https://doi.org/10.18745/pb.24905

Agreement Reference: Ceres Project A13722
Project Reference Code: 1C1P1

Final Report of Ceres Funding Project 1C1P1

March 2019-March 2020

https://doi.org/10.18745/pb.24905

Executive Summary

In 2019 the final on-farm validation of the UH prediction system (funded by Ceres, in collaboration with Agri-tech Services) took place on eight participating sites (from six farms) in England and Scotland. The aim of the project was to conduct an on-farm validation of the prediction system, in order to provide a simple, user friendly decision support system to growers to control the disease with fewer fungicide applications. A wide range of criteria were covered during the validation process: disease control, a range of geographical locations, manufacturers of temperature and humidity sensors, strawberry cultivars, growing media and methods. Pesticide application data for both prediction and control plots, costings and disease assessment results were received from all participating sites at the end of the season. The results of the validation and cost-benefits analysis were presented in this report. The prediction system was used on sites in both England and Scotland and a variety of cultivars were grown including Sweet Eve, Prize, Murano, Katrina and Amesti (everbearers) and Malling™ Centenary (June bearer). Two different types of sensors were used, Davis and SMS. Most growers used coir on tabletops, however on two sites, crops were grown on raised beds in soil. All growers who used the prediction system had commercially satisfactory disease control with fewer fungicide applications (by at least one spray) than the routine spray programme. They also benefited from financial savings due to reduced fungicide applications and labour costs. Positive feedback on using the prediction system in the 2019 validation was received from participating growers, as well as wide interest from other growers on adopting the prediction system in the coming season. The validation of the prediction system in 2019 has met the milestones of the project and has proven that the system, under all criteria, provided improved assistance to growers during their decision-making processes, achieving satisfactory disease control with fewer applications. The licence for the prediction system has now been agreed and will be signed in the Spring of 2020 which enables the system to be commercially available in 2020.

https://doi.org/10.18745/pb.24905

Contents

https://doi.org/10.18745/pb.24905

1. Introduction

Strawberry production in the UK is intensive, with yield doubled per hectare since the introduction of the use of polythene tunnels and fertigation in the 1990s. The environmental conditions under polythene tunnels favour strawberry production, which has resulted in an extended harvest season from 6 weeks to 6 months. These conditions are also favourable to the development of strawberry powdery mildew caused by *Podosphaera aphanis*, one of the most feared diseases of protected strawberries in the UK. This disease can cause 20-70% yield loss where a 20% yield loss in 2016 was worth £56.8 million (Hall et al., 2016). To control the disease, many growers apply fungicides routinely as an 'insurance spray' (every 7, 12 or 14 days) for up to 6 months, which is not only expensive but has environmental impacts.

1.1 Development of the prediction system

Work at the University of Hertfordshire from 2004 – 2018 has resulted in the development of a decision support system based on the temperature and humidity for asexual growth and sporulation of *P. aphanis* (temperature >15.5°C and <30°C, relative humidity (RH) >60%, Figure 1), which leads to disease development. These parameters are used to forecast when the fungus is likely to sporulate and alerts the grower when it is time to apply a fungicide to prevent disease development.

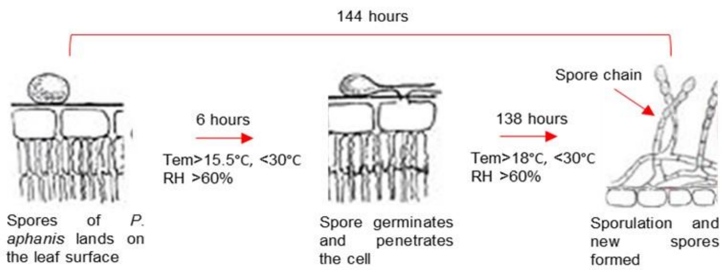


Figure 1 Asexual life cycle of *P. aphanis* (Xiaolei Jin, 2016). 15.5°C is the minimum temperature for spore germination, whereas 18°C is the minimum temperature for sporulation.

This prediction system was evaluated on farms (2007-2015) from an Excel spreadsheet, then from a CD which visualised the disease conducive hours (i.e. the number of hours of correct environmental conditions for a particular fungus to grow) of temperature and humidity. The evaluation showed that the system was reliable, and the disease was controlled with fewer fungicide applications, but the CD was not user friendly. With the availability of the internet and wifi-enabled weather stations, sensors and smart devices, the rule-based prediction system was transferred to a real-time web-based system allowing a grower to use in-crop sensors and monitor the accumulating disease conducive hours.

A validation (delivered via the KisanHub platform from 2016-2018, funded by a UH 'Proof of Concept' grant) was done on two commercial farms in England in 2017 and 2018, which showed that the prediction system gave commercially satisfactory disease control (i.e. no visible disease symptoms) using fewer fungicide applications and growers had the confidence to select their Mode of Actions more judiciously. Savings of £200-400/ha were recorded.

https://doi.org/10.18745/pb.24905

1.2 How does the system work?

It is a decision support system (DSS) designed to support the grower for the intelligent use of fungicides, spraying only when conditions are favourable for disease development, to effectively keep the epidemic to a minimum i.e. in the 'Lag Phase' (Figure 2). The prediction system accumulates the number of hours of correct environmental conditions (i.e. disease conducive hours) such as temperature and RH needed for the fungus to grow from spore germination to producing the next generation of spores, using temperature and humidity sensors within the crop.

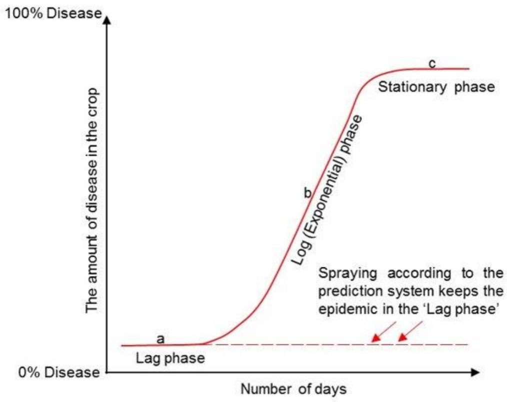


Figure 2 Epidemic growth curve. It shows how disease level can be kept to a minimum if spraying using the prediction system, to keep the epidemic in the 'Lag phase' (Spore germination, and fungus growth to spore production).

At the start of the season the grower assumes that there may be some disease and does a clean-up spray (Figure 3). The prediction system accumulates the hours which have the correct temperature and humidity conditions for the fungus to grow from conidiospore germination, through 'elongating secondary hyphae' to sporulation, i.e. it is accumulating 'disease conducive' hours. This appears as an ascending green line until it reaches 115 hours, when the line turns to amber, which is an indication to the grower that they should start thinking about making a fungicide application (Figure 3). At 125 hours the line turns to red, a fungicide application is needed; at 144 hours, the fungus can start to produce new spores and so initiate an epidemic if the grower has not applied fungicides. After a fungicide application, the grower enters fungicide details and resets the system, which then starts to accumulate disease conducive hours again.

