55 ha | 1.300 L/ha |
| **Biochel CA** | 1.55 ha | 1.500 L/ha |

Reference: Plan 00177 Arnold Farm Majestic Insect + Fung + Foliar Job 3 Issued by: Kate (09/08/2021)
Job reason: SWD control
Botrytis prevention/control
Nutrition
Target growth stage: 89: Most fruits coloured
Job Harvest Interval: 01 Days 00 Hours

**Finish: 14/08/2021 11:00**

*Implement: HOP 1, Volume rate: 1000.000 L*

**Tracer (12438)** 1.55 ha 0.150 L/ha
MAPP:12438, Harvest interval:01 Days 00 Hours, Active Ingredients:Spinosad, Manufacturer:Landseer Ltd., Expires:31/10/2024
**Serifel (19236)** 1.55 ha 0.500 kg/ha
MAPP:19236, Active Ingredients:Bacillus amyloliquefaciens strain MBI 600, Manufacturer:BASF plc., Expires:10/10/2023
**Maxicrop Concentrate** 1.55 ha 1.300 L/ha
**Biochel CA** 1.55 ha 1.500 L/ha

Reference: Plan 00191 Arnold Majestic Insect + Fung + Foliar Job 3 Issued by: Kate (23/08/2021)
Job reason: SWD control
Mildew prevention/control
Nutrition
Target growth stage: 89: Most fruits coloured
Job Harvest Interval: 01 Days 00 Hours
**Finish: 26/08/2021 18:00**
*Implement: HOP 1, Volume rate: 800.000 L*
**Benevia 10OD (99992)** 1.55 ha 0.750 L/ha
MAPP:99992, Harvest interval:01 Days 00 Hours, Active Ingredients:Cyantraniliprole, Manufacturer:FMC Agro Limited, EAMU:1230/21, Expires:30/09/2021
**Sonata (19161)** 1.55 ha 10.000 L/ha
MAPP:19161, Harvest interval:01 Days 00 Hours, Active Ingredients:Bacillus Pumilus QST2808, Manufacturer:Bayer CropScience Limited, Expires:17/10/2023
**Maxicrop Concentrate** 1.55 ha 1.300 L/ha
**Biochel CA** 1.55 ha 1.500 L/ha

Reference: Plan 00206 Arnold Majestic Insect + Fung + Foliar Job 3 Issued by: Kate (02/09/2021)
Job reason: SWD control
Mildew prevention/control
Botrytis prevention/control
Nutrition
Target growth stage: 89: Most fruits coloured
Job Harvest Interval: 01 Days 00 Hours
**Finish: 07/09/2021 16:00**
*Implement: HOP 1, Volume rate: 1000.000 L*
**Tracer (12438)** 1.55 ha 0.150 L/ha
MAPP:12438, Harvest interval:01 Days 00 Hours, Active Ingredients:Spinosad, Manufacturer:Landseer Ltd., Expires:31/10/2024
**Luna Sensation (15793)** 1.55 ha 0.800 L/ha
MAPP:15793, Harvest interval:01 Days 00 Hours, Active Ingredients:Fluopyram, Trifloxystrobin, Manufacturer:Bayer CropScience Limited
**Teldor (11229)** 1.55 ha 1.000 kg/ha
MAPP:11229, Harvest interval:01 Days 00 Hours, Active Ingredients:Fenhexamid, Manufacturer:Bayer CropScience Limited
**Maxicrop Concentrate** 1.55 ha 1.300 L/ha
**Biochel CA** 1.55 ha 1.500 L/ha

