Grower Summary

SF 158

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

Final Report 2020

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

AUTHENTICATION

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

Dr Erika F. Wedgwood

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RSK ADAS Horticulture, RSK ADAS Ltd

Signature Date: 10 September 2020

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Signature Date: 10 September 2020

GROWER SUMMARY

This summary brings together information on research carried out in this project between 2015 and 2020. The work completed in 2019 and 2020, not covered in previous Annual Reports, is addressed in full in the Science Section.

The diseases and pests selected for study were based on current issues identified by industry intelligence and the need for urgent problem-solving work to assist grower practice. Pathology focussed on the control of Phytophthora root rot and the species involved, the detection of Verticillium wilt and reviews of cane blight and biennial cropping were completed. Entomology examined the effects of spraying for spotted wing drosophila on two-spotted spider mite predators and how predator populations could be boosted, and tested the use of entomopathogenic nematodes for the control of blackberry leaf midge.

Seeking alternative solutions to controlling Phytophthora root rot

Headline

- New information has been gathered on Phytophthora root rot and its control in raspberry.

Background and expected deliverables

Phytophthora rubi is the most serious disease of raspberry, causing root death and die-back of canes. It is soil/substrate-borne and the spores spread in water. Many growers reduce the risk of infection by planting in coir substrate and maintaining control has relied on chemical fungicide drenching in Spring and Autumn.

The work in this objective investigated a range of novel plant treatments for *P. rubi* control. Alongside this, in the last two years, any effect of cold storage of long-canes on the incidence and severity of *P. rubi* infection was studied. In the final year, with wilting being increasingly reported in crops, a country-wide sampling of raspberry plants was undertaken to determine whether *Phytophthora* species other than *P. rubi* might be detected in them.

Summary of work and main conclusions

Years 1 to 3 (2015 - 2017); in-vitro testing of Serenade ASO and Prestop, and use against *P. rubi* on plants during propagation

During the early stages, the project aimed to determine whether products other than conventional chemical fungicides used against Phytophthora root rot, could improve root health and produce propagation material that was less susceptible to root rotting by *P. rubi*.

Agar plate tests (see 2016 Annual Report) showed that *P. rubi* mycelial growth was halted by Paraat (dimethomorph) as well as the metabolites present in Serenade ASO (*Bacillus subtilis* strain QT 713). Mycelial growth was also significantly slowed by Prestop (*Gliocladium catenulatum* strain J1446). Technical difficulties caused abandonment of behaviour observation tests with *P. rubi* zoospores related to finding materials to use as baits.

Raspberry cv. Tulameen in multicellular propagation trays and modules were drenched with biostimulants and growth promoters during 2015. In 2016 they were potted up and received further treatments both at a commercial farm in Oxfordshire and at ADAS Boxworth, where plants received an additional inoculation with *P. rubi*. The treatments did not improve plant vigour or reduce root rotting (see 2016 and 2017 Annual Reports).

Years 3 and 4 (2017 & 2018); efficacy of fungicide application and comparison of plants from cold-storage or outdoor overwintering, with *P. rubi* infestation in Spring

Commencing in September 2017, investigation of root health in mature long cane raspberries and the use of biofungicides continued (see 2018 and 2019 Annual Reports). As there had been UK reports of plant losses following cold-storage (before fruiting), studies investigated the effects of cold-storage on the incidence and severity of *P. rubi* infection. Potted plants in a polytunnel were inoculated with *P. rubi* in the Spring following cold-storage. The plants were drenched either in the preceding Autumn or in the Spring using Paraat (at 1 g per 5 L potted plant), Serenade ASO (at 10 L/ha in 10 ml/L water) or Prestop (at 5 g/L water).

Following *P. rubi* inoculation there were no treatment differences throughout the two crops, with symptoms also found in uninoculated plants. Molecular testing of rotted roots in October confirmed *P. rubi* in inoculated plants, but *P. idaei* was also detected in both *P. rubi* inoculated and uninoculated roots and it was presumed this had infested plants during propagation. There was lower than anticipated *P. rubi* incidence even in the untreated control, probably attributable to the unusually hot weather at the time of artificial inoculation in Spring 2018. Uninoculated untreated cold-stored plants had more rotted roots in Spring than ambient-stored and they produced three rather than two primocanes by June, with a greater proportion of primocanes wilting in October. However, the combination of Autumn treatment with Prestop or Serenade ASO followed by ambient storage resulted in more rotted roots in Spring, but differences in plant health did not persist.

Years 4 and 5 (2018 & 2019); efficacy of fungicide application and comparison of plants from cold-storage or outdoor overwintering, with *P. rubi* infestation in Autumn

Starting in September 2018, a further experiment was commenced in which the modules were inoculated with *P. rubi* during Autumn, rather than Spring, followed by placing half the plants in ambient conditions and half in cold storage (see 2019 and current Annual Reports). Paraat applied in either Autumn or Spring, significantly reduced root rot, floricane wilting and death and there was good primocane production after fruiting. Treatment with either Prestop or Serenade ASO was not effective. Plants from neither storage regime showed consistently greater severity of all disease symptoms. Further details are provided in the Science Section.