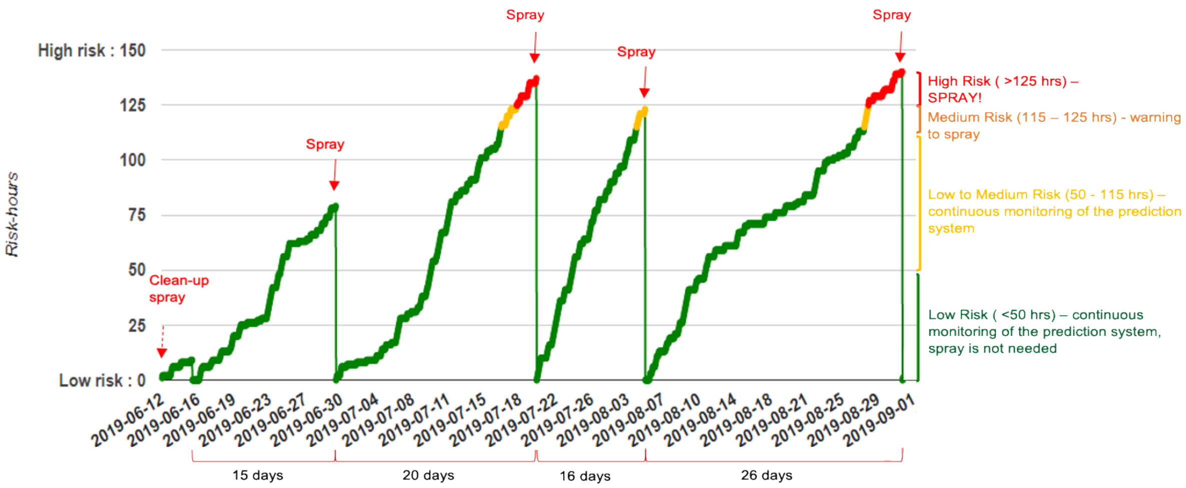


Figure 3 Illustration of a prediction graph. The Y-axis indicates the number of accumulated hours where both parameters i.e. temperature and RH are met, the X-axis showing the date.

Uniquely, in this program, risk is defined by the number of disease conducive hours that have occurred. If only 50 disease conducive hours have occurred, the fungus will not have grown very much, then there is a low risk. The grower is suggested to regularly monitor the system when the disease conducive hours is between 50 and 115. If 115 hours of disease conducive conditions have occurred, the fungus will be growing and there will be a high risk of disease

https://doi.org/10.18745/pb.24905

development. When the ascending line is between 125 and 144 hours it is advised that the grower applies a fungicide application.

The system is recording disease conducive hours, not forecasting disease levels. It is designed to keep the level of inoculum to a minimum (Figure 2 ‘Lag Phase’) throughout the growing season. If there were disease conducive conditions for 24 hours of the day, the grower would be required to apply a fungicide every six days. However, with 12 hours of disease conducive hours a day, a fungicide application would be required every 12 days. When there is only six hours of disease conducive conditions, a fungicide application would only be required every 24 days. The growers make their own decision as to what fungicides to use, using MoA in rotation and biological controls if appropriate.

https://doi.org/10.18745/pb.24905

2. Ceres Project 2019-2020

2.1 Validation of the prediction system

In 2019 the final on-farm validation (funded by Ceres, in collaboration with Agri-tech Services) took place on 8 sites in England and Scotland. The outcome of this validation is provided in Section 3 Results.

2.2 Aim of the validation

The vision of the work is to provide a simple, user friendly decision support system to control the disease with fewer fungicide applications; predict when to apply fungicides to keep initial inoculum as low as possible; the system must be easy to use and completely reliable. The prediction system is aimed to be licenced and commercially available to strawberry growers by March 2020.

2.3 Criteria for validation

The validation criteria of the prediction system cover a range of features, to ensure a full consideration on every possible strawberry growing system in the UK (Table 1). In addition, it must be reliable, simple to use, effective in all conditions and to give commercially satisfactory disease control throughout the growing season.

Table 1: Validation criteria in the 2019 on-farm prediction system validation process

Criteria	Specifications
Disease control	Commercially satisfactory disease control
Geographical location	England, Scotland
Manufacture of temperature & humidity sensor	SMS, Davies etc.
Strawberry cultivar	June bearer, everbearer
Growing media	Soil, coir etc.
Growing method	Raised beds, tabletops etc.

2.4 Ceres project milestones completion progress

Table 2 and 3 include the deliverables according to the project funding milestones, as agreed with Ceres and what work has been completed to meet these deliverables. Table 4 includes details of the initial project milestones set by University of Hertfordshire (UH).

https://doi.org/10.18745/pb.24905

Ceres Project Milestones Completion Progress

Table 2: Milestone 1

	Deliverable	UH milestone in Table 4	UH Work Outcome	Deliverable Met?	Date Milestone report submitted
Milestone 1: End of Month 4	1. At least 5 farms formally agreed to participate in use of the prediction system for 2019	M2-M4	Six farms formally agreed by signing a letter to participate in the validation of the prediction system in 2019 (letters attached in the Milestone 1 report) (Blank letter- Appendix 1)	**Met**	July 2019
	2. All participating farms have the required protocol and equipment	M1-M4	Protocol for using the prediction system produced and distributed to participating farms All participating farms have required equipment	**Met**	
	3. All participating farms formally agreed to release their pesticide data to UH (for prediction system and control plot) at the end of the 2019 growing season	M2-M4	All participating farms formally agreed by signing an agreement letter to release their fungicide data and costings for both the prediction system and the control plot to UH at the end of the 2019 growing season (letters attached in the Milestone 1 report); Additional information such as the growing method, strawberry varieties and types of sensors etc. were also included	**Met**	
	* Additional progress from UH	M5-M6	- All participating farms were visited, and disease assessment was carried out on site - Use of the prediction system were regularly monitored online - Kick-off meeting was held between UH and Agri-tech Services, and weekly review meetings were carried out among the UH team	**Met**	

https://doi.org/10.18745/pb.24905

Table 3: Milestone 2 & Project Completion.

	Deliverable	UH milestone in Table 4	Work Outcome	Deliverable Met?	Date Milestone report submitted
Milestone 2: End of Month 8	1. All seasons pesticide and disease assessment data collected from all participating farms	M8	All seasons pesticide and disease assessment data received from eight participating sites (Appendix 2) n.b. results could only be delivered at the end of harvest	**Met**	(Met late) January 2020
	* Additional progress from UH	M7, M9, M10	- Data analysis for cost benefit analysis started - Fruit Focus events attended in July, with publication materials on the prediction system distributed (Appendix 3 and 4) - Workshops for strawberry growers were run in England and Scotland in October, content included use of the prediction system and other relevant work including nutrition and irrigation etc. (Appendix 5) - Weekly review meetings were carried out among the UH team	**Met**	November 2019
Project completion: End of Month 13	1. Cost/benefit analysis complete and publishable	M11-M13	Cost/benefit analysis complete and publishable (Appendix 6)	**Met**	April 2020
	2. Project completion report		Project completion report completed	**Met**	
	* Additional progress from UH		- Collaboration agreement between UH and Agri-tech Services was signed in January; Licence is also expected to be signed in early 2020 - A paper on the use of prediction system in Scotland farms was published in the Proceedings of Crop Production in Northern Britain in February; a peer-reviewed prediction paper is close to submission - Weekly review meetings were carried out among the UH team	**Met**	

https://doi.org/10.18745/pb.24905

Table 4: University of Hertfordshire Project Milestones

Month	Project Milestone	Milestone Met?	Date Completed
M1	Protocol for using prediction system written, evaluated, and ready for use	Met	March 2019
M2 M3 M4	5-6 farms sign up to use the prediction system for 2019. They will have the protocol to follow, the equipment needed, and will have agreed to release their pesticide data to UH (for prediction system and control plot) at the end of the 2019 growing season	Met	March- August 2019
M5 M6	All participating farms will be using the system and will have been visited, use of prediction system reviewed, disease assessments carried out on each farm.	Met	March- August 2019
M7	End of season review (any need for modification of protocol for use or prediction system itself before use in 2020) (Appendix 7)	Met	January 2020
M8	All seasons pesticide and disease assessment data at UH from all participating farms.	Met	November/ December 2019
M9	Data analysis for cost benefit analysis starts.	Met	December 2019
M10	Workshops for strawberry growers run in England and Scotland. Content to include use of prediction system and other relevant work including nutrition and irrigation etc.	Met	October 2019
M11 M12 M13	Cost/benefit analysis complete and publishable. Commercial launch to growers via Agri-Tech services during January 2020 for wider take up of system in 2020.	Met	February 2020 Early 2020

https://doi.org/10.18745/pb.24905

3. Results

3.1 Participating sites

All season pesticide data, costings, and disease assessment results were obtained from eight sites from the six participating farms (Table 5). Results are provided as below. An additional site (Site 9) was included in this report, from a farm which had access to the prediction system and entered their fungicide applications but did not use it to support their decisions of when to spray; therefore did not participate in the validation process. This provided additional information about how a routine fungicide spray schedule may be operated on a normal commercial farm without using the prediction system.