Reference: Plan 00218 Arnold Majestic Fung + Foliar Job 3 Issued by: Kate (16/09/2021)
Job reason: Mildew prevention/control
Botrytis prevention/control
Nutrition
Target growth stage: 87: Fruit ready to pick
Inspected growth stage: 67: Late Flower, majority of petals fallen
Job Harvest Interval: 01 Days 00 Hours
**Finish: 19/09/2021 15:15**
*Implement: HOP 1, Volume rate: 1000.000 L*
**Charm (18396)** 1.55 ha 0.600 L/ha
MAPP:18396, Harvest interval:01 Days 00 Hours, Active Ingredients:Fluxapyroxad, Difenoconazole, Manufacturer:BASF plc., Expires:30/06/2024
**Serenade ASO (16139)** 1.55 ha 5.000 L/ha
MAPP:16139, Active Ingredients:Bacillus subtilis strain QST 713, Manufacturer:Bayer CropScience Limited, Expires:31/10/2024
**Maxicrop Concentrate** 1.55 ha 1.300 L/ha

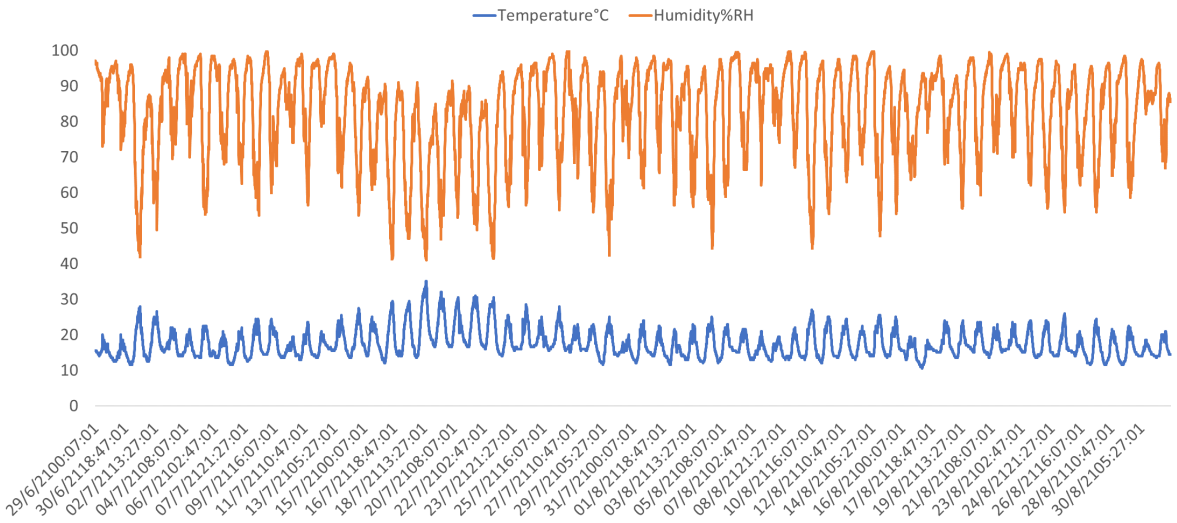
Reference: Plan 00231 Arnold Farm Majestic Fung + Foliar Job 3 Issued by: Kate (29/09/2021)
Job reason: Mildew prevention/control
Botrytis prevention/control
Nutrition
Target growth stage: 89: Most fruits coloured
Job Harvest Interval: 03 Days 00 Hours

## Appendix 2.2.2.

Temperature and Humidity data during the capsid repellent trial, summer 2021.

Block 1:

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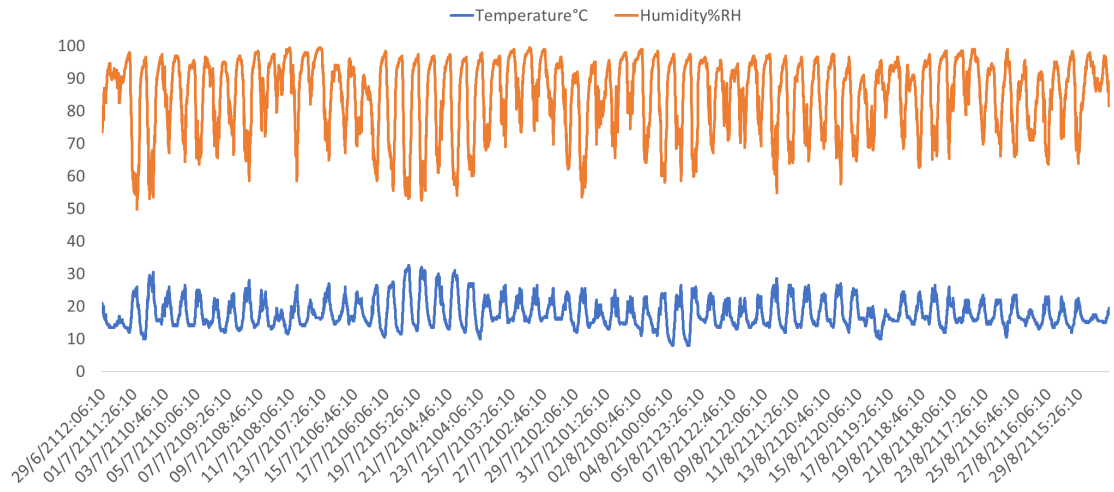
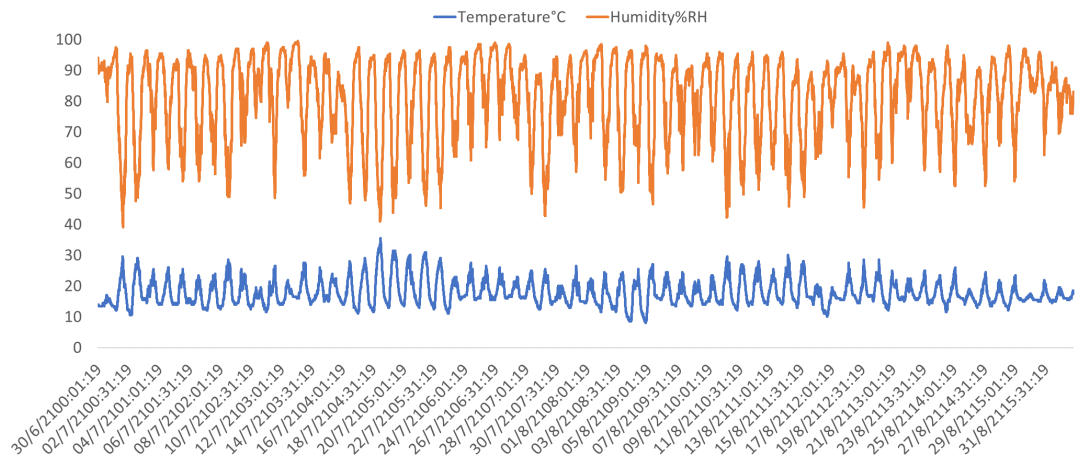


Block 3:

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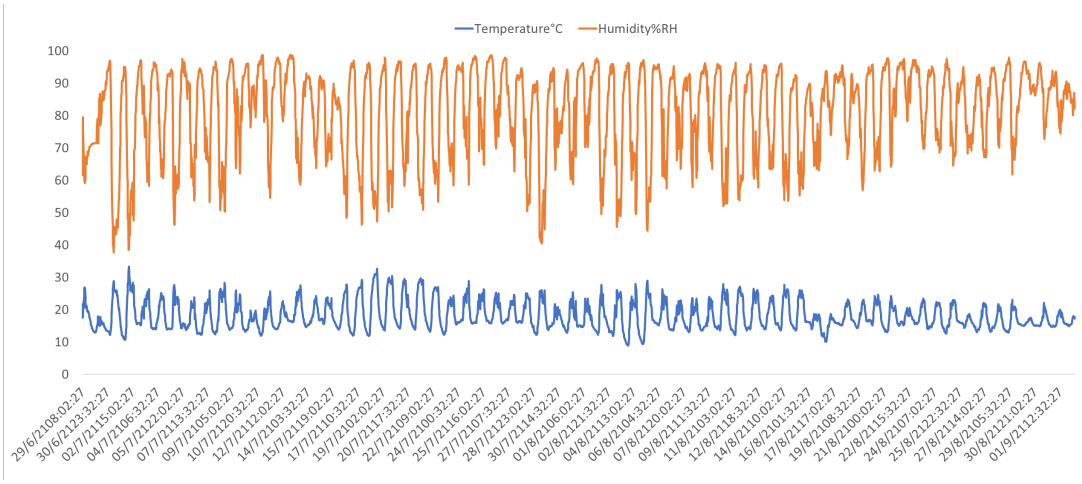