Year 5 (2019/20); sampling survey of crops for wilted plants and the use of lateral flow devices and molecular testing to determine the species of *Phytophthora* present.

A sampling survey of UK raspberry crops was completed in 2019 to determine what species of *Phytophthora* were present in plants showing wilting or root rotting. This arose following concern in the industry that, based on recent samples sent to plant clinics, species other than *P. rubi* could be contributing to plant losses. Within their regions, consultants and growers sampled both partially rotted roots and the lower 100 mm of still-living cane, from symptomatic plants. There was no intention to systematically sample from across the UK. Twenty batches of samples were received between March and September 2019, from approximately 68 plantations, all but one from England. A total of 180 plant tissue samples were tested, from 76 raspberry plants of a range of ages and varieties. Three quarters were containerised rather than soil grown. In most cases one cane and a sample of roots were tested from each plant, resulting in 89 root tissue samples and 79 cane, although 12 raspberry leaves were also tested.

Two experimental lateral flow devices (LFDs) were used, one with the antibody 3H7 which reacts to the presence of a wide range of *Phytophthora* species, and the other with 3C4 which was expected to give a positive test line with *Phytophthora* species only in *Phytophthora* Clade 1 (which includes *P. idaei*), Clade 7 (which includes *P. rubi*) and Clade 8. Subsequently, frozen tissue was re-sampled to extract and amplify DNA of *Phytophthora* spp. by nested PCR to enable sequences to be matched against a database of *Phytophthora* species.

Phytophthora spp. were detected in the majority of samples using the “general” experimental LFD. Tissue which gave positive readings with the 3C4 LFD was later confirmed by DNA sequencing to have successfully detected *P. rubi* and *P. idaei*. The 3C4 LFD also at times was positive for samples later shown to contain DNA of *P. citrophthora*, *P. bishii*, *P. citricola* and *P. plurivora* and, as these are within Clade 2, it was not expected to detect them. It was unclear if this was a true result or whether *P. rubi* had been present only in the tissue sub-sample tested with the LFD. A few instances of *Peronospora sparsa* (downy mildew) DNA were detected and it was unclear whether the positive LFDs for these samples had reacted to the *P. sparsa* or if *Phytophthora* spp. had been present in the material tested by them.

P. rubi was found in 42.8% of samples received. It was isolated from 42.1% of canes and 34.8% of roots. 10.8% of all samples received had no *Phytophthora* spp. DNA detected.

Phytophthora species other than, or in addition, to *P. rubi* were identified from 23.8% of all the samples; principally comprising 8.9% *P. citrophthora*, 6.1% *P. bishii* and 2.8% *P. citricola*. Only 0.5% had *P. idaei.* The extent to which these species contributed to symptom development on raspberry in the UK requires further study. However, *P. bishii*, *P. citrophthora* and *P. citricola* are known as raspberry pathogens in other countries, but only the latter has published records on raspberry in the UK.

A further 16.1% of samples the *Phytophthora* spp. infestation was unable to be defined from the DNA, but probably included *P. rubi* mixed with another species. Some DNA sequences, from nine plants, could not be matched to any *Phytophthora* species currently on the extensive genetic database utilised.

Further details of the survey are given in the Science Section.

Financial benefits

The UK raspberry industry is worth approximately £146.8 million at farmgate prices, from and area of 1,424 ha (Defra Horticulture Statistics, 2019).

Raspberry root rot leads to wilting of crops, and when severe, crops can be lost. Losses before cropping have been reported from long-cane modules that have been cold-stored and in which there has been high investment in order to secure a good fruit yield in the first year of planting. Premature loss in yield of crops normally expected to produce over several years continues to be a problem. Although a drench with Paraat (dimethomorph) is usually used by growers this is not sustainable in the longer-term and more attention will need to be given to identifying where infection is coming from and adopting more plant hygiene measures.

This project has shown that species other than *P. rubi* are present at currently low incidence, and that this includes presence in propagation material. By alerting the industry at this time, action should be able to be taken to find out more about these species and to seek ways to prevent further spread of these and *P. rubi.*

LFDs developed with previous AHDB funding were effective at detecting *P. rubi* and *P. idaei* and other pathogenic *Phytophthora* spp. without including saprophytic species that can mislead disease diagnosis and are detected by the currently commercially available LFDs.

