AHDB HORTICULTURE

Grower Summary

SF158

Integrated Pest Management (IPM) of Cane Fruit Pests and Diseases

Annual report, March 2018

Project title:	**Integrated Pest Management (IPM) of Cane Fruit Pests and Diseases**
Project number:	**SF 158**
Project leader:	Erika Wedgwood, RSK ADAS Ltd.
Report:	Annual report, March 2018
Previous report:	Annual reports, March 2016 & 2017
Key staff:	Erika Wedgwood (RSK ADAS Ltd.) Emma Worrall (RSK ADAS Ltd.) Janet Allen (RSK ADAS Ltd.) Ruth D’urban-Jackson (RSK ADAS Ltd.) Aoife O’ Driscoll (RSK ADAS Ltd.) Jude Bennison (RSK ADAS Ltd.) Sam Brown (RSK ADAS Ltd.) Kerry Boardman (RSK ADAS Ltd.) Steve Richardson (RSK ADAS Ltd.) Chris Dyer (RSK ADAS Ltd.) Chantelle Jay (NIABEMR) Christina Faulder (NIAB EMR) Adrian Harris (NIAB EMR) Jerry Cross (NIAB EMR)

Location of project:	RSK ADAS Ltd. ADAS Boxworth Battlegate Road Boxworth Cambridge, CB23 4NN Rectory Farm Stanton St John Oxfordshire, OX33 1HF NIAB EMR New Road East Malling Kent, ME19 6BJ
Industry Representatives:	Louise Sutherland, Freiston Associates Ltd Richard Harnden, Berry Gardens Salih Hodzhov, W.B. Chambers and Son Richard Stanley, Rectory Farm Ross Mitchell, Castleton Fruit Ltd
Date project commenced:	1 March 2015
Date project completed **(or expected completion date):**	31 March 2020

DISCLAIMER

While the Agriculture and Horticulture Development Board seeks to ensure that the information contained within this document is accurate at the time of printing, no warranty is given in respect thereof and, to the maximum extent permitted by law the Agriculture and Horticulture Development Board accepts no liability for loss, damage or injury howsoever caused (including that caused by negligence) or suffered directly or indirectly in relation to information and opinions contained in or omitted from this document.

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

GROWER SUMMARY

The overall aim of the project is to advance and optimise on-farm integrated management of key pests and diseases of cane fruit. Within this project, it is planned to work on five differing objectives over the five year duration:

1. Investigate the infection process of *Phytophthora rubi* to inform the use of alternative or supplementary means to the use of chemical plant protection products for reducing the level of root rot in raspberries.

2. Develop and maintain IPM approaches to successfully control two-spotted spider mite whilst controlling spotted winged drosophila (SWD) and capsids with insecticides.

3. Develop and combine novel and current IPM approaches to successfully control blackberry leaf midge;

4. Establish cane management approaches on a model crop to optimise IPM strategies and spray penetration into canopies;

5. Disseminate research results to growers and translate research outputs into practical 'ready to use' techniques for immediate uptake on farms.

For ease of reading, this Grower Summary report is split into sections for each of the objectives (pests & diseases) being worked upon. The third year's work (2017) concentrated on Objectives 1 and 2, so only these are reported on in this third annual report.

Raspberry root rot

Objective 1 – Investigate the infection process of *Phytophthora rubi* to inform the use of alternative or supplementary means to the use of chemical plant protection products for reducing the level of root rot in raspberries

Headlines

- In a trial to assess the efficacy of a range of control agents for *Phytophthora rubi*, no significant differences were recorded between treatments.
- A novel system of observing the behaviour of *P. rubi* zoospores has been developed.
- An experiment has been set up to investigate any beneficial effect from the application of biofungicides, either before winter or after potting in spring, on the susceptibility of long cane raspberries to *P. rubi* infection following either cold-storage or outdoor chilling.

