Grower Summary

SF157

Improving integrated disease management in strawberry

Year 4 Annual report, March 2019

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Project title:	**Improving integrated disease management in strawberry**
Project number:	SF 157
Project leader:	Prof Xiangming Xu NIAB EMR
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The results and conclusions in this report are based on an investigation conducted over a one-year period. The conditions under which the experiments were carried out and the results have been reported in detail and with accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results, especially if they are used as the basis for commercial product recommendations.

AUTHENTICATION

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

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GROWER SUMMARY

For ease of reading, this Grower Summary report is split into sections for each of the diseases being worked upon in the project.

Crown rot and red-core caused by *Phytophthora* species

Headline

- Several fungicide and bio-fungicide products significantly reduced the losses due to latent infection by *Phytophthora cactorum* when applied as a dipping treatment at planting

Background and expected deliverables

Adopting a clean propagation system is the first line of defence against crown rot and red-core diseases. This strategy has been working for many years until recent times. Currently, crown rot and red-core can cause significant damage in strawberry even in substrate production. The most likely cause is asymptomatic infection in planting material. Fenomenal (fenamidone + fosetyl-aluminium), an effective product against Phytophthora, is not approved for use beyond November 14 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. Two AHDB Horticulture projects have just been completed; SF 130 focussed on fungal molecular quantification and 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 disease 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.

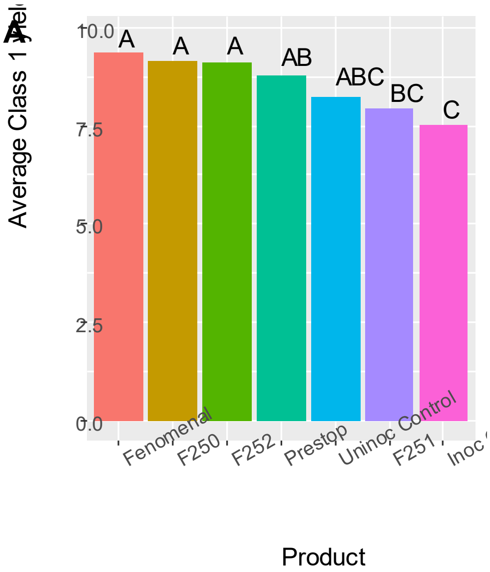

Figure A: Average Class I yield of "Malling Centenary" plants for each product treatment. Each product was applied as dipping or drenching two weeks after dipping. Additional drenching did not affect fruit yield. Treatments sharing at least one

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In the first three years of this project, we showed that (1) *P. fragariae* (red core) was rarely detected in planting material, (2) in contrast, incidence of *P. cactorum* could be up to 30% in planting material, though varying greatly among batches, and (3) neither arbuscular mycorrhizal fungi (AMF) nor plant growth promoting rhizobacteria (PGPR) managed to reduce the losses caused by *P. cactorum*. The aim of this project in year 4 on Phytophthora is to assess whether treating plants at planting time can reduce the losses due to *P. cactorum*.

Summary of the project and main conclusions

In Year 4, we conducted a large study to test existing and new products as dipping/drenching treatments at 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 only is sufficient to reduce the level of *P. cactorum* to the level comparable to the un-inoculated control; thus additional drenching is not necessary. Of the five products tested, four significantly reduced *P. cactorum* development and resulted in similar yield as the un-inoculated control as shown in Figure A. Of the four products, two are registered products; Fenomenal (use-up date 14 November 2019) and Prestop (*Gliocladium catenulatum*); the other two are experimental products: one chemical (F250) and one biological (F252). In contrast, the other experimental biological product (F251) led to increased plant mortality.

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.

Action points

- Results from Year 1 and 2 suggested that growers should consider treating runners for *P. cactorum* at the time of planting
- Year 3-4 results suggested that dipping plants with chemical and biological products should be considered at planting when the level of crown rot in planting material is expected to be high.

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Strawberry powdery mildew (SPM)

Headline

- A managed approach to strawberry powdery mildew control using a risk prediction model can reduce fungicide use by half.

Background and expected deliverables

Powdery mildew, 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 in 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.