Action points for growers

- Paraat (dimethomorph) has been confirmed to provide control against *Phytophthora rubi*, either when applied in Autumn (pre-infection) or in Spring (post-infection).
- Applications of Prestop (two applications) or Serenade ASO (single application) drenches in Spring to cold stored plants are unlikely to reduce the development of Phytophthora root rot, where plants became infected the previous Autumn.
- Plants coming out of cold-storage can show more roots rotted in Spring than those left outdoors and it is important to facilitate good establishment by allowing thorough thawing before potting-up.
- Free-water in pots is conducive to the spread of *Phytophthora* spp. and so aim to adjust irrigation to the uptake of plants with variations in temperature and growth.
- Be alert to any changes in the extent or timing of wilting due to root rot, as *Phytophthora* species other than *P. rubi* have been confirmed in commercial raspberry plants.
- Novel antibodies used in two lateral flow devices (LFDs) were shown to detect a range of *Phytophthora* species, with one of the pair limiting detection to pathogenic *Phytophthora* spp., but further work will be required before commercial release of these as kits. In the meantime, testing on site with currently available LFDs detecting all *Phytophthora* spp. is recommended if not using a diagnostic laboratory.
- To reduce the probability or re-occurrence in subsequent years, when plants are confirmed to be infected by *Phytophthora* spp. efforts should be made to trace the source of the infection through keeping records of the distribution within the plantation and whether worse in particular fields or propagation batches.
- Ensure that infested irrigation water is not used and other hygiene measures are in place to stop pathogens spreading between plants, particularly in propagation areas.

Sampling raspberry and blackberry plants and soil from crops affected by Verticillium wilt in order to test a newly developed molecular assay

Headline

- Quantitative detection of *V. dahliae* was achieved using qPCR on cane and root tissue and from the soil around roots

Background and expected deliverables

Verticillium dahliae and *Verticillium albo-atrum* are the causal agents of Verticillium wilt in raspberry and blackberry, resulting in stunted shoots, extensive wilting and ultimately plant death. Crop loss can occur if the canes die before reaching maturity and as plants succumb once established. Severe outbreaks have occurred sporadically in UK cane fruit crops and widespread infection at a lower incidence is suspected. The area of primocane-fruiting raspberries has been increasing in the UK and the cultivars grown tend to be susceptible to Verticillium wilt. *V. dahliae* and *V. albo-atrum* have a wide host range and persist in soils, with the level present in a field thus affected by previous cropping. The relative damage caused to raspberry by each *Verticillium* species is not known.

The Harris test, a wet sieving method, can be carried out on soil samples before planting to enumerate the microsclerotia of *V. dahliae*. However, many growers do not submit samples because the assay takes 6-8 weeks. *V. albo-atrum* is not detected by the Harris test.

In 2015, Real-time, or Quantitative, PCR assays (qPCR) for testing soils for *V. dahliae* had recently been successfully developed in AHDB Project SF 97, providing results within a few days, with detection of *V. dahliae* down to levels correlating with 0.5 microsclerotia / g soil. Observations have suggested a tolerance of up to 50 propagules / g soil for some commercial floricane raspberry cultivars, while some primocane fruiting cultivars may be ten times more susceptible. Records obtained from qPCR of soil before planting a range of cultivars could be used in future to establish microsclerotia thresholds for raspberry and blackberry.

The work in 2015 sought to use qPCR to determine levels of soil and plant tissue infestation by *V. dahliae* and to examine these in relation to the severity of wilting recorded in the crop.

Summary of work and main conclusions

Years 1-2 (2015-2016); qPCR for quantification of *V. dahliae* in cane fruit tissue and soil

Samples associated with 40 mature plants consisting of raspberry, hybrid berry and blackberry were taken in August 2015 from a variety of farms and ranged from asymptomatic to severely infected. Sampling was carried out by excavating the soil beneath and around an affected plant and sections of cane, crown and attached roots were collected. A further 65 samples of symptomless plants in substrate were collected from propagators. The qPCR assay was carried out utilising pre-extraction processing, buffers to remove reaction inhibitors and an automated DNA binding system to capture total DNA to detect *V. dahliae.*

The symptomatic plants with the higher wilt severity indices were those that tested positive for *V. dahliae* DNA in either or both stem bases and roots. Symptomatic plants that were growing in clay loam were more frequently shown to be positive for *V. dahliae* DNA than those from sand. No *V. dahliae* was detected in plants direct from propagators. In all instances the mean levels of DNA of *V. dahliae* detected in the stem base material was greater than in the roots of raspberry. There was a good correlation between level of *V. dahliae* detected in the stem bases and the roots of each plant.

V. dahliae was detected in almost half of the raspberry plants showing symptoms, but very few of the soils (3 from 22). It was unclear if this was because the assay was less able to detect the pathogen DNA in the soil than it is in plant tissue.

In 2016, the assay was assessed for sensitivity using DNA extracts from pure cultures of *V. dahliae* and detected down to 0.04 pg/ul of extract from *Verticillium* culture.

Survey results were given mainly in the 2016 Annual Report, with an update in the 2017.

Work in 2019 by a PhD student at Fera as part of the AHDB Soil Biology and Soil health project has since reduced soil sample size from 1 kg and is seeking to improve detection sensitivity.

Financial benefits

Verticillium wilt of raspberry and blackberry has become a much greater threat to raspberry and blackberry growers in the past 15 years. Many of the modern primocane raspberry and the recently introduced blackberry cultivars are particularly susceptible to *Verticillium dahliae* (the cause of Verticillium wilt). Plant pathologists and cane fruit growers lack the knowledge of how susceptible different cultivars are to the disease at differing levels of the resting bodies of the pathogen in field soils. This has made it difficult to make management decisions about the safety of a new field destined to host a cane fruit crop.