Table 5 A list of participating farms/ sites

Farm postcode	Site number in the report
HR8 1	Site 1 (Table 6, Figure 4)
HR9 7	Site 2 (Table 7, Figure 5)
HR4 7	Site 3 (Table 8, Figure 6)
ST18 9 (2 sites)	Site 4 (Table 9, Figure 7)
	Site 5 (Table 10, Figure 8)
PH12 8	Site 6 (Table 11, Figure 9)
DD11 3 (2 sites)	Site 7 (Table 12, Figure 10)
	Site 8 (Table 13, Figue 11)
	Site 9* (Table 14, Figure 12)

* Note: Site 9 had access to the UH prediction system, but the grower did not use the system, and followed their own disease forecasting system instead. Therefore, it is shown in the report as an example for comparison.

3.2 Analysis of results

After receipt of the results from the growers, fungicide spray schedules were analysed for the number of sprays, the mode of action used, spray intervals and the number of accumulated hours when a fungicide was applied. Results are presented as a description of the use of the system, a table of results and a figure of the graph used by the grower (Table 6-14; Figure 4-12). In analysis of the results, good use of the prediction system was when a fungicide application has been made between 100 and 144 accumulated hours of disease conducive conditions.

The cost benefit analysis was done by calculating the price per hectare of each fungicide. The sum of the cost of all fungicide sprays was determined to give the total fungicide cost per hectare for the season. The suggested labour cost for a single fungicide application per hectare was given as £27.50 (H. Duncalfe, personal communication, 2017) and multiplied by the total number of sprays; some growers reported their own labour cost. The total cost of fungicides per hectare plus the total labour cost gives a total cost of fungicide applications per hectare for the season. The total cost calculated when guided by the prediction system was compared to the total cost of following a routine spray programme.

Full spray schedules and cost-benefit analyses are given in Appendix 2 and Appendix 6, respectively.

https://doi.org/10.18745/pb.24905

3.3 Grower Results

Site 1: HR8 1

The routine spray programme for this site was applying a fungicide every 8 to 12 days. The end of harvest for this crop was 15th November 2019.

The prediction system has been followed well (Figure 4). The grower has recorded all fungicide applications made and most (three of four) were performed between 115 and 144 hours (Medium and high risk), one fungicide was applied at 80 hours (low to medium risk). Using the prediction system has extended the interval between fungicide applications, thus reducing the number of applications made (Appendix 2, Table 1).

Table 6 Analysis results for Site HR8 1

				Number of fungicide applications			Cost-benefit analysis (cost of fungicides and labour, £/hectare)			Disease report	
Variety	**Growing method**	**Sensor**	**Dates using the prediction system**	**Prediction system**	**Routine programme**	**Saving**	**Prediction system**	**Routine programme**	**Saving**	**Prediction system**	**Routine programme**
Sweet Eve (everbearer)	Coir on tabletops	SMS	12/06/-15/11/2019	4	8	4	454.88	947.87	492.99	No mildew observed	

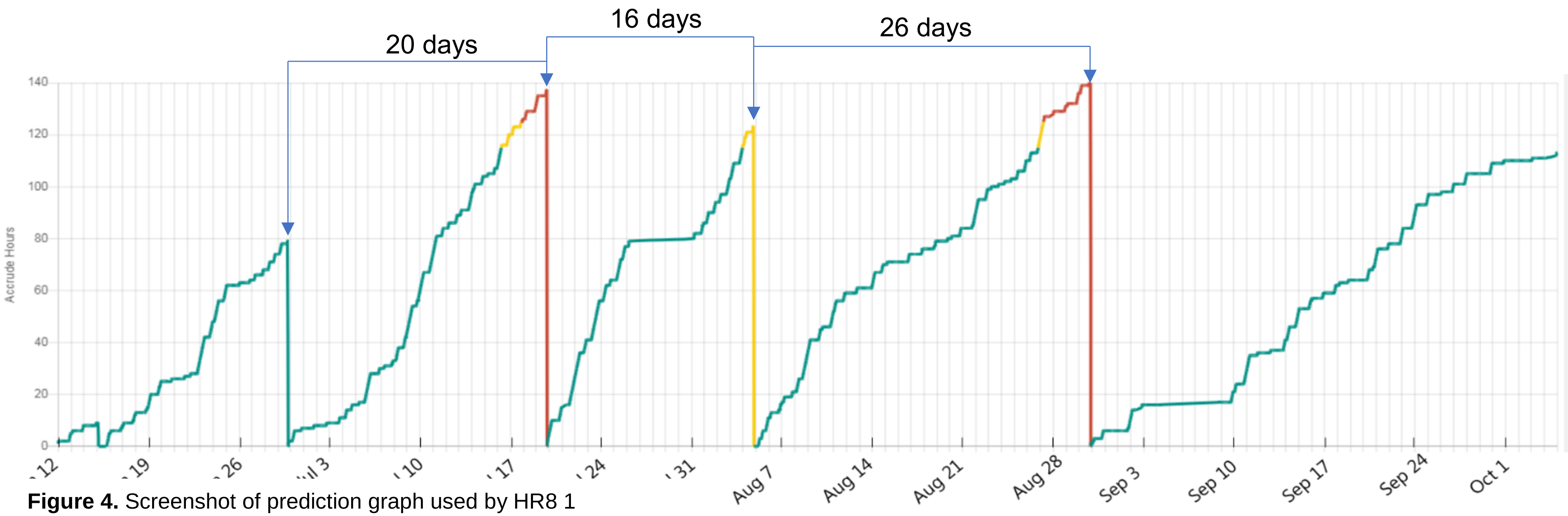


Figure 4. Screenshot of prediction graph used by HR8 1

https://doi.org/10.18745/pb.24905

Site 2: HR9 7

The routine spray programme for this site was applying a fungicide every 3 to 10 days. The end of harvest for this crop was 31st October 2019.

This grower has not used the prediction system to its full potential, nine sprays were applied below 50 hours (low risk), three fungicides applied between 50 and 115 hours (low to medium risk) and five fungicide applications were made over 115 accumulated hours (medium to high risk) (Figure 5). However, this grower has stated that they consider harvest intervals and modes of action used when making decisions about their spray programme. A 'clean up' spray was applied on 26th April, as required when using the prediction system. Using the prediction system has increased the spray interval at the beginning of the season.

The full spray programmes for the prediction system and routine spray programme are given in Appendix 2, Table 2.