Background and expected deliverables

Phytophthora root rot is now the most destructive disease of raspberries worldwide. Where raspberries have been grown in the soil *Phytophthora rubi* (previously known as *P. fragariae* var. *rubi*) is almost ubiquitous. Outbreaks of this disease across Europe at the same time in traditional raspberry-growing areas suggests that the disease has spread through the propagation network and has been distributed to farms in new planting material (Graham et al. 2011). Current approaches for Phytophthora control rely on fungicide applications twice per year either as a soil-applied drench or through the drip irrigation. SL567A (44.7% w/w metalaxyl-M) and Paraat (500 g/kg dimethomorph) can be used, although resistance developing in pathogens where products have only a single mode of action is a major concern.

The work in this project will focus on understanding the activity of non-conventional products that may improve root health and the production of propagation material that is more resistant to the disease. The work in 2017 was divided into three separate packages:

Work package 1 – To investigate the effects of a range of novel plant treatments on raspberry growth and their resilience to pests and diseases from propagation through to primocane production.
Work package 2 - To explore *P. rubi* zoospore behaviour with raspberry root exudates.
Work package 3 - To explore the effect of cold-storage of long cane raspberries on incidence & severity of *P. rubi* infection and the potential for protection using biofungicides.

Summary of the project and main conclusions

Work package 1 – To investigate the effects of a range of novel plant treatments on raspberry growth and their resilience to pests and diseases from propagation through to primocane production

Work in 2017 was a continuation of what began in 2015 and 2016. In 2015, modular Tulameen plants were raised at a propagation nursery in Oxfordshire and treated with a range of novel and traditional control products. These were compared to untreated control plants.

At the end of 2015, half of the plants remained at the propagation nursery where they were cold-stored as 'long-canes'. The other half were sent to ADAS Boxworth where they were cut back, before potting on in spring 2016 and artificially inoculated by *P. rubi* mycelium and zoospores.

The plants were grown-on at both an Oxfordshire soft fruit farm and ADAS Boxworth in 2016, where they were treated again with the same products to assess their effect on plant growth and pest and disease development. No phytotoxicity occurred at either site and no difference in vigour was recorded. Fruit was only harvested at the Oxfordshire site and no yield differences were seen between treatments in 2016. At Boxworth, by termination of the experiment in November 2016, a small increase in primocane number had occurred with the use of the biofungicides Prestop, Root Grow HYDRO, Serenade ASO and a coded product compared to the other treatments and untreated control, but no wilting had developed in any canes.

In 2017, the treatments were repeated in the Oxfordshire trial. A summary of all treatments used in 2015, 2016 and 2017 is set out in Table A below. Note that two of the treatments (Treatment 3 – HDC F201 and Treatment 4 – Root Grow HYDRO – HDC F204) were not applied in 2017. The former is only permitted for use on crops under permanent protection, while the Root Grow HYDRO is a mycorrhizal product which can only be applied when plants are potted up.

Table A. Summary of products and application timings made in 2015, at the propagators in multicell trays and then module pots, and application timings in 2016 and 2017 after the same plants were potted and grown on the Oxfordshire site.

Trt. no.	Treatment	Dilution rate and (product per 10L pot)*	Year: (Month product applied)
1	Untreated	-	-
2	Prestop (*Gliocladium catenulatum*) [MAPP 15103]	5 g/1 L water (5g)	2015: (April, May, July, October) 2016: (April, May, June) 2017: (April, May, June)
3	HDC F201	Not disclosed	2015: (April, May, July, October) 2016: (April, June)
4	Root Grow HYDRO (mycorrhiza species) (HDC F204)	7 g/1 L growing- media (70g)	2015: (April, May) 2016: (April)
5	Serenade ASO (*Bacillus subtilis*) (HDC F228)	10 L/ha using1000 L water (1 ml / m² *pro rata* to area of pot surface) (0.12ml per 10L)	2015: (April, May, July, October) 2016: (April) 2017: (April)
6	HDC F205	Not disclosed	2015: (April, May, July, October) 2016: (April, May, June) 2017: (April, May, June)
7	Paraat (dimethomorph) [MAPP 15445]	1.0 g/plant (1g)	2015: (April, May) 2016: (April) 2017: (April)

*Applying 1 L of diluted product per pot to give a drench of 10% of pot volume per 10 L pot. Treatments were applied up to three times following the treatment manufacturers' instructions.

Full details of the treatments and the methods of application are summarised in the Science Section of the report.

