Grower Summary

SF 157

Improving integrated disease management in strawberry

Final Report 2019/2020

Project title:	Improving integrated disease management in strawberry
Project number:	SF 157
Project leader:	Prof Xiangming Xu NIAB EMR
Report:	Final 2019/2020
Previous reports:	Annual, Years 1, 2, 3 and 4
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Location of project:	East Malling; Cambridge; Wisbech
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Date project commenced:	1 March 2015
Date project completed (or expected completion date):	31 March 2020

DISCLAIMER

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

AUTHENTICATION

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

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GROWER SUMMARY

For ease of reading, this Grower Summary report is divided into sections for each of the diseases being worked upon in the project. **This summary covers all the main findings from the five-year project, not just the final year.**

Crown rot and red-core caused by Phytophthora spp.

Headlines

- Prestop when applied through drip irrigation lines led to significant reductions in plant wilting/death (following inoculation with *P. cactorum*) whilst T34 Biocontrol also showed some promising results in improving plant health.
- A new experimental chemical compound (AHDB code F250) when applied through drip irrigation lines led to significant reductions in plant wilting/death (following inoculation with *P. cactorum*). This compound will be further evaluated in a SCEPTREplus trial in 2020.

Background and expected deliverables

Adopting a clean propagation system is the first line of defence against crown rot and red-core diseases. This strategy worked for many years but prior to project commencement, crown rot and red-core caused significant damage in strawberry even in substrate production. Fenomenal (fenamidone + fosetyl-aluminium), an effective product against Phytophthora, has not been approved for use in strawberry since November 2019. Alternative products for control of crown rot (both fungicides and biocontrol products) were identified in trials conducted by NIAB EMR as part of the SCEPTRE project. In previous AHDB-funded research, SF 130 focussed on fungal molecular quantification; an assay was developed that detected *Phytophthora rubi*, although it was not as sensitive as the *Phytophthora fragariae* assay (which however detects both pathogens). SF 123 investigated alternative products against *P. rubi* on raspberry where one novel chemical product gave reduction. Red-core is more difficult to control and currently there is no work on controlling this disease. More research is required to provide growers with disease-free propagation material in order to reduce crop protection product use and crop losses.

Summary of the project and main conclusions

A survey was conducted along with a molecular screening of bare-rooted runners for the presence of *Phytophthora* spp. The percentage of runners with contamination of *P. fragariae* (causal agent of red core) was so low that subsequent project work did not focus on this pathogen. However, the level of contamination of *P. cactorum* (causal agent of crown rot) could reach 25-30% in some batches of plants although more usually, it was less than 5%; nevertheless there may only be 5% of runners with visible symptoms of crown rot at the time of planting. Further studies assessed the effect of pre-inoculating plants either with arbuscular mycorrhizal fungi (AMF) or plant growth promoting rhizobacteria (PGPR). Neither managed to reduce the losses caused by *P. cactorum*. In addition, we found that latent infection of plants with *P. cactorum* led to reduced tolerance of plants to drought stress.

Two large studies were done to test existing and new products as dipping (at planting) or drenching/irrigation treatments post-planting, to minimise the losses due to latent infection by *P. cactorum*. To ensure a certain level of latent infection by *P. cactorum,* tray plants were inoculated several times (without wounding) before cold storage. Results showed that dipping alone is sufficient to reduce the level of *P. cactorum* to the level comparable to the un-inoculated control; thus additional drenching is not necessary. Further work demonstrated that applying products through drip irrigation lines (more practical for growers) can be as effective as dipping treatments and better than the drenching only treatments. Treatments appeared to delay disease symptom development and/or reduce the disease severity but did not eliminate latent infection. Although no longer approved, Fenomenal was found to offer the best control in managing crown rot on strawberry. Prestop showed promising results, particularly when applied through irrigation lines (giving ca. 45% reduction in plant mortality). T34 Biocontrol showed some reduction in plant mortality by ca. 30%, close to being statistically significant, and thus should be evaluated further. A new experimental compound, when applied through irrigation lines, led to nearly 50% reduction in plant mortality.

Main conclusions (years 1-5)

- The level of bare-root runners with *Phytophthora fragariae* (red-core) DNA detected in commercial planting material is currently very low and can be ignored.
- The level of *P. cactorum* DNA detected in samples of runners can reach 30% although more usually it is less than 5%. The material is mostly in an asymptomatic state; the level of *P. cactorum* detection in runners is not associated with specific cultivars.
- Latent infection by *P. cactorum* reduced plant tolerance to drought stress.
- Pre-inoculation of plants with AMF and PGPR did not reduce the infection of strawberry crowns by *P. cactorum* but may have positive effects against *P. fragariae*.
- Several products when applied as a dipping treatment at planting time, significantly reduced the losses due to plant wilting/death, mostly due to infection by *P. cactorum*.
- Applying products post-planting through irrigation lines can be as effective at controlling crown rot as dipping and better than post-planting drenches alone.

Financial benefits

Potential loss of plants due to *P. cactorum* could reach 20-30%. In 2016, 90,000 tonnes of strawberries were sold in the UK season with the market valued at £386 million (Data from Kantar). Should 25% of plant losses occur in the UK as a result of crown rot, the volume of fruit sold could be reduced by up to 22,500 tonnes, representing a value of £96 million. Techniques and measures to control *P. cactorum* could therefore save such potential losses.