Molecular quantification of *V. dahliae* in soil has become possible and there is potential for this to replace the much slower Harris test method of extraction of microsclerotia and to be less costly. Comparing the quantities of *V. dahliae* DNA in soil with that in plants of various wilting severities growing in the same soil allows the linking of pathogen levels to host symptom severity and whether there may be plant tolerance to certain soil levels.

The future benefit will be that through improving our knowledge of cultivar susceptibility, with futher work to develop threshold levels of soil inhabiting *Verticillium dahliae* for different cultivars, it will allow growers to make informed decisions about the safety of a new field soil which might be used to establish a new crop, thereby avoiding severe crop losses to the disease in the first two to three years of a plantation’s life span.

Action points for growers

- Caution is needed if intending to plant cane fruit in soil as it can be infested with *Verticillium* spp., with selected cultivars particularly susceptible to infection.

- Soil should still be sent for Harris testing to detect microsclerotia until molecular techniques are validated; allow approximately five weeks for test turnaround.

A review of the current threat posed to the UK raspberry industry by cane blight (*Leptosphaeria coniothyrium*) and identifying new control options

Headline

- Control of cane blight in UK raspberries is of increasing importance and requires renewed attention due to the loss of plant protection products for control of both the pathogen and raspberry cane midge.

Background and review findings

A review of cane blight epidemiology and control was carried out for the 2019 Annual Report. This was carried out because UK raspberry growers are beginning to see high levels of infection of cane blight (*Leptosphaeria coniothyrium*). Cane blight is now being seen in double cropping primocane as well as summer fruiting raspberries. Cane blight is a relatively weak pathogen, so often requires damage to the cane in order to enter the plant. Damage can follow poor control of raspberry cane midge (*Resseliella theobaldi*) (exacerbated by the loss of chlorpyrifos), frost, strimming or poor application of desiccant to control unwanted primocane. With the loss of Folicur (tebuconazole), Signum (pyraclostrobin + boscalid) became the sole product for control of cane blight, but the dose rate permitted is lower than that which gave efficacy in trials.

An extensive review of cane blight epidemiology was performed for the AHDB in 2006, as well as a fungicide efficacy trial. This work indicated that infection can take place far later than when fungicides are normally applied during and immediately post-harvest. Infection period is affected by levels of cane maturity, and now, due to most crops fruiting under protection and primocane selection being delayed, the primocane rind is far less mature than previously.

This review for Project SF 158 concluded that there is a need for trials to not only test efficacy of new fungicides against cane blight, but also to understand the disease life cycle in soil and soilless substrate grown crops under protection. No new work in breeding resistance to *L. coniothyrium* has taken place since 2008. The life cycle of *L. coniothyrium* is still not fully known, in particular the time of year and conditions for spore dispersal and any changes to this brought about by growing the crop in tunnels for part of the year. Knowledge of spore release timing and tissue infection susceptibility is important for decisions on fungicide spray timing. In other countries where cane blight is a major issue, such as in Canada, primary control is through the use of good crop husbandry and hygiene. Biennial cropping also significantly reduces the old to new cane spread of pests and diseases and is likely to be of benefit in the control of cane blight.

A review of biennial cropping and annual cropping of long-canes as a means of pest and disease control with a financial comparison of different production systems

Headline

- The yields and gross margins following the first year of biennial cropping were envisaged to be poorer than in the second and third year of traditional systems, in the absence of losses to pests and diseases

Background and review findings

Previous work has demonstrated the benefits of separating the two phases of growth in raspberry in breaking the life-cycles of cane blight, raspberry cane midge and associated midge blight. The purpose of this financial comparison was to assess the impact that this would have on the profitability of raspberry production. A great many assumptions were included in the budget comparisons. These included assumptions on receipts, variable costs of price, variable costs of yield and variable costs based on area.

A table was produced summarising the differences between the systems in each of the three years calculated comparing the yield per hectare for each, the cane management costs for each and the gross margin for each. The traditional Glen Ample (summer fruiting) was used as a baseline against which the annual long-cane Glen Ample and biennial Glen Ample are compared. The traditional Kweli was used as a baseline against which the annual long-cane Kweli is compared.

In Year 1, the yields and gross margins of the annual and biennial systems compare favourably with the traditional summer fruiting and traditional primocane production systems. The annual long-cane system produced over twice the gross margin of the traditional while the biennial system produced over a third more. The annual long-cane primocane system produced almost two and half times the gross margin of the traditional primocane.

In contrast, in Years 2 and 3, the yields and gross margins of the annual (long-cane) and biennial systems compared poorly with the traditional systems and in the majority of cases, these were less than those produced by the traditional Glen Ample and Kweli crops.

In all three years, there were reductions in cane management costs when using annual (long-cane) or biennial cropping compared to traditional.