Mildew is favoured by warm temperatures and high humidity such that conditions are most favourable for mildew from late June to October. Hence mildew 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 mildew is relatively straightforward. However, management of mildew in everbearer crops is much more challenging. The long growing period from March to November with flowering, fruiting and harvest continuous from June-November, a range of crop protection products is usually required with a continuous series of spray rounds needed to cover the whole period. Disease control is currently based on use of fungicides. Given the pressure to reduce use of conventional plant protection products and continuing loss of approved actives, this approach is not sustainable.

The SCEPTRE project (2010-2014) identified alternative products, including Cultigrow (a biostimulant / elicitor) and two biofungicides (biological control agents - BCAs) – AQ10 (*Ampelomyces quisqualis*) and a bacterial based biofungicide (F208). The purpose of the work in this project was to confirm the efficacy of these products, evaluate them in programmes with fungicides and develop a simple decision-based management system for mildew control.

The trial in 2015 confirmed the efficacy of the BCAs AQ10 and F208 and the biostimulant Cultigrow alone or in combination with fungicides, in controlling mildew. In 2016 further trials were conducted in which programmes were evaluated for control of powdery mildew where the biofungicides (F208 or AQ10) were combined in programmes with Cultigrow with and without a reduced fungicide programme compared to a 7 or 14 day fungicide programme and

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an untreated control. The mildew risk was high in 2016 but the results showed that the BCAs were as effective in controlling mildew as the standard 7-day fungicide programme, particularly when applied alone in a programme and especially in reducing mildew on fruit.

Having identified alternative products that were effective on June-bearer crops, the next step was to combine their use in programmes and incorporate other factors such as disease risk (determined from model predictions based on tunnel humidity and temperature and also the forward weather forecast), 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 an everbearer cultivar. The mildew control achieved by managed programmes of fungicides and BCAs 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), 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 mildew, there was little opportunity to omit sprays. However, in the managed treatment, intervention with a fungicide in place of the BCA (F208) occurred only twice. The mildew risk throughout the trial was high. Mildew incidence on the leaves was very low. However, on fruit the mildew 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. Mildew incidence on the fruit in all treated plots was negligible throughout the harvest period. This trial demonstrated that use of BCAs, with or without Sirius or Cultigrow, gave good control of mildew in strawberry comparable to a fungicide-based programme.

The objective in 2018 was to explore how the approach for managing mildew could be integrated with control of botrytis and other fruit rots on everbearer crops in a replicated trial at NIAB EMR. In addition, a trial was conducted on a commercial farm as a demonstration to encourage growers to take up a more managed approach to disease control.

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Summary of the project and main conclusions

Management trials

At NIAB-EMR, 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 mildew and botrytis risks were lower. Three managed treatments were compared to a routine 7 day fungicide programme and an untreated control. Simple ‘Look up’ tables were produced from SPM and Botrytis computer models (previously developed at NIAB-EMR) for use in conjunction with the forward weather forecast (from BBC Weather website) to determine disease risk for spray decisions.

The weather conditions (warm temperatures coupled with high humidity) were very conducive to powdery mildew 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 mildew at planting time and this combined with the hot dry weather in June and July meant that mildew failed to establish in the crop, despite the higher risk identified in August and September. Therefore, only four fungicide sprays (and seven BCAs) for mildew were applied in the managed plots compared to 14 (and two BCAs) in the routine treated plots, a saving of £356 /ha. 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. There was a saving of only two fungicides compared to the routine treatment with a cost saving of £485 /ha (see table below). However, the incidence of Botrytis in post-harvest tests showed that for most of the 20 harvests, differences in Botrytis between the untreated control and treated plots was very small, questioning the need for the fungicide inputs with potential savings in cost. There were also no treatment effects on yield and fruit quality.