The project results suggested that growers should consider treating runners for *P. cactorum* at the time of planting. Effective control as a result of this research could reduce crown rot development by 40-50%, amounting to savings of £48 million across the industry.

Action points for growers

- Growers should consider treating runners with a post-planting application of Prestop via irrigation lines to improve plant health.

Strawberry powdery mildew (SPM)

Headlines

- Employing a managed approach to strawberry powdery mildew control can reduce fungicide use by up to 50% whilst maintaining the same level of control as a routine 7-day fungicide programme.
- The use of fungicides for Botrytis control in protected table-top strawberries offers no advantages over an unsprayed control.

Background and expected deliverables

Strawberry powdery mildew (SPM), caused by the fungus *Podosphaera aphanis*, is one of the most important diseases affecting strawberry production in the UK. All above ground parts of the plant are attacked and severe infection can have a significant effect on yield and fruit quality. The disease is more prevalent on protected crops and hence a particular problem in the UK where the majority of commercial crops are grown under polytunnels or in glasshouses. Strawberry cultivars do vary in susceptibility but most of the cultivars preferred by the market are susceptible. SPM is favoured by warm temperatures and high humidity such that conditions are most favourable from late June to October. Hence SPM problems are mainly seen in late cropping June-bearers (planted in May and cropping in August and September) or in the later production of the everbearer crops. In June-bearer type crops with the short harvesting period, control of SPM is relatively straightforward. However, SPM management in everbearer crops is much more challenging. Due to the long growing period from March to November coupled with flowering, fruiting and harvest continuous from June-November, a range of crop protection products is usually required to control SPM with around 15 or more spray rounds needed to cover the whole period. Control is currently based on fungicides, an approach which, given the concerns about residues in the fruit and the likely reduction in fungicide availability in the future, is not sustainable. The SCEPTRE project (2010-2014) identified alternative products, including Cultigrow (a biostimulant / elicitor) and two biofungicides (BCAs) – AQ10 (*Ampelomyces quisqualis*) and Sonata (*Bacillus pumilis*) a bacterial based biofungicide from Bayer. The purpose of the work in SF157 was to confirm the efficacy of these products, evaluate them in programmes with fungicides and develop a simple decision-based management system for SPM control.

Evaluating biofungicide and biostimulant products (Year 1 and 2)

This work was conducted at NIAB EMR under polytunnels. Efficacy trials in 2015 and 2016 were done in small plots (30 plants per plot) on cv. Elsanta planted in July / August to ensure the crop was growing in the high SPM risk part of the season. They were planted in soil on plastic-covered raised beds with trickle irrigation. The trial in 2015 confirmed the efficacy of the biofungicides AQ10 and Sonata (both applied with a wetter if used alone) and the biostimulant Cultigrow in controlling SPM either alone or in combination with fungicides. In 2016, further trials were conducted in which programmes were evaluated for control of SPM where the biofungicides (Sonata or AQ10) were combined in programmes with Cultigrow (CBL) with and without a reduced fungicide programme and compared to a 7- or 14-day fungicide programme and an untreated control. The mildew risk was high in 2016 but the results showed that the biofungicides were as effective in controlling SPM as the standard 7-day fungicide programme, particularly when applied alone in a programme and especially in reducing SPM on fruit.

Developing simple decision-based programmes to control SPM (Years 3-5)

Having identified alternative products that were effective on June-bearer crops, we then turned our attention to everbearer crops. We combined alternative products in programmes and incorporated other factors such as disease risk, growth stage, type of fungicide (curative, protectant, anti-sporulant) in order to develop a simple decision-based management programme for use on everbearer crops.

In 2017, programmes were tested in larger plot trials on a commercial everbearer. The SPM control achieved by managed programmes of fungicides and the biofungicide Sonata (used with a wetter if applied alone) was compared with that achieved by a routine 7-day fungicide programme and an untreated control. The managed programmes included routine applications of either a silicon-based product Sirius (applied every two weeks), based on the research of Dr Avice Hall (University of Hertfordshire) or Cultigrow (applied monthly) or no additional treatment. A total of 11 spray rounds were applied from 10 July to 18 September. As the trial was conducted from July to September in the high-risk part of the year for SPM, there was little opportunity to omit sprays. However, in the managed treatment, intervention with a fungicide in place of the biofungicide Sonata occurred only twice. The mildew risk throughout the trial was high. SPM incidence on the leaves was very low. However, on fruit the SPM incidence on untreated plots rose rapidly to more than 90% after four harvests and remained at that level for the remaining ten harvests with consequent reductions in yield and fruit quality. SPM incidence on the fruit in all treated plots was negligible throughout the harvest period (Fig. 1).

This trial demonstrated that use of biofungicides, with or without Sirius or Cultigrow, gave good control of SPM in strawberry, which was comparable to a traditional 7-day fungicide-based programme.