Table 7 Analysis results for Site HR9 7

				Number of fungicide applications			Cost-benefit analysis (cost of fungicides and labour, £/hectare)			Disease report	
Variety	**Growing method**	**Sensor**	**Dates using the prediction system**	**Prediction system**	**Routine programme**	**Saving**	**Prediction system**	**Routine programme**	**Saving**	**Prediction system**	**Routine programme**
Prize (everbearer)	Coir on tabletops	Davis	26/04/-31/10/2019	17	19	2	1146.12	1321.59	175.47	Low disease level, no epidemic development	

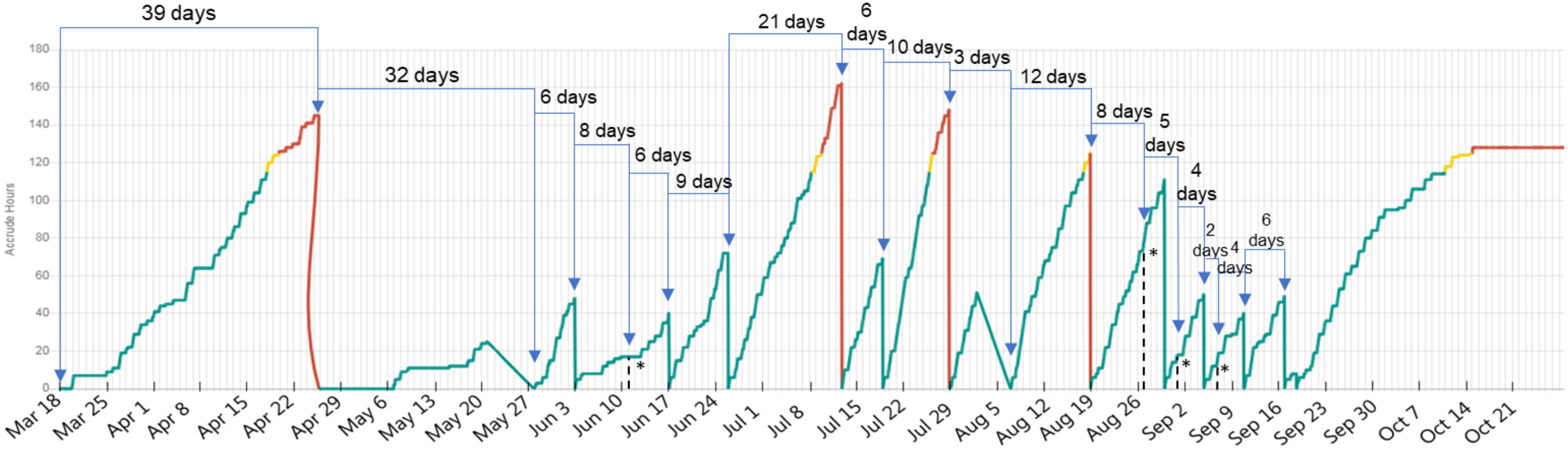


Figure 5. Screenshot of prediction graph used by HR9 7. ----*Fungicide application made but system was not reset

Site 3: HR4 7

The routine spray programme for this site was applying a fungicide approximately every 5 to 14 days. The end of harvest for this crop was 23rd October 2019.

This grower has not used the prediction system to its full potential. Five fungicide were applied below 50 hours (low risk) and five fungicides were applied between 50 and 115 hours (low to medium risk) (Figure 6). Additionally, they did not input one of their sprays into the system and reset the system twice when no application had been made. In order to gain an accurate prediction, the grower needs to reset the system only when they have made a fungicide application. Using the prediction system, the spray intervals have increased in the middle and towards the end of the season (Appendix 2, Table 3).

Table 8 Analysis results for Site HR4 7

				Number of fungicide applications			Cost-benefit analysis (cost of fungicides and labour, £/hectare)			Disease report	
Variety	**Growing method**	**Sensor**	**Dates using the prediction system**	**Prediction system**	**Routine programme**	**Saving**	**Prediction system**	**Routine programme**	**Saving**	**Prediction system**	**Routine programme**
Murano (everbearer)	Coir on tabletops	SMS	14/06/-23/10/2019	15	18	3	1826.95	1948.41	121.45	No disease observed	

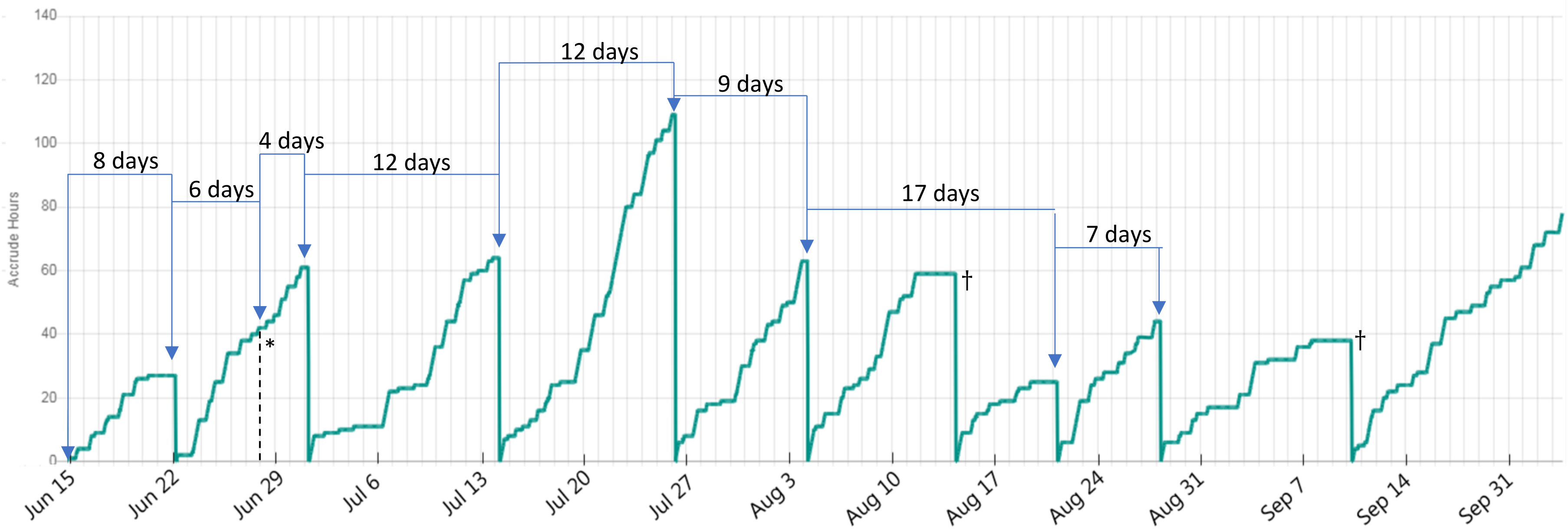


Figure 6. Screenshot of prediction graph used by HR4 7.

---* Fungicide application made but system was not reset
† System reset but no fungicide application made

https://doi.org/10.18745/pb.24905

Site 4: ST18 9 (a)

The routine spray programme for this site was applying a fungicide every 14 days until July and August, when a fungicide was applied every 7 days. The final harvest date for this crop was 5th November 2019. This grower was primarily using the Berry Gardens prediction system, whilst entering fungicide applications into this system.

Ten fungicides were applied below 50 accumulated hours (low risk), six fungicides were applied between 50 and 115 accumulated hours (low to medium risk) and one fungicide was applied over 115 accumulated hours (medium risk) (Figure 7). This grower did not utilise the system fully and used 'insurance spray' (spraying every fourteen days) from 3rd April until July and August when a fungicide was applied weekly (Figure 7). The situation had been improved after the meeting with the UH group on 23rd July, the grower extended the number of accumulated hours before applying a fungicide. The full spray programmes are given in Appendix 2, Table 4.