The Tulameen canes in the trial treatments were grown within a commercial raspberry plantation and received the same fertigation and crop protection spray programme as the surrounding crop. Paraat drenches by the grower were withheld from the experiment. The crop assessments made in 2017 are summarised in Table B below.

Table B. Dates and types of assessments and product application dates, Oxfordshire 2017.

Date	Procedure
7 April 2017	Pre-treatment assessment. Product applications.
9 May 2017	Phytotoxicity and floricane vigour assessment. Products applied.
23 May 2017	Phytotoxicity and floricane vigour assessment. Products applied.
7 June 2017	Phytotoxicity and floricane vigour assessment. Products applied.
19 June to 5 July 2017	Harvest assessments. Fruit yield. Mean berry weight.
29 June 2017	Phytotoxicity and primocane vigour assessment.
10 July 2017	Leaf samples for nutrient analysis.
6 September 2017	Final primocane vigour assessment.
4 December 2017	Suitability assessment of new cane produced in 2017.
15 January 2018	Final disease assessments of new floricane and roots.

In addition to these assessments, root samples were collected from the treatments in September 2017 for testing in bulk using a lateral flow device (LFD) for *Phytophthora* spp. and again in January 2018 when roots from each treatment were placed in float dishes to stimulate oomycete sporangia production. Fruit yields were recorded during harvest (June – July 2017) and on two harvest dates, mean berry weight and fruit quality were recorded.

No foliar disease, cane wilting or root rot were recorded in the trial, even in the untreated plots. Therefore no conclusions could be drawn regarding product effects on disease incidence or severity. Natural *Phytophthora* infestation may have started, as a faint positive was recorded on the LFD, but no sporangia developed in the root floats indicating it was not widespread.

In addition, there were no significant differences recorded, either between any of the treatments or between the treatments and the untreated control in plant vigour during crop growth, fruit harvest measurements or the number and strength of cane produced by January 2018. The treatments caused no adverse effects in the plants and had no apparent effect on growth promotion. There were different levels of nutrients in the leaves in July, with product HDC F205 recording higher than average levels of phosphorus and potassium. It is not clear why this occurred and what impact it might have on plant growth and physiology.

At the start of the 2017 growing season, plants treated with Serenade ASO produced significantly more new primocanes (spawn) than all other treatments. However, five canes per plant may be in excess of numbers actually required for retention as floricane.

When monitoring for Botrytis on floricanes pre-treatment in April 2017, those treated with HDC F205 had more Botrytis infection than all but the untreated and Root Grow Hydro treatments.

This suggests there might be a reduction in resistance to this pathogen. However, after the final cane Botrytis assessment in January 2018, there were no significant differences between treatments. Pre-season Botrytis coverage ranged from 5% - 13% whereas post-season winter coverage was much higher at 53% - 68%. This indicates the time of year when cane Botrytis becomes particularly prevalent.

Work package 2 - To explore *P. rubi* zoospore behaviour with raspberry root exudates

Like other *Phytophthora* species, *P. rubi* zoospores are released by mature sporangia and swim towards raspberry root tips, before encysting and entering the root. It is thought that zoospores use chemotaxis to target the root. However, compared to other Phytophthora spp. relatively little is known about *P. rubi* and its exact mode of infection. Work therefore needs to be done to understand the behaviour of *P. rubi* zoospores (the infecting part of its lifecycle) to help in the search for robust control solutions.

Initial work was done with an isolate of *P. rubi* on the technique for producing sporangia and releasing zoospores as this differed from those standard for other Phytophthora species. Work has also been set up to develop techniques to investigate the movement of zoospores towards root exudates in laboratory conditions. Useful progress has been made but further work is required to refine the process.

Another experiment was undertaken to confirm that the isolate of *P. rubi* being used is pathogenic. A technique developed by the James Hutton Institute was employed. Three healthy Glen Moy plants were inoculated with the *P. rubi* isolate and grown inside a growth cabinet. Both root and stem sections from each plant were tested for *P. rubi* infection following the removal of the plants from the growth cabinet.