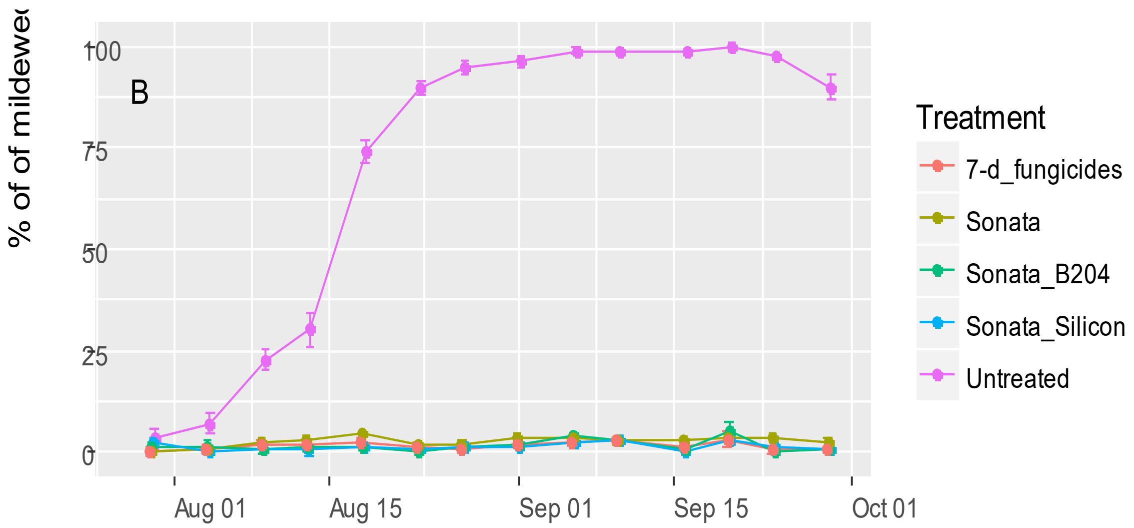

Figure 1. Percentage mildewed fruit at each harvest for a commercial everbearer following treatment with five management programmes against powdery mildew at NIAB EMR in

In 2018, trials were conducted on the same everbearer cultivar to further develop the managed approach and explore how the system could be integrated with control of Botrytis and other fruit rots. The crop was planted in April and cropped from early July to mid-September, giving the opportunity for saving sprays in the early part of the season, when the SPM and Botrytis risks are usually lower. Three managed treatments were compared to a routine 7-day fungicide programme and an untreated control (Table 1). The managed treatments were derived from the SPM risk prediction model developed by NIAB EMR and employed in previous AHDB funded SPM research projects managed by the University of Hertfordshire (SF 62 and SF 62a). From the model, simplified 'look up' tables were produced for use in conjunction with the forward weather forecast, obtained from the internet, to determine disease risk. Decisions on when to start the programme for SPM control along with choice of product were based on this (Table 2).

The weather conditions (warm temperatures coupled with high humidity) were very conducive to SPM and Botrytis development in late May / early June and from the end of July onwards. The high temperatures with very low rain in June and July gave a low risk for both diseases. There was a very low incidence of SPM at planting time and this combined with the hot dry weather in June and July meant that SPM failed to establish in the crop, despite the higher risk identified in August and September. Therefore, only four fungicide sprays (and 7 biofungicides - Sonata) for SPM were applied in the managed plots compared to 14 (and 2 biofungicides - Serenade) in the routine treated plots (Table 3). By contrast, the high risk of Botrytis rot identified in August and September required frequent applications of fungicides with little opportunity for saving sprays in the managed plots (Table 3). However, the incidence of Botrytis in post-harvest tests (Fig. 2) showed for most of the 20 harvests, differences in Botrytis between the untreated control and treated plots were very small. This questioned whether fungicides are needed at all for Botrytis control, which could lead to potential savings in cost and a reduction in fruit residues (Table 3).

Table 1. Treatment programmes evaluated in 2018

Treatment	Type	Products	Other
1	Untreated	-	-
2	Routine	Fungicides	None
3	Managed for SPM Sprays for Botrytis as for T2	Fungicides, Biofungicides,	Cultigrow applied monthly from start of growth
4	Managed for Botrytis and rots; sprays for SPM as in T2	Fungicides, Biofungicides	None
5	Managed SPM, Botrytis, and rots	Fungicides, Biofungicides	Cultigrow applied monthly from start of growth

Table 2. Simplified strawberry SPM and Botrytis risk in relation to daily average temperature and relative humidity

Condition		SPM risk
Temperature	**Humidity**	
< 14	Not relevant	Low
≥ 14	< 82%	Moderate
≥ 14	≥ 82%	High
		Botrytis risk
Not relevant	< 82%	Low
< 16	82% - 87%	
< 16	≥ 87%	Moderate
≥ 16	≥ 82%	High

In 2019, trials were conducted on the same everbearer cultivar to further evaluate the SPM management system and to reassess the value of fungicides for rot control. Cool chain management of the fruit post-harvest was also included as part of the fruit rot management programme. The crop was planted on 1 May and cropped from 9 July to 17 September. This provided the opportunity for saving sprays in the early part of the season, when the risks of SPM and Botrytis infection are usually lower. Two managed treatment programmes were compared to a routine 7-day fungicide programme and an untreated control. Both managed programmes were based on the biofungicide Sonata (used with a wetter if applied alone) applied as a protectant programme once a mildew risk had been determined, with the option to intervene with a traditional fungicide when the risk was high. One managed treatment included fungicides for Botrytis applied according to risk (Treatment 3). No fungicides for Botrytis control were included in the second managed treatment (Treatment 4). As in 2018, the simple 'look up' table (Table 2) derived from the SPM risk model, was used in conjunction with the forward weather forecast, obtained from the internet, to determine disease risk, dictating decisions on the when to start sprays for SPM and choice of product.