Although the yields and gross margins were favourable on the first year of production for the annual (long-cane) and biennial systems and less so on the second two years, caution was urged when considering these. The budgets which were constructed took no account of crop loss caused by insect pests or diseases, assuming that optimum yields could be achieved from each system.

The exercise demonstrated the change in finances that may occur should labour availability and loss of crop protection products render the systems of growing more or less viable than at present. Many pests and diseases are becoming increasingly difficult to contain with a diminishing number of crop protection products available. As the availability of these products declines further, raspberry growers may find they have no alternative but to turn to annual cropping of long canes or biennial cropping to achieve satisfactory control.

Developing and maintaining Integrated Pest Management (IPM) to successfully control two-spotted spider mite whilst controlling spotted wing drosophila (SWD) and other pests with conventional sprays

Headlines

- Early releases of *Amblyseius andersoni* led to better control of a late infestation of spider mite compared to a preventative release of *P. persimilis* in a commercial propagation raspberry crop.
- Experimental overhead, rather than crop-face, spraying resulted in less deposition on leaf undersides, so providing refuges for natural predatory mites (mainly *A. andersoni*) thus resulting in their reduced mortality, without any loss of control of SWD.

Background and expected deliverables

Spotted wing drosophila (SWD), *Drosophila suzukii*, has established in the UK and this fruit pest is currently controlled with conventional spray programmes, coupled with good farm hygiene. Given that much of the control for other pests in raspberry crops, such as the two-spotted spider mite, *Tetranychus urticae*, relies on biological control within Integrated Pest Management (IPM) programmes, it is important to develop IPM-compatible strategies for control of SWD. It can be hypothesised that as spray programmes for SWD can negatively affect the biocontrol agents for spider mite, leaving unsprayed refuges on the undersides of leaves for commercially introduced and naturally occurring predatory mites may help to maintain the population of predators. Therefore spray application methods which would provide good coverage on the upper leaf surface, but leave the lower leaf surface unsprayed were explored.

Experiments were carried out (by NIAB-EMR) 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.

Options for control of two-spotted spider mite (TSSM) with acaricides are very limited, so biological control of the pest within an IPM programme is key to successful management. However, growers need to know how to maintain their IPM programmes whilst applying control products for SWD. The predatory mite *Phytoseiulus persimilis* can give very effective control of TSSM. However it needs warm temperatures to establish and is very susceptible to plant protection products applied for control of other pests including SWD, aphids and capsids. The native predatory mite *Amblyseius andersoni* occurs naturally on raspberry crops and is also commercially available for release on both protected and outdoor crops. *A. andersoni* is also active at a wider temperature range than *P. persimilis*, can establish earlier in the season, does not need TSSM to survive as it can feed on other food sources such as pollen, fungal spores and certain other pests, and is considered to be more tolerant of conventional spray products than *P. persimilis*.

Investigations were therefore carried out (by ADAS) to monitor populations of natural and released predators on commercial raspberry crops and to investigate the role of *A. andersoni* in the control of TSSM whilst controlling SWD and other pests with sprays of Plant Protection Products. The use of a commercially available pollen to boost *A. andersoni* populations was also studied.

Summary of the project and main conclusions

Year 1 (2015); monitoring effects on predators and other pests of sprays against SWD on commercial raspberry crops

In the first year of this project, ADAS monitored the effects of Plant Protection Product sprays applied for control of SWD and other pests on both released and naturally occurring TSSM predators on two commercial tunnel-grown raspberry crops. At the first site low numbers of released *P. persimilis* and naturally occurring *Amblyseius andersoni* and *Neoseiulus californicus* survived applications of thiacloprid (Calypso) and spinosad (Tracer). At the second site, no *P. persimilis* were released but naturally occurring *A. andersoni* and *N. californicus* survived applications of clofentezine (Apollo), abamectin (Dynamec), Tracer and pyrethrins. The conclusion was that naturally occurring predators are likely to have played an important role in maintaining control of TSSM at both sites.

Year 3 (2017); testing the effect on predators of a spray against SWD on a commercial raspberry crop

The 2017 study by ADAS aimed to build on the 2015 monitoring work to provide more robust information on a commercial tunnel-grown primocane raspberry crop. A high density of TSSM was controlled by late July by a combination of *P. persimilis* (released by the grower) and by four naturally-occurring predators; *A. andersoni*, the predatory midge *Feltiella acarisuga,* the ladybird *Stethorus punctillum* and the predatory bug *Orius* sp. A tank mix of Tracer and deltamethrin (Decis) was then applied in early August for control of SWD and blackberry leaf midge respectively and this timing avoided the disruption of IPM.