After removal of the plants from the cabinet, all three were wilting, indicating Phytophthora infection. The stem base was brown up to 20mm on all three plants and in the roots, browning was seen in every plant to varying extents. Sections of roots from each plant were removed and placed in soil water and observed. After 2 days, around 200 spores were seen around many of the roots from all plants. These zoospores indicate the presence of an oomycete. Tests on the stems of all three plants confirmed *P. rubi* on two plants.

In conclusion, the work confirmed that the isolate of *P. rubi* being used in the project is pathogenic to raspberry. The imaging and video capacity of ADAS laboratory equipment, alongside a novel observation set-up, enables clear monitoring of zoospore behaviour, for further work on raspberry exudates, chemical fungicides and other solutions.

Work package 3 - To explore the effect of cold-storage of long cane raspberries on incidence & severity of *Phytophthora rubi* infection and the potential for protection using biofungicides.

Long cane raspberries require a chilling period at the end of their propagation year in order to produce fruit in the following Summer. Some propagators place their containerised plants into cold-storage rather than leave them outside and risk inadequate chilling in a warmer Winter. In cold-stored strawberry there is experimental evidence that healthy plants become more susceptible to Phytophthora when planted in infested soil than those not cold-stored. Cold-stored plants can also succumb more readily to Phytophthora already in the crowns before storage.

It was therefore hypothesised that losses of cold-stored long cane raspberries in their fruiting year might follow as a result of increased plant susceptibility, potentially also linked to greater *P. rubi* inoculum pressure. This is because should long cane or module raised raspberries be infected by *P. rubi* before they are cold-stored, it is known that the pathogen can survive the period of storage on the roots. On returning the plants to ambient conditions and commencing watering, it is thought that this may trigger a mass zoospore release rather than a steady release. Cold-storage of healthy plants may also reduce their resistance to root infection.

In 2017, investigations were started to determine whether healthy cold-stored plants were more susceptible to *P. rubi* infestation in Spring than those left outside and also whether product application before or after Winter might reduce plant susceptibility. In 2018, work will be started with the same product applications and timings, but with *P. rubi* inoculation in November so that only the Autumn treatments will be protectant.

A trial was set up in summer 2017 at a propagation site in Oxfordshire where long cane Tulameen grown in 1.5 litre pots were chosen for experimentation. Two experiments were begun, one (Experiment 1) where canes were treated with drenches of control products in autumn 2017 and the other (Experiment 2) treated in spring 2018. In each experiment, half of the canes were cold-stored from December 2017 to March 2018 and half were left to stand in the field in ambient conditions.

In April 2018, all of the canes (both cold-stored and field-grown) were moved to ADAS Boxworth where they were potted into 5 litre pots (1 cane per pot) and those canes in Experiment 2 were drenched in the same way as Experiment 1 had been treated in Autumn 2017. One month later, all pots from both experiments (except untreated controls) were inoculated with *P. rubi*. Full assessments of cane height, vigour, disease incidence and root health were recorded throughout the trial. Full details of the treatments in each experiment are listed in Table C.

Table C. Products and number of applications in either Winter 2017 (Experiment 1) or Spring 2018 (Experiment 2). Inoculation with *P. rubi* in Spring 2018 (except T1) at ADAS Boxworth. Treatments 1-5 with cold storage are shaded in blue.

Experiment 1 (drenching in 2017 inoculation in 2018)		**Experiment 2** (drenching and inoculation in 2018)	
T1 UT no *P. rubi*	Cold Store December 2017 to March 2018	T1 UT no *P. rubi*	Cold Store December 2017 to March 2018
T2 UT		T2 UT	
T3 Prestop x2		T3 Prestop x2	
T4 Serenade x1		T4 Serenade x1	
T5 Paraat x1		T5 Paraat x1	
T6 UT no *P. rubi*	Ambient outdoors December 2017 to March 2018	T6 UT no *P. rubi*	Ambient outdoors December 2017 to March 2018
T7 UT		T7 UT	
T8 Prestop x2		T8 Prestop x2	
T9 Serenade x1		T9 Serenade x1	
T10 Paraat x1		T10 Paraat x1	

Full results will be recorded in the spring and summer of 2018, then included in the next annual report in 2019.