Table 3. Summary of fungicides, Biofungicides, biostimulants applied to strawberry plots at NIAB EMR 2018 and programme costs

Treatment	Management treatment				
	Untreated	Routine fungicide	SPM managed / Routine, Botrytis	Routine SPM / Managed Botrytis	Managed for SPM and Botrytis
Botrytis fungicides	0	13	14	12	11
SPM fungicides	0	14	4	15	4
Total fungicides	0	27	18	27	15
Biofungicide	0	2	7	0	5
Biostimulant	0	0	4	0	4
Cost £/ha					
Total cost	0	2,278	2,169	1,905	1,579
SPM only	0	1,033	677	890	677
Botrytis only	0	1,596	1,700	1,223	1,111

In 2019, the weather conditions (warm temperatures coupled with high humidity) were very conducive to SPM and Botrytis development in late May / early June and continued for much of the trial period from the end of June onwards. Despite the favourable conditions for most of the trial period, only a low incidence of SPM was present on leaves in untreated plots with negligible incidence on treated plots. SPM eventually established on fruit in early August reaching a mean of around 15% of fruit by the final harvest (Fig. 3). The incidence on treated plots was similar and remained very low. On SPM managed plots the first spray was delayed until 20 June. Fungicide intervention in response to increased mildew risk was made on two occasions. A total of 10 biofungicides, 2 fungicides and 4 biostimulants were applied to the two managed treatments compared to the routine treated plots where sprays started on 15 May and a total of 18 fungicides were applied (Table 4).

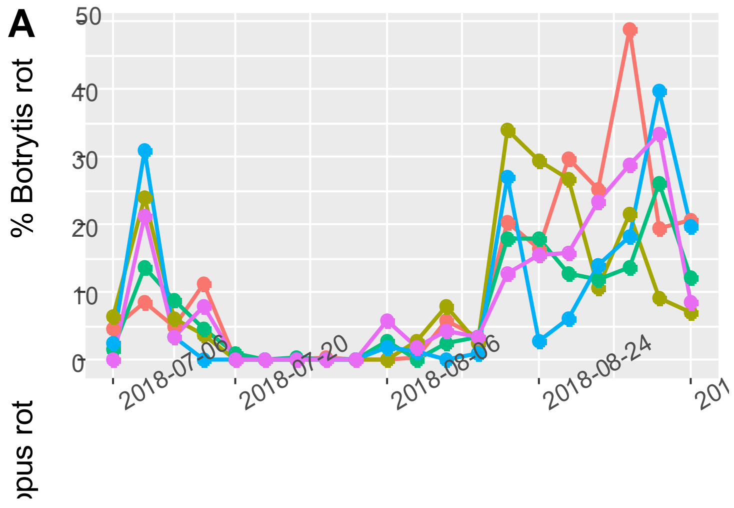

Figure 2. Percentage fruit with Botrytis rot over 20 harvests, in post-harvest tests on a commercial everbearer strawberry following treatment with 4 different programmes compared to an untreated control at NIAB EMR in 2018:

- Red: untreated;
- Pale green: routine;

Table 4. Summary of fungicides, Biofungicides, biostimulants applied to strawberry plots at NIAB EMR 2019 and programme costs

Item	Management treatment / Number of sprays			
	Untreated	Routine fungicide	Routine SPM and Botrytis managed	SPM managed No Botrytis fungicides
Botrytis fungicides	0	15	12	2
SPM fungicides	0	18	2	2
Total fungicides	0	29	12	2
Biofungicide	0	0	10	10
Biostimulant	0	0	4	4
Total products	0	29	26	16
Cost £/ha				
Total cost	0	2006.09	1933.76	1081.99
SPM only	0	888.97	933.94	1081.99
Botrytis only	0	1360.66	1184.16	184.34

A total of 15 fungicide sprays were applied for Botrytis control in routine-treated plots compared to 12 fungicide sprays in the managed plot (Treatment 3). No fungicide treatments for Botrytis were applied to Treatment 4 managed plots. The incidence of rots recorded at harvest was very low ranging from 0 to 1.3% in untreated plots. The incidence of Botrytis in post-harvest tests at ambient temperature (maximum rot potential) in untreated plots ranged from 0 to 27.5% (Fig. 4). There were no consistent effects of treatments on Botrytis rot incidence in any of the 19 harvests, indicating that the 12-15 fungicides applied had little benefit. There were obvious reductions in the incidence of soft rots (*Mucor* and *Rhizopus*) in treated plots compared to the untreated control, however, the reduction in rot incidence in the treated plots was small and still resulted in more than 55% soft rots and therefore of little value. The incidence of rots in the cool chain fruit management was very low compared to the fruit held at ambient temperature (maximum rot potential) for the same period.

Between 3 and 7 fungicide (mainly Botrytis fungicides) residues were detected in the routine and SPM / Botrytis managed treatments in fruit sampled in August and September compared to no residues detected in the August sampling and 2 fungicides in the September sampling of fruit from Treatment 4. All residues were below the MRL.