Table 9 Analysis results for Site ST18 9 (a)

				Number of fungicide applications			Cost-benefit analysis (cost of fungicides and labour, £/hectare)			Disease report	
Variety	**Growing method**	**Sensor**	**Dates using the prediction system**	**Prediction system**	**Routine programme**	**Saving**	**Prediction system**	**Routine programme**	**Saving**	**Prediction system**	**Routine programme**
Katrina (everbearer)	Coir on tabletops	SMS	18/04/-05/11/2019	17	19	2	1193.50	1228.50	35	Low disease level, no epidemic development	

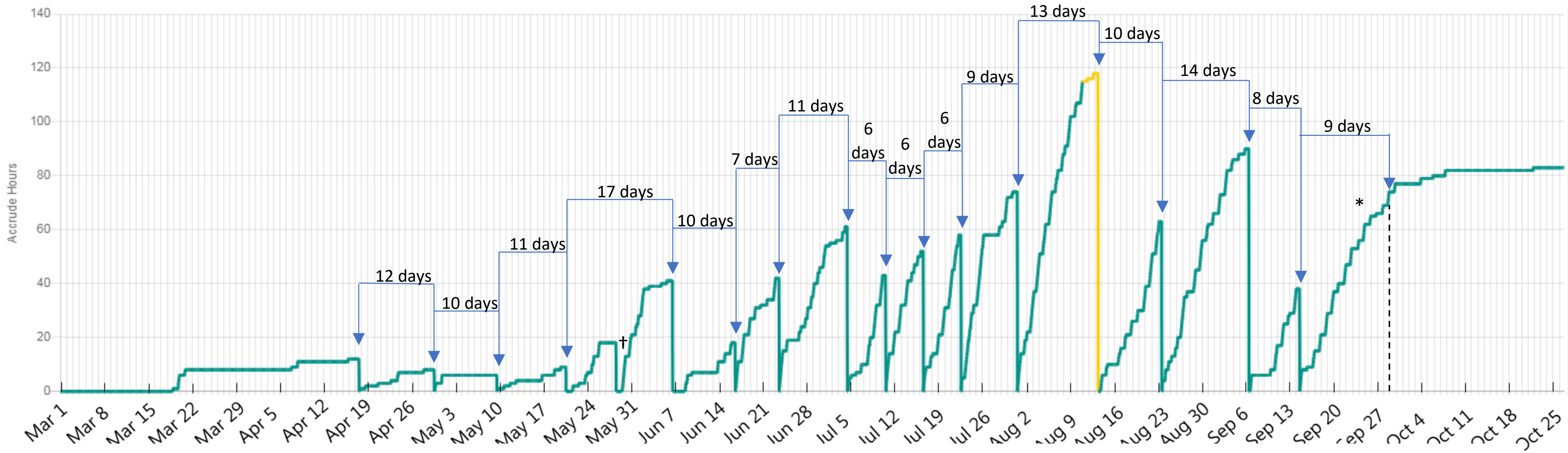


Figure 7. Screenshot of prediction graph used by ST18 9 (a).

----*Fungicide application made but system was not reset
† System reset but no fungicide application made

https://doi.org/10.18745/pb.24905

Site 5: ST18 9 (b)

The routine spray programme for this site was applying a fungicide every 14 days until July and August, when a fungicide was applied every 7 days. The final harvest date for this crop was 8th October 2019. This grower was primarily using the Berry Gardens prediction system, whilst entering fungicide applications into this system.

This grower did not utilise the system fully and used 'insurance spray' from 3rd April until July and August when started spray weekly (Figure 8). Thirteen fungicides were applied below 50 accumulated hours (low risk) and three fungicides were applied when the prediction system was between 50 and 115 accumulated hours (low to medium risk). The grower had been spraying more than was necessary. The situation had been slightly improved after the meeting with the UH group on 23rd July, the grower started to follow the system more closely and extended the number of accumulated hours before applying a fungicide. The full spray programmes are given in Appendix 2, Table 5.

Table 10 Analysis results for Site ST18 9 (b)

				Number of fungicide applications			Cost-benefit analysis (cost of fungicides and labour, £/hectare)			Disease report	
Variety	**Growing method**	**Sensor**	**Dates using the prediction system**	**Prediction system**	**Routine programme**	**Saving**	**Prediction system**	**Routine programme**	**Saving**	**Prediction system**	**Routine programme**
Amesti (everbearer)	Coir on tabletops	SMS	03/04/-08/10/2019	16	19	3	1101.00	1228.50	127.50	Low disease level, no epidemic development	

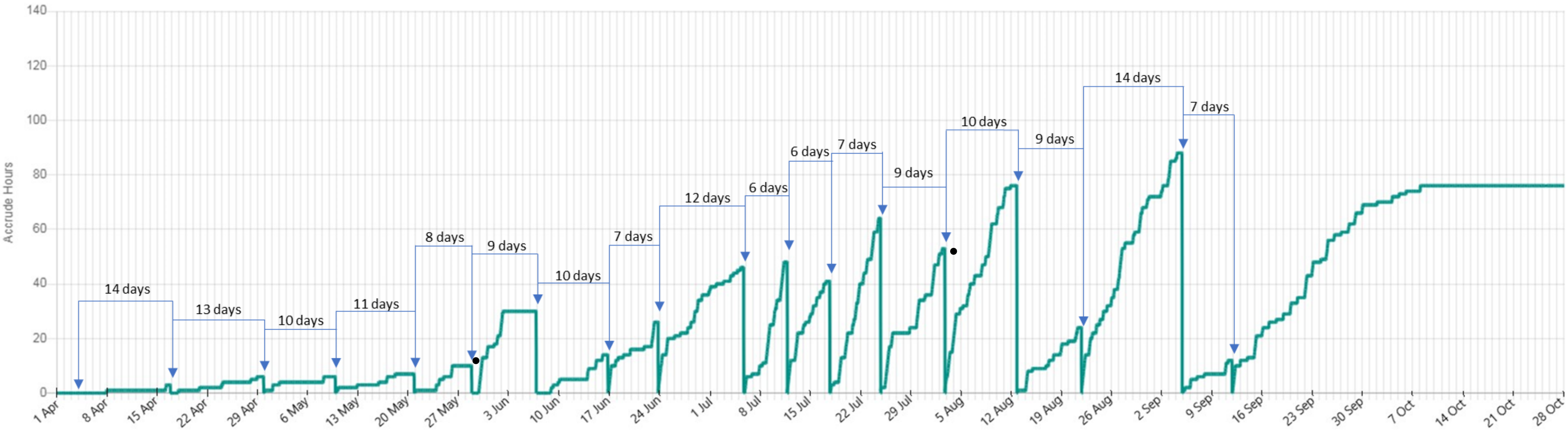


Figure 8. Screenshot of prediction graph used by ST18 9 (b). • Prediction system reset; fungicide entered is a control product for *Botrytis cinerea*

https://doi.org/10.18745/pb.24905

Site 6: PH12 8

The routine spray programme for this site was applying a fungicide every 10 days. The final harvest date for this crop was 2nd October 2019.

The prediction system has been used reasonably well; two fungicides were applied below 50 accumulated hours (low risk) and four fungicides were applied between 50 and 115 accumulated hours (low to medium risk) (Figure 9). This grower has managed to extend the interval between applications throughout the season by using the prediction system, when compared to their routine spray programme of every ten days. The full spray programmes are available in Appendix 2, Table 6.

Table 11 Analysis results for Site PH12 8

				Number of fungicide applications			Cost-benefit analysis (cost of fungicides and labour, £/hectare)			Disease report	
Variety	**Growing method**	**Sensor**	**Dates using the prediction system**	**Prediction system**	**Routine programme**	**Saving**	**Prediction system**	**Routine programme**	**Saving**	**Prediction system**	**Routine programme**
Murano (everbearer)	Coir on tabletops	SMS	21/06/-02/10/2019	6	9	3	547.86	804.07	256.21	No disease observed	