Financial benefits

Raspberry root rot (caused by *Phytophthora rubi*) is the most devastating disease currently faced by cane fruit growers and in particular by raspberry producers. The disease spreads rapidly through the root system of the crop, leading to complete death of large areas of a plantation. Where severe, in soil grown crops, it commonly kills 75% of a raspberry plantation within two to three years of establishment. Although perhaps slower to spread in container grown crops, it has a similar effect in killing significantly large areas of a plantation within a few years of planting and establishment. Not only do growers make significant financial losses, they also incur additional labour costs in setting up new replacement plantations more frequently, along with the associated costs of establishing a new plantation along with the support system that goes with it.

Assuming a typical return for raspberries of £6.49/kg to growers (Defra Basic Horticultural Statistics 2014) and a yield of 14 tonnes/ha, then 75% crop loss would lead to a financial loss of £68,166/ha. Increasing the health of propagation material and providing material that is more resistant to the disease would not only significantly reduce such losses but lengthen the life expectancy of a raspberry plantation, thereby reducing the additional costs of re-establishing new plantations on a frequent basis.

Action points for growers

- Consider biological alternatives to plant protection products for the control of *Phytophthora. rubi.*
- A drench application of Serenade ASO to outdoor container raspberries may increase cane production.

Two-spotted spider mite

Objective 2 – Maintaining Integrated Pest Management of two-spotted spider mites whilst controlling spotted wing drosophila

Headlines

- Establishing populations of introduced and naturally occurring predatory mites early in the season can achieve control of two-spotted spider mite before any control sprays for SWD are required.
- Applying SWD control sprays over the top of a raspberry crop can provide refuges for predatory mites on the undersides of leaves, to limit the adverse effect of SWD control programmes on biological control systems.

Background and expected deliverables

A key current question for growers of soft fruit is how to maintain the successful Integrated Pest Management (IPM) approaches that have been developed over the past 10 years whilst applying crop protection products to control SWD. Two-spotted spider mite (TSSM) can be a devastating pest of raspberries, especially on crops grown under glasshouse or polytunnel protection and during hot weather. Control of TSSM with acaricides requires good spray cover, as most acaricides are contact acting. Effective leaf cover is difficult to achieve in raspberry crops which often have dense canopies. Recent changes in legislation have also meant that there is a limited range of acaricides for use in protected and outdoor raspberries and other cane fruit crops and it is likely that this trend will continue (e.g. abamectin is under threat due to potentially being an endocrine disrupter). The difficulties of applying sprays to a raspberry crop and restrictions on crop protection products mean that predators of TSSM are an important method for the control of this pest.

Phytoseiid predatory mites are the main natural enemies of TSSM. There are two main naturally occurring, overwintering, species in raspberry (predominantly *Amblyseius andersoni* but *Neoseiulus californicus* is also common). These mites naturally regulate TSSM populations to a greater or lesser extent, but not reliably. In recent years, growers have been successfully introducing *Phytoseiulus persimilis* predatory mites and the predatory midge *Feltiella acarisuga* for the control of TSSM mite in outdoor/protected raspberry and blackberry crops. However, information on side effects of crop protection products on biological control agents and experience in other countries, demonstrates that applications of products to control SWD such as spinosad (Tracer), lambda-cyhalothrin (Hallmark) and deltamethrin (e.g. Decis), can adversely affect these biological control agents leading to serious outbreaks of TSSM.

Outbreaks of TSSM and other mites, as a result of disruption to biocontrol by naturally occurring and introduced predatory mites, by sprays of products for SWD and/or capsid bugs, is an immediate serious threat which the UK cane fruit industry faces.

This study aims to address this problem in Year 3 through two specific objectives:

Objective 2.1**:** To develop and maintain IPM approaches to successfully control two-spotted spider mite whilst controlling SWD and other pests with insecticides.

Objective 2.2: To develop compatibility strategies for biocontrol of two-spotted spider mites (TSSM) by predatory mites with insecticide sprays for spotted wing drosophila (SWD) and capsids

Summary of the project and main conclusions in year 3

Objective 2.1**:** To develop and maintain IPM approaches to successfully control two-spotted spider mite whilst controlling SWD and other pests with insecticides.