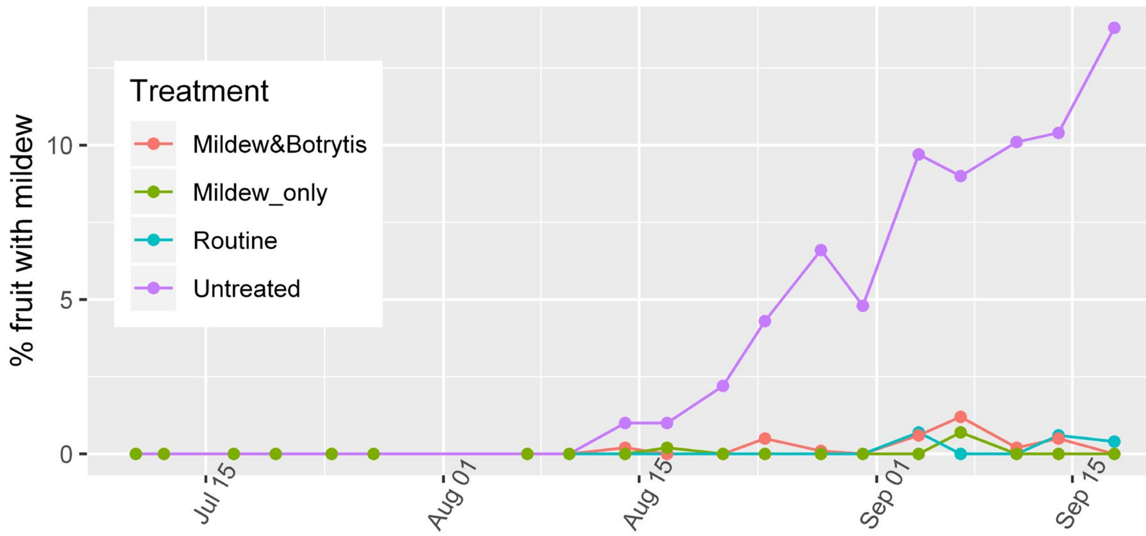

Figure 3. Percentage fruit with SPM at harvest on strawberry cv. everbearer in 2019 at NIAB EMR following treatment with three different programmes compared to an untreated

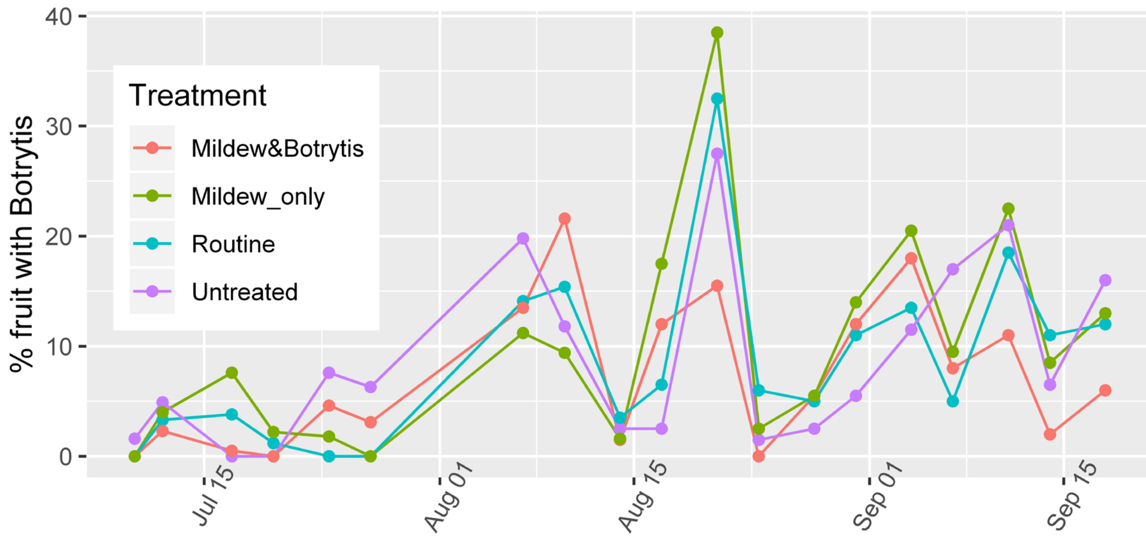

Figure 4. Percentage fruit with Botrytis rot over 19 harvests, in post-harvest tests (7days at ambient temperature) on an everbearer strawberry cultivar following treatment with four

Overall, a simple decision based system for determining treatments for SPM and rots in protected everbearer strawberries based on biofungicides as protectants (with fungicides included when the risk determines it) for mildew control and omitting fungicides for Botrytis control resulted in a 90 % reduction in fungicide use and a cost saving of around £900 /ha compared to a routine programme with no penalties in yield, fruit quality or disease control.

Commercial Demonstration (Years 4 and 5)

Commercial site 2018

A separate demonstration trial was established on a commercial farm using an everbearer cultivar. The treatments applied were based on the same criteria for SPM and rots as used in the trials at NIAB EMR. They were compared to that in a similar sized tunnel following the standard farm programme. Similar to the trial at NIAB EMR, SPM failed to establish in the trial allowing savings in fungicide inputs in the SPM managed tunnel with only 10 fungicides applied compared to 19 fungicides in the control and with a cost saving of £261.87 /ha (See Table 5 below).