Year 4 (2018); testing the use of pollen as a food source to boost predator numbers on a commercial raspberry crop

The 2018 experiment by ADAS tested whether a commercial pollen product (Nutrimite^{TM}) could boost numbers of either naturally occurring or released *A. andersoni* and improve control of TSSM on a commercial primocane raspberry crop where *P. persimilis* was also released. Nutrimite^{TM} is being used in Europe and Canada to improve the establishment of other predatory mite species on other horticultural crops but has not previously been tested on raspberry with *A. andersoni.* Numbers of naturally occurring *A. andersoni* were low and adding pollen did not increase their numbers. However, on some of the assessment dates, adding pollen to the plants where *A. andersoni* were released led to significantly higher numbers of these predators. Numbers of TSSM were similar in all treatments and the pest was controlled by late July through a combination of *P. persimilis* and *A. andersoni*, before Tracer was applied on 31 July for control of SWD, this timing thus avoiding disruption of IPM.

Year 5 (2019); testing predator and pollen releases to improve TSSM control

Gaining control of TSSM in raspberry crops during propagation is critical to managing the pest in the fruiting crop the following year. The 2019 experiment by ADAS tested the use of *A. andersoni* compared with and combined with preventive releases of *P. persimilis* to a raspberry propagation crop. The benefits of adding the pollen food supplement Nutrimite^{TM} was tested with *A. andersoni*. Preventive predator and pollen releases started on the young crop in the propagation tunnel and continued after transplant into the field. Early preventive releases of *A. andersoni* led to better control of an unusually late infestation of spider mite compared with preventive releases of *P. persimilis* which disappeared before TSSM was present. There were significantly fewer TSSM, eggs and damage where *A. andersoni* was released with pollen compared to where only *P. persimilis* was released, but no fewer than where *A. andersoni* was released without pollen. Nutrimite™ boosted the *A. andersoni* population on one date immediately after transplant to the field.

In 2020 the experiment on the propagation crop was followed through winter to compare the survival of *A. andersoni, P. persimilis* and TSSM from the different treatment programmes in cold storage and in ambient conditions. This work showed that *Amblyseius andersoni* and TSSM survived 15 weeks of commercial cold-storage at -1°C in low numbers. The results also showed that significantly more *A. andersoni* eggs were found in the cold-stored primocane buds of plants where *A. andersoni* and Nutrimite™ had been released in the previous season compared with the plants where *A. andersoni* had been released alone or alone with an additional autumn release. In this experiment the additional autumn release of *A. andersoni* on 5 September did not significantly affect the number of overwintered *A. andersoni* or TSSM. The numbers of overwintered TSSM and *A. andersoni* largely reflected the population dynamics seen in each treatment in the previous season. This shows that it is important to gain control of TSSM in a propagation crop before TSSM has a chance to find overwintering positions and also that releasing *A. andersoni* will 'seed' the crop with a reproductively active population of predators for the following spring.

Years 1 - 3 (2015 - 2017); to compare populations of TSSM and predatory mites after either overall canopy spraying or overhead misting application against SWD in small experimental 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 and the effects of date and treatment were significant. In early August, the numbers of natural predatory mites (mainly *A. andersoni*) 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 Decis/Bandu and Tracer was used, with different nozzles to give a slightly larger droplet size. This gave less spray on the underside of the leaves in the overhead spray treatment and although the natural phytoseiids (mainly *A. andersoni*) 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. 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. 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 predatory mites. As in 2016, the sprays reduced the numbers of natural predatory mites, 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 only low numbers of *P. persimilis* present it was not possible to determine the effect of the deltamethrin sprays in the polytunnel experiment in 2017. However, laboratory work showed that direct application of deltamethrin killed almost all *P. persimilis* adults within 24 hours, demonstrating that the commercially available strain of *P. persimilis* was not resistant to pyrethroids. The numbers of SWD were low in 2017 therefore no significant treatment effects could be determined.

Year 4 (2018); to assess and adjust spray deposition throughout a commercial crop canopy

In 2018, a field trial was done to assess the spray coverage, spray deposition, and distribution of spray throughout the crop canopy. The raspberry crop was sprayed with a fluorescent tracer and a handheld imaging fluorometer recorded the fluorescence values that were a proxy for the volume of sprayed liquid on the leaf surfaces. The spray was applied to the crop in July, using an Ideal Alsazia axial fan spray machine at 840 L/ha, with either yellow Albuz ATR 80 nozzles (very fine spray quality) or blue ATR 80 nozzles (medium spray quality), and with the air-assistance set to full rate or half rate. The plant canopy was divided into three vertical zones: Top third, Middle third, Bottom third, with an additional zone at the middle section but deep in the canopy referred to as the Inner zone. At each of the zones, the spray deposition was measured on both upper and lower leaf surfaces (**Figure 1**).

Spray deposition (coverage and volume of sprayed liquid) was highly variable throughout the raspberry canopy. A common trend was more spray deposited at the top and middle sections of the canopy, much less deposition at the bottom of canopy, and very little deposition at the inner section of the canopy.

The very fine quality spray in combination with half-rate air-assistance spray settings provided a more even distribution of spray throughout the canopy, with significantly increased spray coverage and deposition in the bottom and inner canopy sections. The medium quality spray in combination with half-rate air-assistance also partially increased spray deposition at the middle and inner canopy sections.