This work was undertaken by ADAS. A commercial tunnel-grown raspberry crop of Maravilla was monitored between 29 June and 13 October 2017. Visits were made before and after a chemical control product was applied to control SWD. On each visit, records were made of numbers of TSSM, leaf area damaged by spider mites, numbers of *P. persimilis* and numbers and species of any naturally-occurring TSSM predators. An assessment of SWD adult emergence from treated fruit was made eight days after the SWD spray.

High numbers of TSSM and eggs were recorded on the preliminary assessment on 29 June when numbers of *Phytoseiulus persimilis* were still low following release by the grower on 29 May.

On the second assessment on 21 July, mean numbers of TSSM and eggs were significantly reduced. This reduction is likely to have been due to predation, not only by *P. persimilis* which had established well by this date, but also by four naturally-occurring predators; the predatory mite *Amblyseius andersoni*, the midge *Feltiella acarisuga,* the ladybird *Stethorus punctillum* and the predatory bug *Orius* sp.

On the third assessment on 2 August, immediately before the SWD spray was applied, mean numbers of TSSM and eggs were significantly reduced still further and this is likely to have been due to both predation by the combination of predators and to some of the floricane being cut back six days earlier on 27 July. Mean numbers of *P. persimilis* and *A. andersoni* were also significantly lower on this date than on the previous assessment and this is likely to have been due to both cutting back the floricane and to the reduced availability of spider mite prey.

On the fourth assessment on 9 August, seven days after the grower applied a tank mix of deltamethrin (Decis) for SWD control and thiacloprid (Calypso) for blackberry leaf midge control, mean numbers of *P. persimilis* mites and eggs were significantly lower (83% and 98% respectively) than on the previous, pre-spray date. This reduction is likely to have been due to both the harmful effects of Decis and Calypso and to the scarcity of TSSM prey. Both TSSM mites and eggs had reached very low numbers by this date which is likely to have been due to predation by the remaining predators. Mean numbers of *A. andersoni* and eggs were also lower than on the pre-spray date (55% and 67% lower respectively) but this reduction was not statistically significant. This predator seems to be more tolerant of crop protection products than *P. persimilis* and it is less dependent on TSSM for food as it will also feed on other prey and food sources such as pollen. Mean numbers of *F. acarisuga* and *S. punctillum* were both significantly lower than on the pre-spray assessment and this is likely to have been due to both the effects of the SWD spray and to scarcity of TSSM prey.

No SWD adults emerged from the fruit samples collected eight days after the SWD spray. Initially the grower intended to apply further SWD sprays but due to a combination of the spray on 2 August, good site hygiene and cut back of the floricane, further applications were not needed.

Both spider mite and predator numbers were very low on the final assessment on 13 October. TSSM damage to leaves did not increase during the monitoring period, but decreased by the final assessment. This was likely to have been due to any new leaves developing since the previous assessment showing less damage symptoms due to the decrease in numbers of spider mites.

Although the SWD spray is likely to have killed many of the spider mite predators, due to early good establishment, the predators had controlled the TSSM before the spray was applied and no acaricides were needed.

The results are neatly summarised in Figure A below.