The Botrytis risk was similar to that for SPM with the main risk period shown by the model in late May / early June and from late July onwards and very low risks in June and July. Savings in fungicide use were made in the early part of the season but there was little opportunity in August and September. However, a total of 13 fungicides were applied for Botrytis in the control tunnel compared to 8 in the trial tunnel. There is a saving in cost of £310.45 /ha but with little effect on Botrytis incidence in fruit from the two tunnels which was similar in both plots at each of the harvest dates. There were also no clear differences in fruit quality.

WET Centre site 2019

In 2019, the system was further evaluated in the WET Centre demonstration area at NIAB EMR on the everbearer cultivar Malling Champion. In two tunnels, the treatments applied were based on the same criteria for SPM and rots as used in the trials at NIAB EMR. These were compared to the rest of the WET Centre, which followed the standard farm programme. Weather conditions from June onwards were favourable for SPM and Botrytis. The cultivar used in the planting – Malling Champion - was newly introduced and classified as moderately susceptible to SPM but with no experience in large commercial plantings. Hence caution was needed as the development of SPM on leaves and fruit in response to favourable conditions was not known. At the start of the trial, the biofungicide Sonata was not approved for use and therefore could not be used in this trial and hence control was based on fungicides only. A very low incidence of SPM developed in the trial from mid-June, and therefore there was little opportunity to reduce fungicide inputs. However, delaying the start of the 7-day programme in the managed area resulted in a small saving of 3 mildew fungicides compared to the routine programme. Although the incidence of SPM was always higher in the managed plots, SPM on leaves and fruit generally remained very low. Similarly sprays for Botrytis were delayed in the managed area until the weather risk increased. A total of 13 fungicides were applied for Botrytis control to the routine tunnels compared to 11 in the managed tunnel.

Table 5. Summary of fungicides, BCAs, biostimulants applied in demonstration strawberry trial on a commercial farm in Kent in 2018 and the programme costs

Item	Control tunnels	Trial tunnel
Total Fungicides		
for Botrytis	13	8
for SPM	19	10
Total	**26**	**15**
Other products		
BCAs	2	1
Cultigrows	0	5
Other biostimulants	13	11
Cost £/ha		
Total	**1715.08**	**1272.22**
SPM only	1110.10	848.23
Botrytis only	934.44	623.99

Overall, the experience with the simple decision-based management system for SPM in the commercial trials, especially in 2018, supported the results in the trial at NIAB EMR. The commercial trials also showed little benefit in controlling Botrytis using fungicides.

Mode of action

The results from this work have indicated that the three new fungicides (Luna Sensation, Takumi and Talius) all have good effects against SPM. Charm is not very effective against SPM when applied as a protectant. The two biocontrol products have some effects against SPM but are not expected to be useful on their own where more than a trace level of fresh SPM lesions are already present in the crop. The overall test results from three-year testing are summarised in Table 6 below:

Table 6. Protectant, curative and anti-sporulant properties of **new** products effective for the control of SPM

Product	Curative: number of days applied after infection	Protectant: number of days applied before infection	Anti-sporulant: number of days with good suppression of sporulation
Talius	7-8	2-3	2-3
Takumi	4-5	2-3	2-3
Luna Sensation	4-5	2-3	4
Charm	2-3	Not tested	4
Silwet	1-2		2-3

Silwet & **AQ 10**	1-2	Not tested (but not expected to have an effect)	4
Silwet & **Sonata**	1-2		2-3

Overall conclusions

- Strawberry powdery mildew (SPM) is one of most important diseases in protected strawberry production. Once the disease is established in the crop, control is difficult to achieve and losses in yield and quality are likely with crop abandonment a possibility.
- Managing SPM with a simple decision-based system to determine treatment enables savings in fungicide use when the risk of infection is low in the early part of the season, ensuring products are available for the higher risk period in late summer, reducing fungicide input by at least 40%.
- Biofungicides such as Sonata and biostimulants were shown to be effective against SPM in the trials and can form the basis of a protectant programme for control of SPM, using fungicides only in high risk periods.
- Botrytis still remains a potential problem in protected strawberries. However, the importance has declined compared to SPM.
- Growing under protection and use of cool chain management of the fruit has considerably reduced the development of Botrytis fruit rot. In addition, management of fruit waste at harvest to control SWD has reduced the Botrytis inoculum and hence the build-up of the disease in the everbearer crop.
- The results from 2018 and 2019 consistently show little benefit in Botrytis control from the use of fungicides.
- There was a consistent effect of fungicides in reducing soft rots from around 80-90% in untreated to 50-70% in sprayed plots; but this was observed when fruit were stored under ambient conditions post-harvest, hence representing the maximum potential of pot-harvest rot development.
- Development of any Botrytis or soft rots can be delayed by cool chain management of the harvested crop.
- Basing the disease control programme for protected everbearer strawberries on biofungicides for SPM control with intervention with fungicides during high-risk infection periods and minimising the use of fungicides for rot control, offers large potential savings in residues in the fruit.

- Several new fungicides were shown to have good effects against SPM (Table 6); when these products are used, special attention should be paid to their efficacies when applied as protectant, anti-sporulant or curative treatments.