The variations in spray product coverage about the calculated means was shown to be important. More than 50% of leaves sampled from the middle canopy section-lower leaf side, inner canopy-both leaf sides, and bottom canopy-lower leaf side had less than 5% spray coverage, potentially providing many refuges for insects and mites from control sprays. At these canopy-leaf sections, it was broadly the same for all of the spray settings assessed.

Further research is needed on the role of *A. andersoni* in TSSM control on raspberry and its best-practice use in an IPM programme.

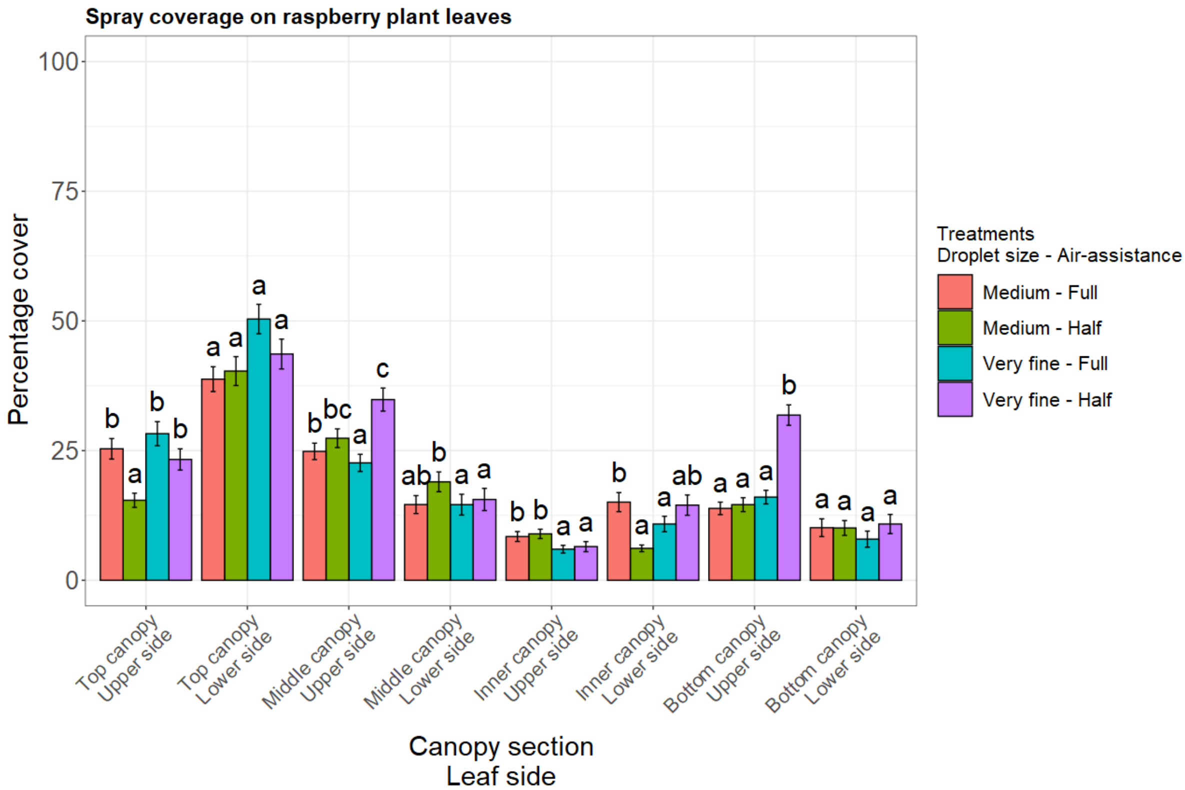

Figure 1. Percentage of leaf area covered with spray deposits at each canopy zone and leaf side, for each of the four spray treatments. The error bars show standard error. Significant differences were identified by GLMER and multiple comparisons Tukey's tests. If significant differences were identified, letter labels denote significant differences between the treatments within each canopy zone / leaf side

Financial benefits

The UK raspberry industry was worth £146.8 million grown over 1,424 ha in 2019 (Defra Horticulture Statistics, 2019). Plant protection products (PPPs) (fungicides, herbicides, insecticides) in raspberry production can cost between £450 and £1,700 per hectare, depending on the cropping system. Application of spray products reduces both natural and purchased predator populations. Increased grower awareness of, and modifications to, the distribution of spray deposits and the timing of applications could achieve improved pest management by the better integration of both chemical and biological methods.

Figures are not available for the cost of spider mite damage to the raspberry industry. Damage caused to raspberry plants reduces photosynthesis and plant quality. Severe infestations can lead to total defoliation, at great cost to the industry. If an untreated spider mite infestation accounted for only 5% damage to raspberry leaflets and was equivalent to 5% loss in crop value then savings would be made with four biological control treatments, according to the results of the final year of this project (**Table 1**). The cost of six applications of Nutrimite™ (two under protection, four in the field, 26p / pot) was less than one release of *A. andersoni* in the field (31p / pot). Far more *A. andersoni* than *P. persimilis* were released, at a higher cost per pot, but a lower cost per 1,000 mites because they were distributed in breeding sachets rather than released directly in a carrier. Also, since spider mite was not seen in the crop until 5 September, *P. persimilis* was only released three times preventively and once curatively. If TSSM was recorded on earlier assessment dates *P. persimilis* would have been released weekly or fortnightly until established.