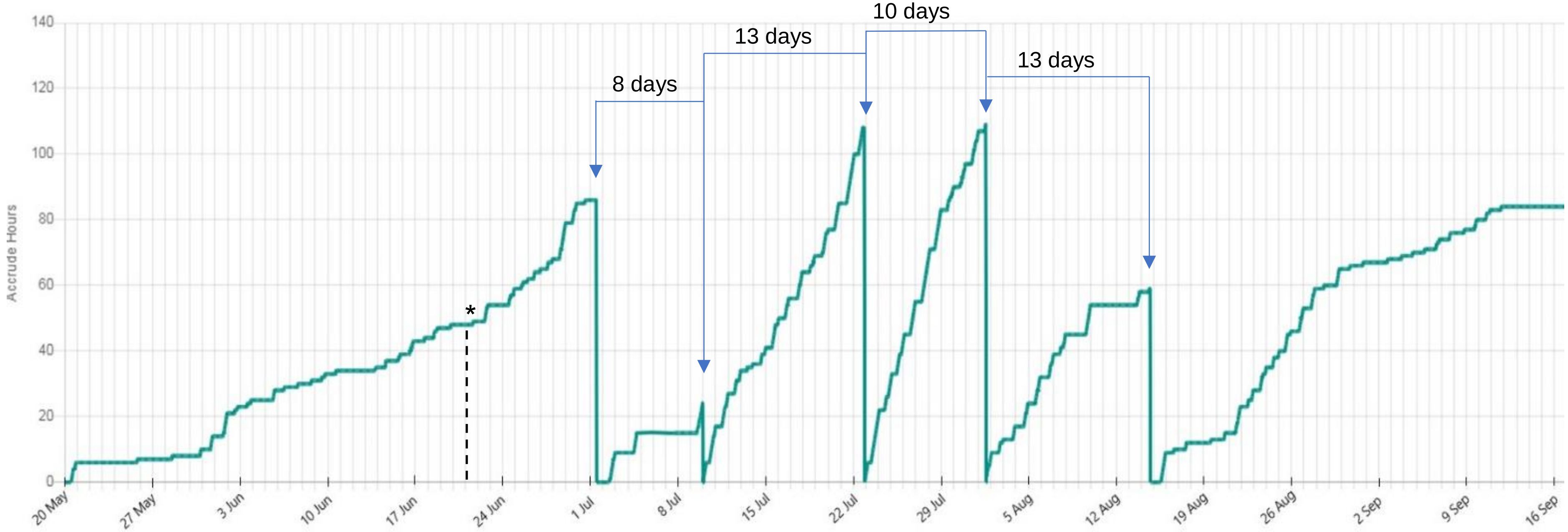


Figure 9. Screenshot of prediction graph used by PH12 8. ----*Fungicide application made prior to use of prediction system

https://doi.org/10.18745/pb.24905

Site 7: DD11 3 (a)

The routine spray programme for this site was applying a fungicide every 10 days. The final harvest date for this crop was the beginning of October 2019.

The prediction system hasn't been used to its full potential. The first fungicide application entered in the system was done on 9th August 2019 (Figure 10), eight fungicide applications were made prior to its use. More savings may have been made if the grower had started using the prediction system earlier in the season. Five fungicides were applied between 50 and 115 accumulated hours (low to medium risk). If more sprays were applied over 100 accumulated hours, the interval between fungicide applications could have been greater. The full spray programmes are given in Appendix 2, Table 7.

Table 12 Analysis results for Site DD11 3(a)_

				Number of fungicide applications			Cost-benefit analysis (cost of fungicides and labour, £/hectare)			Disease report	
Variety	**Growing method**	**Sensor**	**Dates using the prediction system**	**Prediction system**	**Routine programme**	**Saving**	**Prediction system**	**Routine programme**	**Saving**	**Prediction system**	**Routine programme**
Murano (everbearer)	Soil on raised beds	Davis	07/05/-02/10/2019	13	15	2	1402.39	1618.14	215.75	No disease observed	

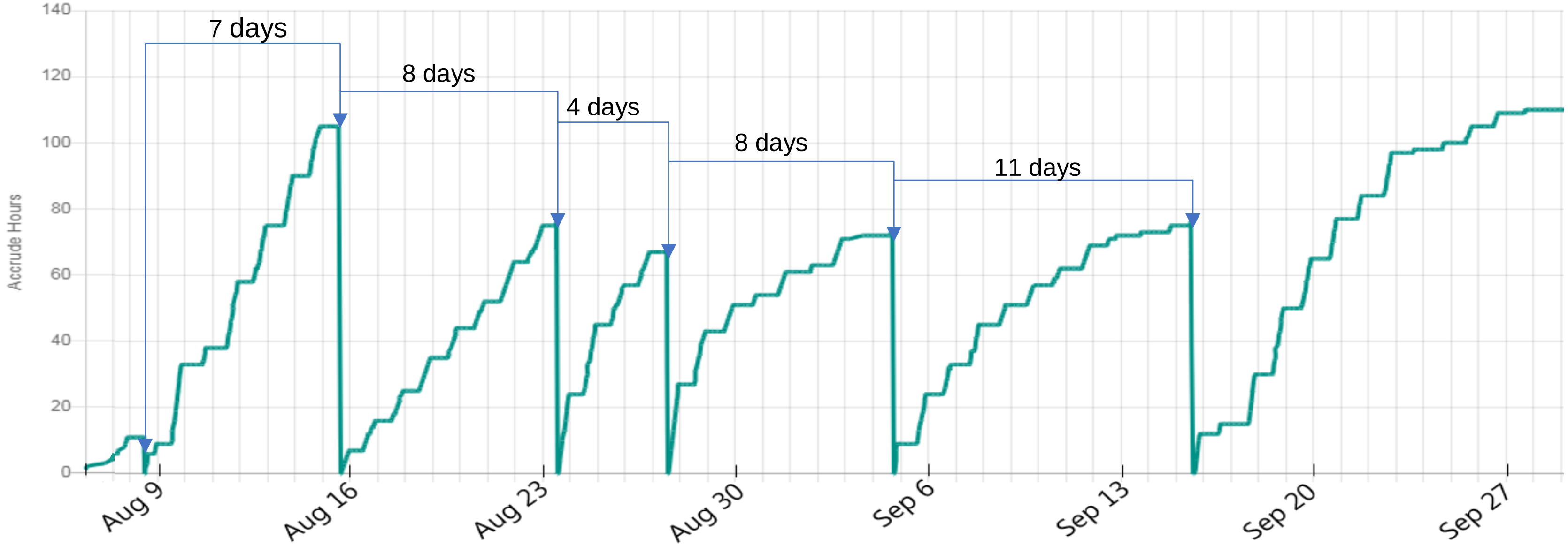


Figure 10. Screenshot of prediction graph used by DD11 3 (a), from 9th August to 27th September 2019.

https://doi.org/10.18745/pb.24905

Site 8: DD11 3 (b)

The routine spray programme for this site was applying a fungicide every 10 days. The final harvest date for this crop was mid-July 2019.

The prediction system hasn't been used to its full potential; two fungicides were applied below 50 accumulated hours (low risk) and two were applied between 50 and 115 accumulated hours (low to medium risk) (Figure 11). This grower has managed to extend the interval between sprays throughout the season, when compared to their routine spray programme of spraying every ten days. However, the interval between sprays could have been extended further if fungicides were applied between 100 and 144 accumulated hours.

The spray programme reported by the grower for both the prediction system and routine spray programme began on 21st June 2019, with the first fungicide application entered into the system on 5th June 2019. The full spray programmes are given in Appendix 2, Table 8.