Financial benefits

The replicated trial at NIAB EMR and the demonstration trial on the commercial farm in 2018 have demonstrated the ability to reduce fungicide inputs where treatments used for SPM and fungal rots are based on a simple decision based system compared to a routine or standard farm programme. The results were confirmed in the replicated trial at NIAB EMR in 2019. In both cases in 2018, cost savings were made (£699 /ha and £443 /ha respectively) with no adverse effects on yield, fruit quality or rot incidence. There were also advantages in reduced residues in the fruit, particularly for sprays targeted at SPM. The results from 2018 and 2019 also consistently show little benefit in Botrytis control from the use of fungicides hence offering further savings in fungicide costs and residues in the fruit.

Action points for growers

- Integrate the new fungicide products Luna Sensation and Takumi (both curative and anti-sporulant activity) and Talius (curative activity) with other control measures
- These products should be saved for use in the programme when the SPM risk is high.
- The adjuvant Silwet on its own also offers good anti-sporulant activity and can complement traditional spray programmes.
- Growers should consider adopting a decision-based managed approach to powdery mildew control using the mildew risk model along with forward weather forecasts and crop stage.
- Basing the disease control programme for protected everbearer strawberries on biofungicides (used with adjuvants if applied alone) for SPM control with intervention with fungicides during high risk periods and minimising the use of fungicides for rot control, offers large potential savings in costs and residues in the fruit.
- Growers should consider trying the approach on part of their farm to gain experience and confidence in the system.

Fruit rot complex

Headline

- *Pestalotiopsis* spp. do not appear to be important as pathogens of strawberry in the UK.

Background and expected deliverables

Recent evidence in the UK and New Zealand has shown that Botrytis is not the only pathogen causing fruit rot, and that the importance of *B. cinerea* in strawberry may have been over-stated because of similar morphological characteristics of Botrytis fungal morphology with two other rotting fungi – *Mucor* and *Rhizopus* spp. The relative importance of these three pathogens may vary greatly with time and location. Although the overall direct loss to these pathogens may be relatively small compared with other diseases, the consequence (e.g. rejection of a consignment by retailers) of fruit rot is much more serious.

Projects SF 74 (Defra Horticulture LINK HL0175) and SF 94 (Defra Horticulture LINK HL0191) suggested that in raspberry and strawberry, rapid post-harvest cooling to storage at 2°C is effective in delaying Botrytis development. However, such cooling treatment is not effective against *Mucor,* which can develop in cold conditions. In Project SF 98, NIAB EMR identified a few fungicides that can give partial control of *Mucor*. Berry Gardens Growers (BGG) recently funded a PhD project at NIAB EMR on the epidemiology and management of *Mucor* and *Rhizopus* rot in strawberry; significant progress has been made in this project but due to commercial confidentiality, the findings cannot be disclosed in this report. BGG continues to fund work on the control of fruit rotting at NIAB EMR.

Towards the end of Year 2 of this project, there were increasing reports on the occurrence of *Pestalotiopsis*, a new pathogen being isolated from the crowns of wilting plants. In addition, this pathogen was shown to cause fruit rot on strawberry in Egypt. In year 3, we carried out preliminary work on this new pathogen of strawberry to determine the importance of this disease to the UK industry. Although *Pestalotiopsis* strains can produce disease lesions on detached leaves and fruit, they failed to infect crowns of intact plants in artificial inoculation even under disease conducive conditions.

Summary of the project and main conclusions

Using a detached fruit and leaf pathogenicity test, we demonstrated that all the *Pestalotiopsis* isolates tested can establish infection and colonise the host tissue. The pathogen was also able to cause a post-harvest rot following inoculation during fruit development. However, we failed to show that the isolates tested were able to cause a disease in the crown. Plant leaves and crown were inoculated with the *Pestalotiopsis* spore and mycelium inoculum and despite providing highly favourable conditions, only a background level of disease was recorded. Based on our findings and the literature, we conclude that *Pestalotiopsis* is a weak pathogen, which is able to infect the plant when it is under other stresses. Furthermore, only one sample from more than 100 plant samples of year 1-2 Phytophthora survey had positive DNA result for *Pestalotiopsis.*

Work on developing strategies for managing Botrytis fruit rot is presented in the previous section (SPM). The key message is that post-harvest cool-chain management is essential for managing *B. cinerea* without fungicide input.

Preliminary data also showed that *B. subtilis* (Serenade ASO, Solani) can maintain sufficient densities of viable propagules for 10 days after application to control *B. cinerea* under protected conditions in the autumn; whereas the corresponding period is 4 days for *Gliocladium catenulatum* (Prestop). However, previous results at NIAB EMR showed the limited movement of *B. subtilis* among flowers under protection, which meant that frequent application is necessary to protect flowers from infection because of the nature of continuous flower development in everbearers. Further work is needed to study the extent of spread/movement of *G. catenulatum* among plants following its application.

Financial benefits

Based on the results so far, we conclude that *Pestalotiopsis* spp. are not important on strawberry under the UK conditions. Indeed, there were no reports of this pathogen in the UK in 2018.