Table 1: Costs of the final year treatment programmes compared with potential savings, based on the findings of the experiment. Labour costs have not been included and product costs would be subject to economies of scale. *Estimated savings based on an untreated spider mite infestation causing 5% leaflet damage, equating to 5% loss in crop value.

Treatment	Biocontrol treatment programme	Cost per pot of 3 plants (£)	Total number of mites released	Cost per 1,000 mites	Average % leaflet damage on 16th Oct	Estimated savings to industry* (£ / ha)
T1 *A. andersoni*	4 x release of *A. andersoni*	0.90	1,050,000	£ 0.27	0.325	3,920
T2 *A. andersoni* + pollen	4 x release of *A. andersoni* + 6 applications of Nutrimite™	1.16	1,050,000	£ 0.35	0.062	4,141
T3 *A. andersoni* + *P. persimilis*	4 x release of *A. andersoni* & 4 x release of *P. persimilis* (3 preventive, 1 curative)	1.34	1,080,000	£ 0.40	0.237	3,994
T4 *P. persimilis*	4 x release of *P. persimilis* (3 preventive, 1 curative)	0.45	30,000	£ 4.77	0.587	3,701

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, preventive release of *A. andersoni* for TSSM control as soon as temperatures reach 6°C as this predatory mite is more tolerant of low temperatures than *P. persimilis*.
- Use IPM-compatible plant protection products or those with least harmful effects on biological control agents for control of all pests including SWD wherever possible.
- If using plant protection products known to be harmful to biological control agents, some predators may survive in spray refuges' where less deposition occurs, but try to time predator releases to reduce adverse effects.

Developing and combining novel and current IPM approaches to successfully control blackberry leaf midge

Headline

- *Steinernema kraussei* reduced blackberry leaf midge emergence from pupae in laboratory-based coir pot tests but was ineffective in a field trial. More research would be needed to further test potential control in a commercial crop.

Background and expected deliverables

Blackberry leaf midge (*Dasineura plicatrix*) has become an increasing problem on blackberry, hybrid berry and raspberry, with double cropping primocane raspberry being particularly vulnerable to attack. The pest can have up to four generations per year under protection and damages the leaf tips and growing points, which can stunt cane growth, give rise to cane branching and reduce yield. As the midge larvae feed within the leaf tips they are very difficult to target using foliar sprays of plant protection products. Deltamethrin (Decis) can give some control, probably of adults, but is incompatible with IPM. In SF 102 'Biology and integrated control of blackberry leaf midge on blackberry and raspberry', a laboratory pot test showed that using polythene or woven ground-cover matting over the substrate inhibited successful pupation of larvae dropping to the ground, reducing adult midge emergence by 96% and 53% respectively compared with the substrate control. Although covering the entire floor of a polythene tunnel may not be practical, the experiment demonstrated that a ground-based strategy for control of the pest could be effective. Therefore in years 1 and 2, a ground-based strategy was tested using entomopathogenic nematodes to target fully-grown larvae of blackberry leaf midge that drop to the ground to pupate.

Year 1 (2015); testing entomopathogenic nematodes against blackberry leaf midge

In a laboratory pot test, a drench of the entomopathogenic nematode *Steinernema kraussei* (Nemasys® L) significantly reduced mean numbers of blackberry leaf midge adults emerging from treated coir substrate compared with water control pots after adding fully grown midge larvae to the substrate surface to mimic their natural behaviour of dropping to the ground to pupate. Drenches of two other nematode species (*S. feltiae* and *S. carpocapsae*) were ineffective. Nemasys® L is widely used already as a drench for control of vine weevil on soft fruit crops.

Year 2 (2016); in-crop assessment of nematode drenches against blackberry leaf midge
In a second year, the efficacy was tested of two consecutive drenches of Nemasys® L applied to the soil beneath the canopy of a commercial, soil-grown, tunnelled raspberry crop with a history of blackberry leaf midge, timed to target first and second generation larvae that dropped to the soil. The treatments did not reduce the percentage of leaf tips infested compared with untreated controls. Possible reasons for lack of control were insufficient soil moisture for nematode movement and survival and the short 'window' of opportunity for nematodes to infest the midge larvae before they spin a protective cocoon within which to pupate.

Financial benefits

The blackberry leaf midge is a relatively new pest of raspberry and blackberry in the UK, having assumed greater importance as increasing crop areas have been protected by temporary polythene tunnel structures in the field. It is not uncommon to find that the midge has reduced raspberry yield by 40% and blackberry yield by 10%.

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 40% crop loss caused by blackberry leaf midge would lead to a financial loss of £36,355/ha. Developing a novel IPM approach will significantly reduce such losses from blackberry leaf midge.

Action points

- No action points were given for blackberry leaf midge control from this piece of work.