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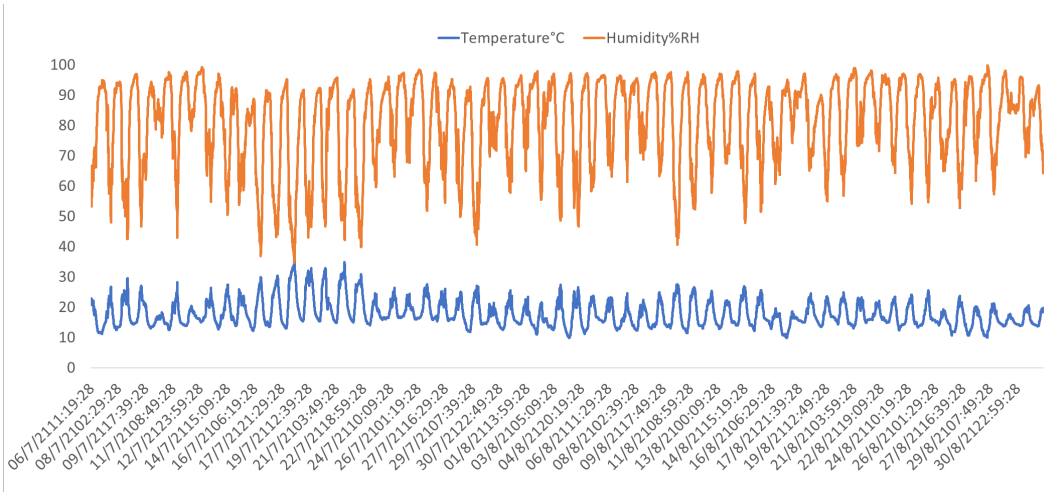


## Appendix 2.2.3.

Leaf phytotoxicity key used during the capsid repellent trial, summer 2021.

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

Local leaf discolouration or abnormal coloration of:

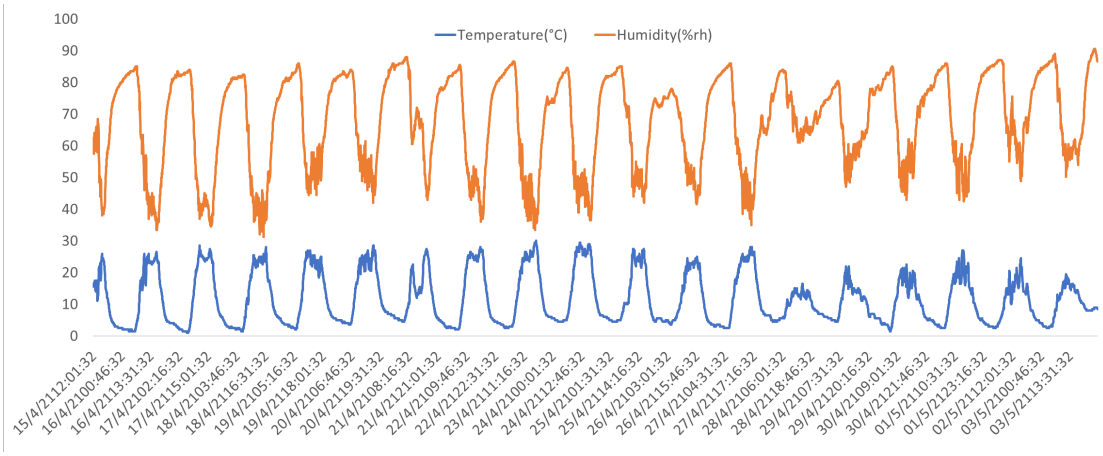
- veins
- areas between veins
- edges of leaves
- tip of leaves
- along the veins
- the whole leaf lamina
- stunting, dwarfing, curling, etc.
- deformation of the leaf lamina (wilt, swelling, curling, etc.)
- modification of venation (position and form of veins)
- sticking together of organs (petioles,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