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Summary of fungicides, BCAs and biostimulants applied to strawberry plots at NIAB EMR in 2018 and the programme costs

Treatment period	Treatment	Management treatment				
		T1: Untreated	T2: Routine	T3: SPM managed, routine Botrytis	T4: Routine SPM. Managed Botrytis	T5: Managed SPM and Botrytis
5 June- 2 July	Botrytis Fungicide	0	4	4	1	1
	Mildew Fungicide	0	5	2	5	2
	BCA	0	0	0	0	0
	biostimulant	0	0	1	0	1
9 July-30 July	Botrytis Fungicide	0	4	5	4	3
	Mildew Fungicide	0	4	1	5	1
	BCA	0	0	2	0	2
	Biostimulant	0	0	1	0	1
6 Aug-17 Sep	Botrytis Fungicide	0	5	5	7	7
	Mildew Fungicide	0	5	1	5	1
	BCA	0	2	5	0	3
	Biostimulant	0	0	2	0	2
Total	Botrytis fungicides	0	13	14	12	11
	Mildew fungicides	0	14	4	15	4
	Total fungicides	0	27	18	27	15
	Biofungicides	0	2	7	0	5
	Biostimulant	0	0	4	0	4
Cost £/ha	Total programme	0	2,278	2,169	1,905	1,579
	Mildew only	0	1,033	677	890	677
	Botrytis s only	0	1,596	1,700	1,223	1,111

Commercial Demonstration

A demonstration trial was established on a commercial farm on an everbearer variety. In this trial, two tunnel treatments were compared. One tunnel followed the same mildew and Botrytis control programme as the rest of the farm. In the other, the control criteria used for powdery mildew and rots in the NIAB EMR trial were adopted. As in the trial at NIAB EMR, strawberry powdery mildew 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 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 eight in the trial tunnel. There was 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.

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Summary of fungicides, BCAs and biostimulants applied in a 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 mildew	19	10
Total	26	15
Other products		
BCAs	2	1
Cultigrows	0	5
Other biostimulants	13	11
Cost £/ha		
Total	1715.08	1272.22
Mildew only	1110.10	848.23
Botrytis only	934.44	623.99

Mode of action

Three new fungicides, Luna Sensation (fluopyram & trifloxystrobin), Takumi (cyflufenamid) and Talius (proquinazid), have good anti-sporulant ability, especially Luna Sensation. They could reduce sporulation by up to 50% within 4 days of their application. Silwet on its own also achieved a comparable level of anti-sporulant effect to the three fungicides especially for the periods immediately following its application. AQ10 and F208 were each applied together with Silwet, giving a similar level of control to Silwet. It is therefore open to question as to how much additional effect each biocontrol agent contributed to the observed effect. Nevertheless, over the four sampling occasions, AQ10 (with Silwet) gave better control than Silwet alone and F208 (+ Silwet), although the actual difference was small. The overall test results from two-year testing are summarised in the table below:

Effectiveness of several products applied as a curative, protectant or anti-sporulant treatment against strawberry powdery mildew

	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	2-3	7-8	2-3
Takumi	2-3	4-5	2-3
Luna Sensation	2-3	4-5	4
Charm	Not tested	To be tested	4
Silwet	Not tested (not expect to have an effect)	Not tested	2-3
Silwet + AQ10		2 (AQ10 only)	4
Silwet + F208		2-3 (F208 only)	2-3

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Main conclusions

A simple decision-based system for determining treatments for powdery mildew and rots in protected everbearer strawberries resulted in a 50 % reduction in fungicide use and a cost saving of £699 /ha compared to a routine programme. This system incurred no adverse effects in yield, fruit quality or disease control.

In addition, while the routine programme employed all permitted applications of approved fungicide products through the season, some permitted fungicide applications were held in reserve for use at the end of the season where the managed programme was adopted. This could be helpful should a late outbreak of infection occur.

Financial benefits

Both the replicated trial at NIAB EMR and the demonstration trial on the commercial farm 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. In both cases cost savings were made (£699 /ha and £443 /ha respectively) with no adverse effects on yield, fruit quality or rot incidence. 2018 was a low mildew year for both trial sites and this will need to be taken into account. There were also advantages in reduced residues in the fruit, particularly for sprays targeted at SPM.

Action points for growers

- Three new products including Luna Sensation and Takumi (both curative and anti-sporulant activity) along with Talius (curative activity) offer growers with additional protection against powdery mildew.
- All three can be integrated within spray programmes.
- 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 growth stage.
- Use of such a system can reduce both the number of fungicides applied and the subsequent total cost of the spray programme.
- The model is being used and demonstrated at the NIAB EMR WET Centre and those growers who employ the Precision Irrigation Package are supplied with the model and are trained in its use.