Table 13 Analysis results for Site DD11 3(b)_

				Number of fungicide applications			Cost-benefit analysis (cost of fungicides and labour, £/hectare)			Disease report	
Variety	**Growing method**	**Sensor**	**Dates using the prediction system**	**Prediction system**	**Routine programme**	**Saving**	**Prediction system**	**Routine programme**	**Saving**	**Prediction system**	**Routine programme**
Malling™ Centenary (June bearer)	Soil on raised beds	Davis	21/05/-07/2019	6	7	1	749.52	874.44	124.92	No disease observed	

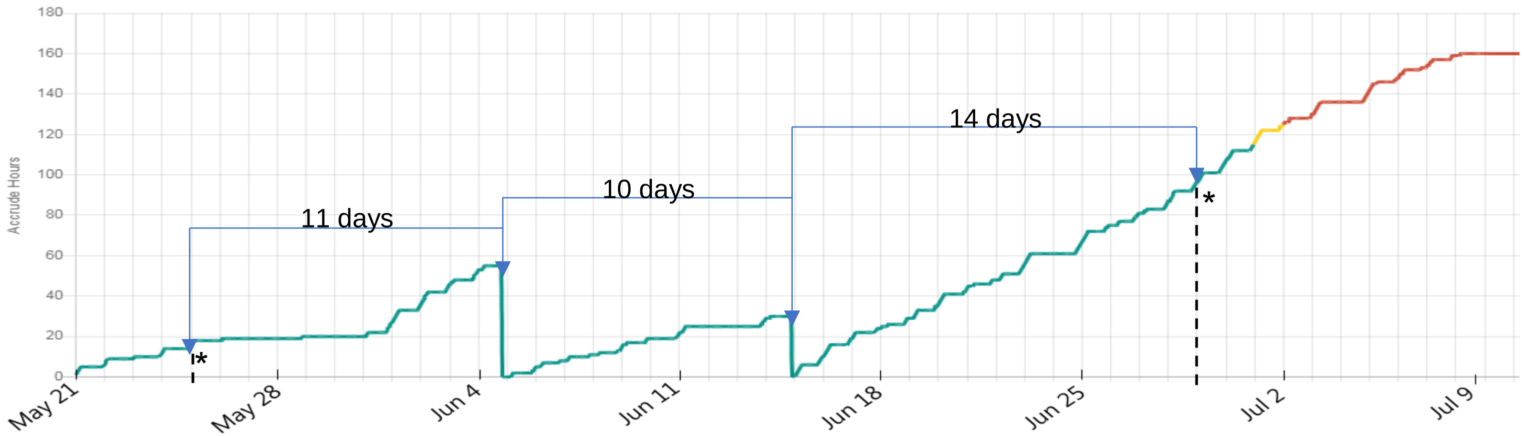


Figure 11. Screenshot of prediction graph used by DD11 3 (b). -------*Fungicide application made but system was not reset

https://doi.org/10.18745/pb.24905

Site 9: Did not use prediction system

The routine programme for this site was applying fungicides on average every 5 days. The end of harvest for this crop was October 2019. The prediction system was accessed from 21st May 2019, each fungicide application was recorded in the system, three fungicide applications were made prior to access to the system. However, it was not used to guide when to apply fungicide sprays.

Figure 12 shows what a spray programme may look like when the prediction system isn't used. Ten fungicide applications were made when the system was below 50 accumulated hours (low risk) and one fungicide was applied between 50 and 115 accumulated hours (low to medium risk). Therefore, the interval between fungicide sprays is very short and many applications are done when they aren't necessary. The full spray programme is given in Appendix 2, Table 9.

Table 14 Analysis results for Site 9_

				Number of fungicide applications			Cost-benefit analysis (cost of fungicides and labour, £/hectare)			Disease report	
Variety	**Growing method**	**Sensor**	**Dates using the prediction system**	**Prediction system**	**Routine programme**	**Saving**	**Prediction system**	**Routine programme**	**Saving**	**Prediction system**	**Routine programme**
Murano (everbearer)	Coir on tabletops	Davis	21/05/-10/2019	-	22	-	-	1516.12	-	-	Disease present with visible infection symptoms

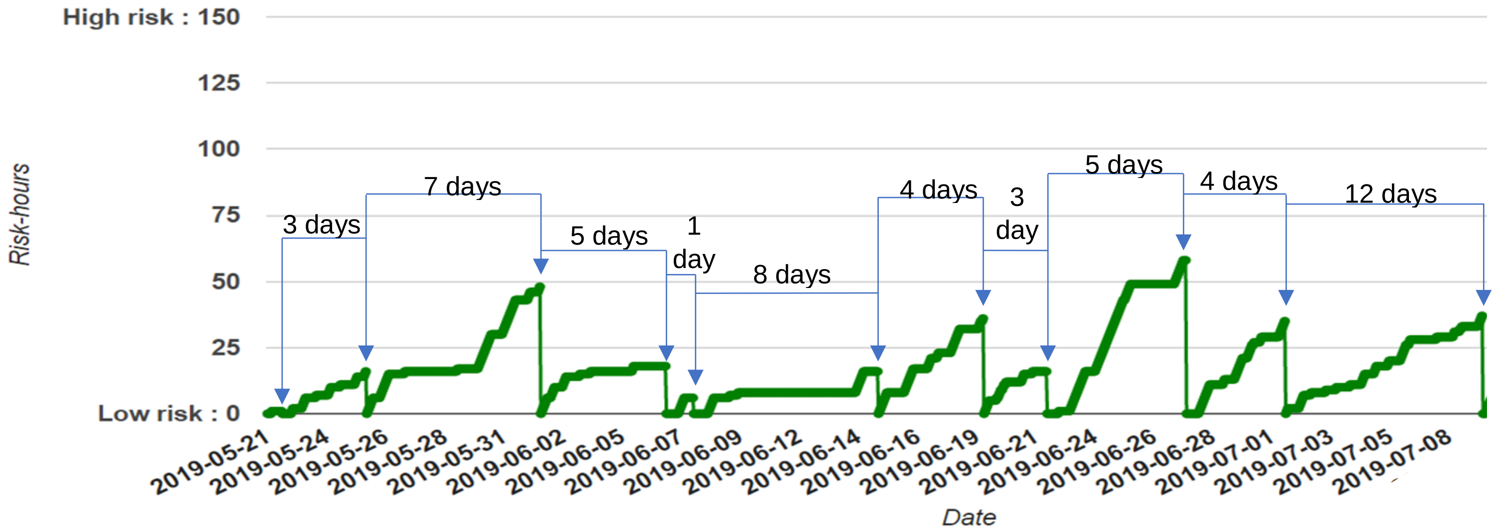


Figure 12. Screenshot of prediction graph used by a grower who did not follow the prediction system (21st May 2019 to 8th July 2019)

https://doi.org/10.18745/pb.24905

4. Discussion

4.1 Outcome from the validation of the prediction system

The validation of the prediction system in 2019 met all criteria set. All participating farms achieved commercially satisfactory disease control in their prediction plots. A range of geographical locations were used including sites in both England and Scotland. A variety of cultivars were grown including Sweet Eve, Prize, Murano, Katrina and Amesti (everbearers) and Malling™ Centenary (June bearer). Two different types of sensors were used, Davis and SMS. Most growing systems used coir on tabletops, however on two sites, crops were grown on raised beds in soil. Growers reported that the prediction system was simple to understand and easy to use.

The success of the prediction system is dependent on how well it is followed by the grower. The grower needs to have enough confidence to allow the hours to accumulate above 100 hours before applying a fungicide. Additionally, for the use of the prediction system to be successful, a ‘clean up’ spray must be applied at the start of the season, due to the fungus being present on crops from propagators or present on over-wintered crops.

In this validation of the prediction system, all participating growers saved at least one fungicide application and reduced costs. It was used relatively well by two growers (Site 1 & 6), whereby most fungicide applications were made over 100 accumulated hours. These two growers had the confidence to follow the prediction system well, used the system as a decision support tool, and linked the timing of fungicide sprays to the recorded weather conditions (i.e. disease conducive conditions). As a result, they increased the interval between fungicide applications and achieved savings in both the number of sprays performed and in costs.

The other growers (Site 2, 3, 4, 5, 7 & 8) who took part in the validation did not make many fungicide applications over 100 accumulated hours and were spraying relatively frequently. These growers could have achieved greater savings by making fungicide applications at larger intervals, when guided to do so by the prediction system. These growers were more inclined to follow routine programmes rather than linking the timing of fungicide sprays to the disease conducive conditions. The grower at site 9 applied fungicides at short intervals and when the risk was low. This resulted in more fungicides applied than other routine spray programmes followed, with greater costs incurred.

In some instances, a grower was not required to spray for over 20 days (Site 1 & 2), this was due to there being fewer disease conducive hours early in the season. The likelihood of a 24-hour period of disease conducive conditions is low, therefore spraying every six days or less is not needed. The number of disease conducive hours will vary for different growing seasons, however, when the system is used well savings could still be made, especially at the start of the season.