# Appendix 3.1.1

Temperature and Humidity data during the aphidophagous hoverfly trial, spring 2021.

Block 1:

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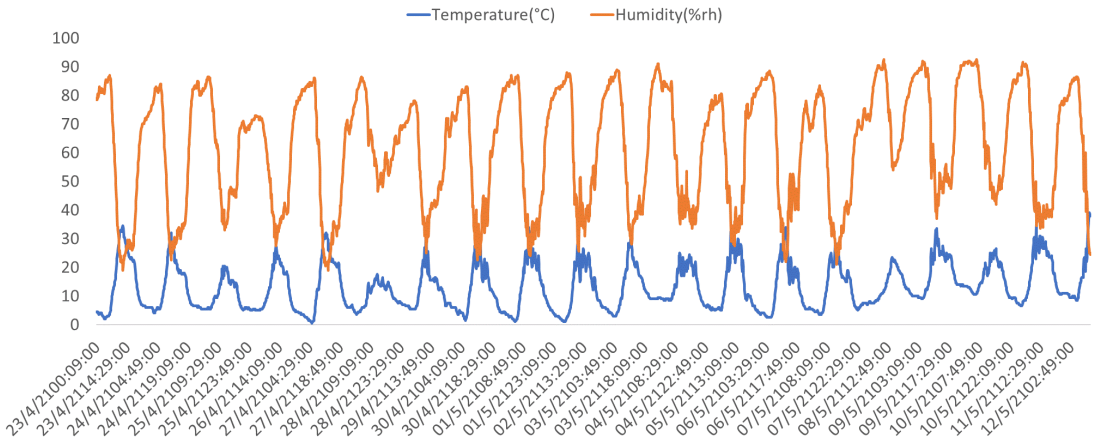

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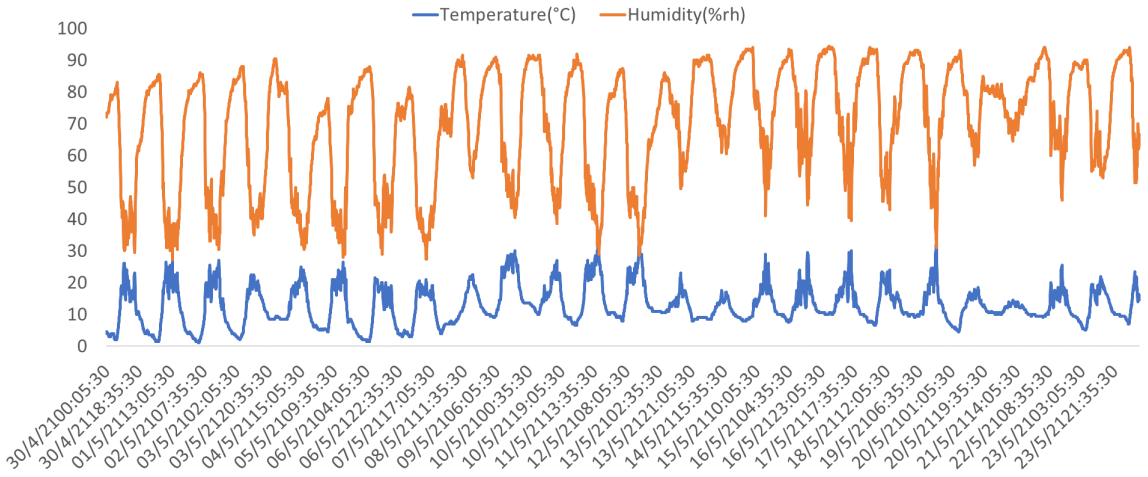