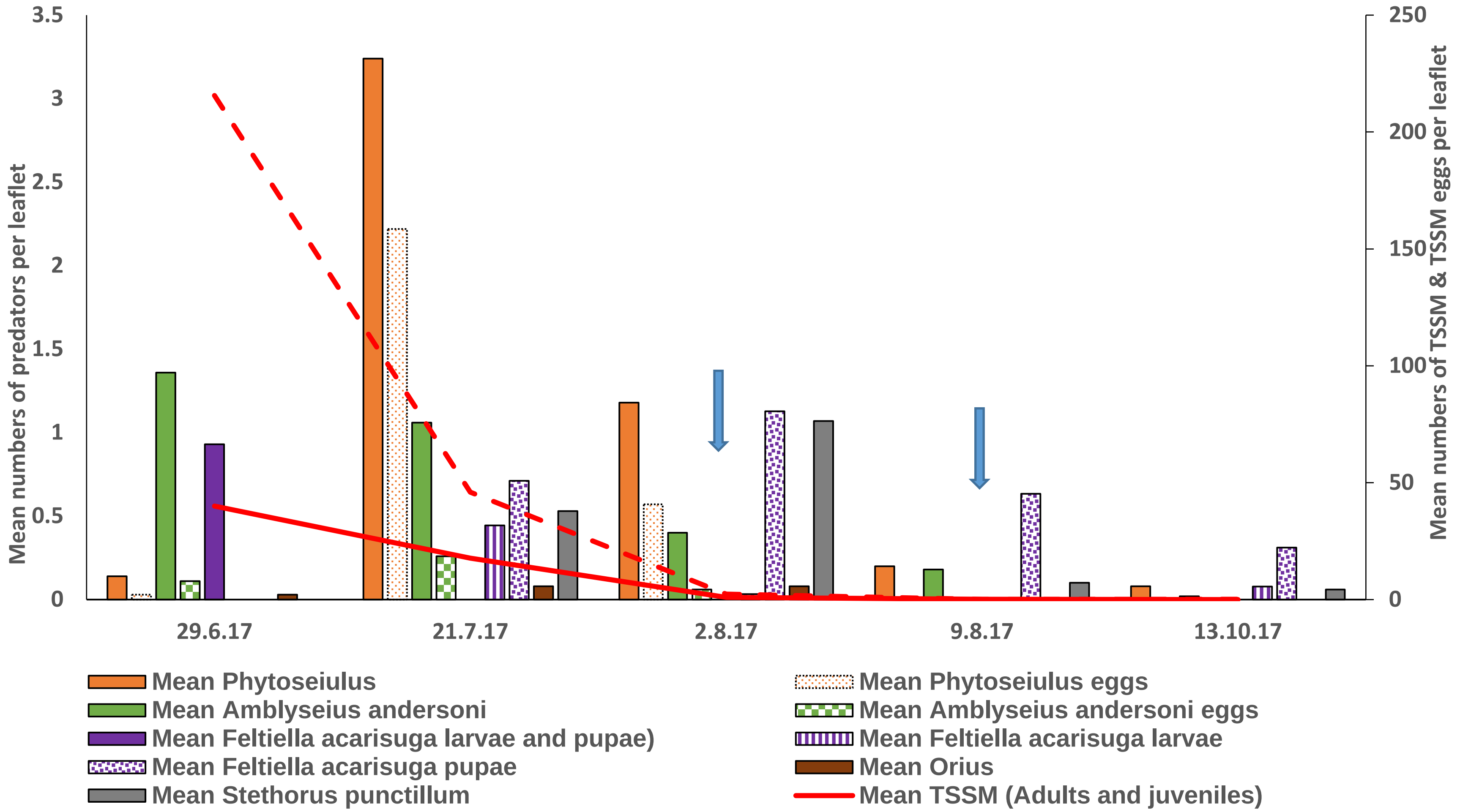

Figure A. Mean numbers of TSSM predators per leaflet (left hand axis) and mean numbers of TSSM and eggs per leaflet (right hand axis) on each assessment date

Objective 2.2: To develop compatibility strategies for biocontrol of two-spotted spider mites (TSSM) by predatory mites with insecticide sprays for spotted wing drosophila (SWD) and capsids

This work was undertaken by NIAB EMR. To maintain control of spider mite within a spray programme for SWD, it is assumed that the sprays may negatively affect the biocontrol programme. Leaving unsprayed refuges in the crop for commercially introduced and naturally occurring predatory mites may help to protect and maintain predatory mites. Therefore spray application methods which would provide good coverage on the upper leaf surface, but leave the lower leaf surface unsprayed were explored. To determine whether the method of spraying could be important, experiments were done in small purpose-built poly-tunnels to compare the same spray programme applied by two different spraying methods: pervasive canopy spraying using an air-assisted knapsack sprayer and a system of overhead spraying to give spray deposits mainly on the upper leaf surface (Figure B). The work began in 2015 (Year 1 of the project).

Figure B. A system of overhead spraying using nozzles directing sprays from above the crop canopy was set up in purpose built polythene tunnels.

In 2015, the effects of overall canopy spraying versus overhead misting application of a programme of sprays of deltamethrin (Decis/Bandu), spinosad (Tracer) and chlorpyrifos (Equity) on TSSM and naturally occurring predatory mites were compared using a suite of nine mini tunnels. The effects of date and treatment were significant. In early August, the numbers of natural phytoseiid mites were lower in both of the sprayed treatments. The numbers of TSSM then rose significantly in the sprayed plots from 17 August 2015. The numbers of SWD were lower in both of the treated plots.