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Fruit rot complex

Headline

- *Pestalotiopsis* species are unimportant in fruit rots and plant death in UK strawberry.

Background and expected deliverables

Recent evidence in the UK and New Zealand has shown that *Botrytis cinerea* is not the only pathogen causing fruit rot in strawberry. The importance of *B. cinerea* may have been over-stated because of similar morphological characteristics of *Botrytis* fungal morphology with two other rotting fungi – *Mucor* and *Rhizopus* species. 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*. Recently Berry Gardens Growers (BGG) 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 the second year of this project, there were increasing reports on the occurrence of a new pathogen isolated from the crowns of wilting plants. In addition, this pathogen was shown to cause fruit rot on strawberry in Egypt. In year three, 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.

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Summary of the project and main conclusions

We used the molecular primers developed in Year three to screen for the presence of *Pestalotiopsis* species. in a number of selected samples taken for testing *P. cactorum* in Year 1 and 2. Of the 136 samples tested, only one sample showed positive for presence of *Pestalotiopsis.*

In addition, we carried out a preliminary study to investigate the survival of two commercial biocontrol agents in strawberry flowers; this work will be completed by May 2019 and reported in 2020.

Financial benefits

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

Action points for growers

- Current results are insufficient for making any recommendations. Keep an eye out for this disease in plantations, manifesting itself either as a crown rot or a fruit rot.

Verticillium wilt

Headline

- A drench of Serenade ASO at plant establishment appears to reduce crown wilting over a year later.

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 is used by growers, but methyl bromide in no longer authorised and chloropicrin use now requires annual Emergency Authorisation.

Some varieties have greater resistance to Verticillium wilt, but other measures are also required to reduce the impact of the disease. There is the potential for soil amendment 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.

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Summary of the project and main conclusions in Year 4

In May 2017 part of a field with a *Verticillium dahliae* count of four propagules per gram of soil was withheld from chloropicrin fumigation. Replicated 7 m lengths of bed were instead left untreated or given one of two different pre-planting treatments;

1. The incorporation of pasteurised anaerobic maize and vegetable digestate solids.
2. The incorporation of *Brassica carinata* pellets (Bio-Fence) which released isothiocyanates under the polythene.

Cold-stored strawberry runners (cv. Symphony) were planted in the trial area on 6 June 2017. Symphony plants were established on the same date in the adjacent chemically fumigated commercial beds. A week after planting, Serenade ASO (*Bacillus subtilis*) was applied to half of the Bio-Fence treated plots and to half of the untreated plots. This resulted in four treated plots and one untreated plot, randomised within each of five replicate beds.

The week of planting was exceptionally hot and some plants struggled to establish, especially in the Bio-Fence plots. It is possible that the seven-day ventilation period used for the chloropicrin treated area should have been extended. By May 2018, only occasional plants were starting to wilt. Fruit harvesting was carried out between 11 and 27 June 2018 during a period of exceptionally hot weather. The total weight of fruit and the weights that were marketable or unmarketable did not differ between the untreated and any of the four treatments, with a mean 555 g total weight per plant and 89% marketable. On the one date (27 June) that fruit yield and berry weights were also recorded from the commercial crop, the total weight of marketable fruit was 104 g per plant with 91% marketable, compared with 43 g per plant in the trial area. Average fruit weight of Class 1 fruit harvested on 27 June was 21 g, whereas from the trial plots, the mean was 12 g.

In July 2018, after plants had experienced both the stress of fruiting and enough heat to scorch the fruit in the field, wilting was seen across the trial area (Figure B). A significantly ($P < 0.001$) greater proportion of the plants (42.6%) had severe wilt after receiving Bio-Fence than after all other treatments except the untreated. Of plants which received Serenade ASO, only 15.5% had severe wilt, significantly ($P<0.001$) fewer than any of the other treatments.