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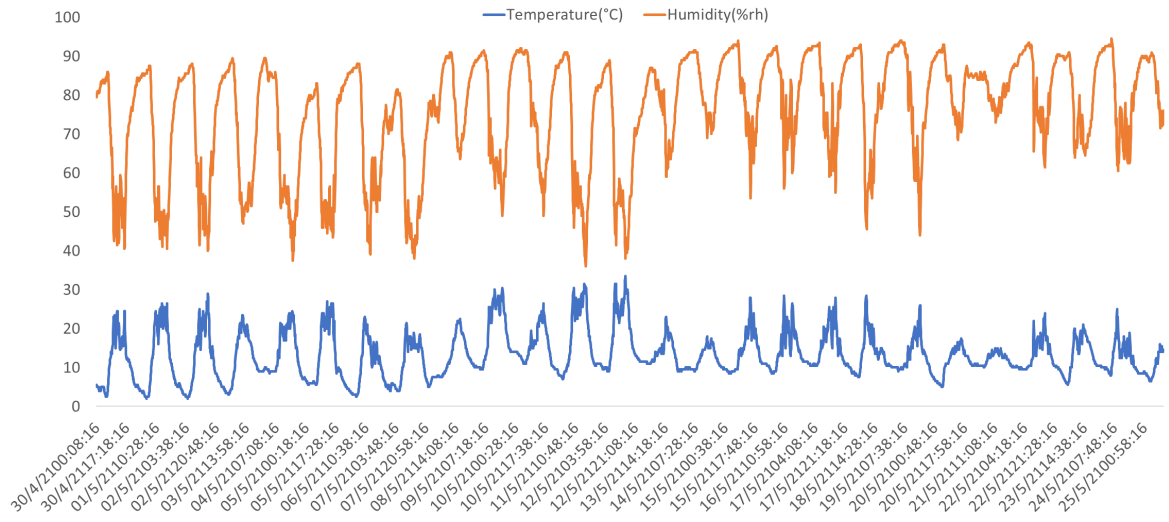


 

## Appendix 3.5 Site BF1 seed mix

Tested seed mix for orchard margin planting with 2% of the total orchard area in the treated plot of 5 sites.

| **41.4 kg Apple Orchard Perennial Mix** | **1.9 kg Apple orchard Annual/Biennial Mix** |
|---|---|
| *Achillea millefolium* (Yarrow) | *Alliaria petiolata* (Garlic Mustard) |
| *Anthyllis vulneraria* (Kidney Vetch) | *Anthemis austriaca* (Corn Chamomile) |
| *Barbarea vulgaris* (Winter-cress) | *Centaurea cyanus* (Cornflower) |
| *Centaurea nigra* (Common Knapweed) | *Echium vulgare* (Viper's Bugloss) |
| *Daucus carota* (Wild Carrot) | *Glebionis segetum* (Corn Marigold) |
| *Leontodon hispidus* (Rough Hawkbit) | *Papaver rhoeas* (Common Poppy) |
| *Leucanthemum vulgare* (Oxeye Daisy) | Crimson Clover |
| *Lotus corniculatus* (Birdsfoot Trefoil) | Gold of Pleasure |
| *Plantago media* (Hoary Plantain) | Fodder raddish |
| *Primula veris* (Cowslip) | - |
| *Ranunculus acris* (Meadow Buttercup) | - |
| *Reseda lutea* (Wild Mignonette) | - |
| *Silene dioica* (Red Campion) | - |
| *Taraxacum officinale* (Dandelion) | - |
| *Trifolium pratense* (Red Clover) -agric | - |
| ESG1 - Basic fine grass mixture | - |

 