In 2016, the same system of overhead spraying was used, with different nozzles to give a slightly larger droplet size. This resulted in less spray deposit on the underside of the leaves in the overhead spray treatment and although the natural phytoseiids were affected by the spray treatments, the effect could be mitigated by spraying from above. TSSM numbers were higher in the sprayed treatments (for all life stages with the knapsack spray). Introduced *P. persimilis* was less affected by the spray programme than anticipated; the spray programme did not negatively affect *P. persimilis* which significantly increased in the sprayed treatments compared to the control. The population development of *P. persimilis* followed that of the TSSM, albeit on a different numerical scale. Both methods of application, boom spraying and knapsack spraying, reduced the number of SWD compared to the control.

The work in 2017 repeated the 2016 experiment, again to determine the effects of overall canopy spraying verses overhead application of a programme of sprays of deltamethrin and spinosad on TSSM and predatory mites, both commercially introduced and naturally occurring.

In 2017, although it was not possible to determine any treatment effects for the TSSM and *P. persimilis* due to the low numbers per leaf, there were treatment effects for the naturally occurring phytoseiids. As in 2016, the sprays reduced the numbers of natural phytoseiids, however this effect could be mitigated by spraying from above. The assessment of spray deposition showed that there was less spray on the underside of the leaves in the overhead spray treatment, which could provide a refuge for predatory mites. The data also showed that the amount of spray deposited on the underside of leaves in the overhead spray treatment was highly variable.

As there were few *P. persimilis* motiles, it was not possible to determine the effect of the deltamethrin sprays in the field. However, bioassay work showed that with direct application of deltamethrin in the laboratory, almost all adults were killed within 24 hours. Therefore it is not believed that the commercially available strain of *P. persimilis* is resistant. The numbers of SWD were low in 2017 therefore no significant treatment effects could be determined.

Financial benefits

Before the spotted wing drosophila first arrived on UK shores, raspberry growers had refined their IPM programmes reasonably well and were gaining satisfactory control of two-spotted spider mite using biological and naturally occurring control programmes, primarily through the introduction of the predatory mite *Phytoseiulus persimilis* and sometimes complemented with other predatory midges such as *Feltiella acarisuga*.

The vital importance of controlling spotted wing drosophila at all costs, has resulted in a conflict with IPM programmes, given the nature of the crop protection products used for SWD control and the fact that they upset the predator/prey balance that is developed. However, failing to gain control of two-spotted spider mite can lead to serious reductions in the efficient photosynthetic area of the plant and this can lead to the production of small and shrivelled fruits and a subsequent reduction in the marketable yield of raspberry or other cane fruit crops.

Assuming a typical return for raspberries of £6.49/kg to growers (Defra Basic Horticultural Statistics 2014) and a yield of 14 tonnes/ha, then a 25% crop loss caused by two-spotted spider mite (a typical loss incurred) would lead to a financial loss of £22,722/ha. Developing a refined IPM programme on raspberries which can also cater for the control of other pests such as SWD and common green capsid, will significantly reduce such losses from two-spotted spider mite.

Action points for growers

- Aim to establish *P. persimilis* as early as possible and be aware of the contribution of naturally-occurring predators in the control of TSSM.
- Consider early release of *A. andersoni* for TSSM control before temperatures are suitable for *P. persimilis* as this predatory mite is more tolerant of low temperatures than *P. persimilis*. However, released predators of this species may be less tolerant of certain crop protection products such as pyrethroids, than naturally occurring populations.
- Wherever possible, use IPM-compatible plant protection products or those with the least harmful effects on biological control agents for control of all pests including SWD.
- As naturally occurring predatory mites, such as *A. andersoni*, may be harmed by plant protection products, consider leaving unsprayed refuges, for example by overhead spraying to reduce deposits on the lower leaf surface.
- Where unsprayed refuges are used, monitor regularly to ensure that other pests such as aphids are controlled, and treat within an IPM programme.
- Re-introduce *P. persimilis* for TSSM control where necessary.