Harris testing of the soil for *V. dahliae* before treatment with Serenade ASO determined that this had not followed a lower starting population of micro-sclerotia than in the untreated plots. The Bio-Fence plots had only 16.2% of plants with very slight or zero visible wilt, significantly ($P < 0.05$) fewer than in all the other four treatments (with a mean 31.5%). That the plots which received both Bio-Fence plus Serenade ASO had significantly more plants that were healthy compared with plots with Bio-Fence alone suggests that Serenade ASO helped to prevent wilt that would otherwise have occurred. Serenade ASO may have triggered plant

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defences and/or the *B. subtilis* competed with the *V. dahliae*. *Verticillium* presence was not able to be confirmed by isolation in wilted plants sent for laboratory examination in 2018, even though soil infestation by *V. dahliae* of 4 propagules / gram of soil in 2018 was confirmed from three untreated plots.

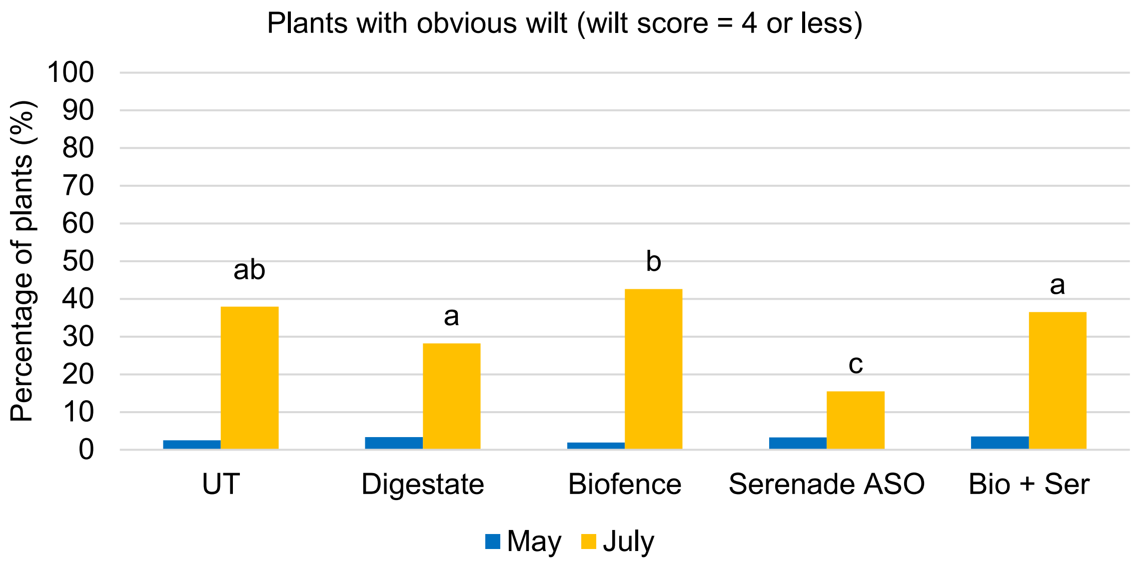

Figure B. Percentage of plants with obvious wilt (vigour/wilt index 4 or less), on 17 May and 19 July 2018. Significant differences ($P < 0.001$) from regression analysis indicated by letters in July. No significant difference ($P = 0.945$) in May. 'UT' refers to untreated plots; 'Bio + Ser' refers to the treatment with both Biofence and Serenade ASO.

Financial benefits

Up to and including harvest in 2018 no financial benefits were shown from the use of the products at planting. However, post-harvest by July 2018, 38% of the plants in the untreated plots had severe wilt compared with those given a single drench of Serenade ASO at planting (where 16% of plants had obvious wilt). If over a third of plants are weakened or die in a commercial crop then this will result in a substantial yield reduction, potentially leading to early termination of the crop. Serenade ASO could therefore save the crop from destruction, making a third year of production financially viable.

Action points for growers

- In soil grown strawberry production, carry out a soil (Harris) test for the presence of *Verticillium dahlia*e before establishing a new crop.
- The result will determine the need to fumigate the soil before planting.
- If infected soil is not fumigated, most commercially grown varieties are likely to be affected, leading to reduced yield and fruit size.
- Be aware that if a biofumigant is used, an adequate ventilation period before planting should be allowed, potentially longer than that used for chloropicrin.
- Consider a drench application of Serenade ASO at plant establishment, as this can reduce crown wilting over a year later.

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