Action points for growers

- Current results are insufficient for making any recommendations. Be vigilant for this disease in plantations, manifesting itself either as a crown rot or a fruit rot.
- When biocontrol products are used, special attentions need to be paid to survival/movement of biocontrol organisms and the rate of crop growth.

Verticillium wilt

Headline

- *Bacillus subtilis* (Serenade ASO, Solani) showed some promise in reducing the level of *Verticillium dahliae* inoculum in the field.

Background and expected deliverables

Verticillium wilt of strawberry develops from micro-sclerotia of *Verticillium dahliae* in the soil and can reduce yields by 75% through death of plant crowns and reduced water movement into the fruit. Chemical soil fumigation was traditionally used by growers to reduce the pathogen in the soil to levels safe for strawberry production, but the most successful fumigant methyl bromide, is no longer authorised and the best alternative chloropicrin, now requires annual Emergency Authorisation.

Some cultivars have greater resistance to *Verticillium* wilt, but other measures are also required to reduce the impact of the disease. There is the potential to use soil amendments with either organic matter or a biofungicide drench to change the microbial population and so compete for resources with *Verticillium*. Biofumigation may result in reduced viability of *Verticillium* microsclerotia. This work set out to investigate this approach.

Summary of the project and main conclusions

In 2015, we investigated an alternative to the use of pre-planting chloropicrin applied in a soil grown crop using plastic mulched raised beds. Anaerobic soil disinfestation ("soil-setting") was carried out on a sandy silt soil collected from a soft fruit farm that had a natural infestation of 2.3 microsclerotia of *Verticillium dahliae* per gram of soil. The soil was collected into replicated 10 L pots treated with either just Herbie 82 or this plus a "starter" of 670 ml of soil pre-incubated anaerobically with Herbie 67P. Both products from Thatchtec BV were organic by-products from the food industry and purported to provide nutrition to encourage the activity of anaerobic bacteria present in the soil and allow metabolites anticipated to be produced by these bacteria to reduce the viability of microsclerotia. Pots were irrigated with either 5 mm or 10 mm of water (resulting in 10% or 14% moisture content) and then sealed for eight weeks with a mean soil temperature of 16°C. Significant reduction in propagule viability occurred at either moisture level after the incorporation of Herbie 82 with or without the "starter soil", to give a mean 0.28 microsclerotia/g of soil, with four out of the sixteen pots having zero. No further work was done with Herbie.

With increasing restrictions on the use of the soil fumigant chloropicrin, a randomised block experiment was set up in 2017 with the pre-planting incorporation of products into *V. dahliae* infested sandy-loam soil (4 propagules/gram of soil) to investigate their potential to reduce losses in a strawberry crop. Either a bio-fumigant, Bio-Fence, (a granular product made from *Brassica carinata* meal) applied at 2,000 kg/ha, or anaerobic digestate solids (composed of maize plants plus vegetable waste and PAS 110 certified) at 50 t/ha, were incorporated into the top 150 mm of formed soil beds before sheeting and then irrigated using trickle tape under the plastic. A week later, on 6 June 2017, cold-stored bare-root plants of a variety moderately susceptible to *Verticillium*, cv. Symphony, were planted into slits in the plastic mulch. A week later, Serenade ASO (*Bacillus subtilis* strain QST 713) was sprayed at 10 L/ha in 1,000 L of water / ha on both half of the untreated plots and half of the BioFence treated plots. Fruit were too few to pick, and only a few indications of *Verticillium* wilt had appeared by the end of 2017, but in June 2018 total fruit yield was similar across treated and untreated plots. Clear *Verticillium* wilt symptoms did not show until July 2018, after fruiting, when there were significantly more plants obviously wilted in the Bio-Fence alone treated plots (43% wilted), compared with the Serenade ASO alone (15% wilted) or in combination with Bio-Fence

(37%). Some BioFence treated plots had been poor to establish in 2017, possibly because of too short a ventilation period after isothiocyanate release, and this may have led to their greater wilt susceptibility. The small proportion of Serenade ASO treated plants that wilted was significantly less than the untreated control plants (38% wilted) and it was confirmed by Harris testing that this was not because of initially lower soil microsclerotia infestation in the Serenade ASO plots.

Financial benefits

Potential loss of plants due to *V. dahliae* in soil grown crops can vary between 5-90%. In 2016, 90,000 tonnes of strawberries were sold in the UK season with the market valued at £386 million (Data from Kantar). At present, it is estimated that around 10% of the UK strawberry crop is grown in field soils, equating to £38.6 million. Should 25% of plant losses occur in the UK as a result of Verticillium wilt, this would represent lost revenue of £9.6 million. Techniques and measures to control Verticillium wilt could therefore save such potential losses.

Action points for growers

- If growing strawberries in field soils, ensure soil samples are sent for enumeration of *Verticillium* microsclerotia several months before preparing for planting, so that results can be returned in time to make decisions about the need for soil fumigation and cultivar selection.
- Leaving *Verticillium* affected soils untreated is likely to result in reduced berry weight through reduced water-fill ability and thus lower total fruit yield
- Be aware that if a biofumigant is used, an adequate ventilation period before planting should be allowed, potentially longer than that used for chloropicrin or traditional fumigants. Use a cress test to ensure crop safety.
- Consider a drench application of Serenade ASO at plant establishment as it can reduce crown wilting over a year later.

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