4.2 Grower education

Grower education is vital in increasing the confidence of growers to use the system well. It can also help the grower to understand the risk better. The prediction system may not have been used very well due to growers being risk averse, being more confident in an insurance spray programme than allowing hours to accumulate for longer than their normal spray interval. Confidence in the prediction system can be increased through education; informing

https://doi.org/10.18745/pb.24905

the growers and associated advisors about the lifecycle of the fungus and how the prediction system works.

4.2.1 Farm visits and information dissemination

During the validation of the prediction system on-farm visits were made to each participating grower. In these meetings the lifecycle of the fungus and how this underpins the prediction system was explained, as well as discussing the importance of a 'clean up' spray. The grower was also given the opportunity to have any queries answered. These meetings were positive and encouraged the growers to think more about their use of the system. Delivering presentations at conferences is also a good way to disseminate information about the prediction system. During 2019 and 2020, oral and poster presentations were given at the British Society of Plant Pathology presidential meeting, Crop Production in Northern Britain (Paper included as Appendix 8) and an in-house meeting the Life and Medical Science research conference. Running a stand at Fruit Focus was also beneficial for the dissemination of information about the prediction system and meeting growers who may be interested in using the system (Materials distributed given in Appendix 3 & 4). An article about the University of Hertfordshire stand was published in The Fruit Grower (Appendix 9).

4.2.2 Grower Short Course

The grower and advisor courses 'Optimising Growth of Strawberries Under Protection' held in both England and Scotland in October 2019 were successful in educating growers and advisors in principles of the prediction system and how it can be used. The course also included other aspects of strawberry production that would be useful to growers, including presentations on plant defence, the use of silicon nutrient and its benefits, irrigation and Agri-Tech Service's new app. Incorporating an interactive session into the course allowed the delegates to have first-hand experience of using the prediction system. Additionally, two growers gave their experiences of using the prediction system, which enabled an open discussion about the practicalities of its use (Full timetable given in Appendix 5)

4.3 Growers Feedback

4.3.1 Feedback from Short Course

The course was well received by the delegates, who rated each talk between four and five out of five, when they completed the feedback questionnaire. Fifteen delegates expressed further interest in the prediction system. The course was also attended by journalists, with an article published in The Fruit Grower (Appendix 10). By holding meetings, attending talks and short courses, growers have more confidence in the use of the prediction system when making their decisions when to apply a fungicide.

4.3.2 Feedback from using the prediction system

Feedback from some of the growers that took part in the validation has been obtained:

- "Yes, the system was very user friendly. Very easy to use and to enter in data such as when sprays have been applied"
- "I didn't solely rely on the system this year for all decisions but for the one block that we used it on we didn't have an issue with mildew there. We will use it more next year."
- "This season, following the prediction system has been our 'cleanest year' in terms of mildew, with no outbreaks at all."

https://doi.org/10.18745/pb.24905

4.4 Benefits of using the prediction system

There are many benefits to using the prediction system. Using the system quantifying the risk in the number of hours, the grower can use fewer fungicide sprays by targeting with precision. This allows satisfactory disease control with fewer applications. Other benefits include:

- Increase growers' confidence and supports decision of when to apply fungicides, avoiding frequent insurance sprays
- Work showed a reduction in the number of sprays from 16 or more a season to 8 or 10 depending on weather conditions
- More financial savings in the early season
- Reliable, quick and simple to use, easy access to real-time data
- Worked well on several cultivars, on both everbearer and June bearer crops
- Being applicable to at least two types of commonly used weather sensors, and is in the process of incorporating with more manufactures
- Can be used in different geographical locations worldwide.

4.5 Conclusion

The validation of the prediction system in 2019 has proven that the prediction system can be used in different geographical locations on a range of cultivars using a variety of growing methods. All growers reduced the number of fungicide applications made, reduced costs and achieved commercially satisfactory disease control when using the prediction system. The better the system is followed; the greater savings can be gained from its use. The system is ready for the commercial launch in the 2020 growing season, with a licence almost complete. Additionally, the prediction system is currently being used by growers in Australia and South Africa.

https://doi.org/10.18745/pb.24905

5. References

Hall, A.M., Jin, X. L. & Dodgson, J. (2016). AHDB Factsheet 29/16: Control of strawberry powdery mildew under protection, Project SF62, SF62a & SF 113.

6. Acknowledgements

We thank Ceres for funding for research assistant, Hannah Wileman from March 2019 to March 2020 and for part funding of research assistant, Bo Liu. We thank Ceres for funding the collaboration between Agri-tech Services and University of Hertfordshire for 2019/2020.

We thank Dr Richard Southern, Dean of Life and Medical Sciences, University of Hertfordshire for funding for Hannah Wileman from 2017 to 2019. We also thank the University of Hertfordshire for the initial ‘Proof of Concept’ funding in 2016 and the Impact Case Study funding for February 2019 to fund Bo Liu.

The Principal Investigator thanks the University of Hertfordshire for continuing payment well beyond retirement age.

Finally, we would like to thank Agri-tech Services for sharing our vision for many years and then being instrumental in delivering the vision to the growers.

https://doi.org/10.18745/pb.24905

Appendix 1

July 2019

Dear Grower,

Prediction System Requirements

Thank you for considering taking part in the use of the prediction system this year.

The prediction system was developed to identify high risk days when strawberry powdery mildew sporulation may occur. This is based on the measurement of the number of hours of optimum temperature and humidity for disease development (144 hours). The prediction system actively records the accumulation of these conducive hours, which helps the grower spray at the optimal time to prevent infection. The web-based real-time prediction system has worked successfully for three years.

To aid in our validation of the prediction system, it would be helpful if two areas containing the same strawberry variety could be used in this trial; one with fungicide applied according to the prediction system and the other according to the normal fungicide spray schedule of the farm. We will regularly visit both areas, to assess for any disease development.

At the end of the season we would require some additional information:

- Spray schedule for both prediction system and normal fungicide spray schedule of the farm
- Costings: Costs of chemicals used and rate per hectare (so the cost of using the prediction system can be compared to a normal spray programme); and labour costs
- Screenshot of prediction system graph at the very end of the season
- How did you use the prediction system to support your decision making?
- Did you find any evidence of strawberry powdery mildew anywhere, this season?

If you have any questions, please contact Dr Avice Hall: a.m.hall@herts.ac.uk or 01707284539.

Kind Regards,

Dr Avice Hall

https://doi.org/10.18745/pb.24905

Appendix 2: Comparison of fungicide spray programmes between the use and non-use (routine) of the prediction system on six farm sites in the 2019 season

Table 1: Site 1: HR8 1

Prediction System						Routine Spray Programme					
Application Date	**Spray Interval[1]**	**Fungicide Name**	**Active Ingredient**	**FRAC Code**	**MOA**	**Application Date**	**Spray Interval**	**Fungicide Name**	**Active Ingredient**	**FRAC Code**	**MOA**
30/06/2019	N/A	Charm	fluxapyroxad + difenoconazole	7 + 3	Inhibit mitochondrial respiration; Inhibit ergosterol biosynthesis	02/07/2019	N/A	Charm	fluxapyroxad + difenoconazole	7 + 3	Inhibit mitochondrial respiration; Inhibit ergosterol biosynthesis
20/07/2019	20 days	AQ10	*Ampelomyces quisqualis*	N/A	Biofungicide- penetrates hyphal wall, dehydrates cytoplasm	10/07/2019	8 days	AQ10	*Ampelomyces quisqualis*	N/A	Biofungicide- penetrates hyphal wall, dehydrates cytoplasm
05/08/2019	16 days	Charm	See above on 30/06	7 + 3	See above on 30/06	21/07/2019	11 days	AQ10	See above on 10/07	N/A	See above on 10/07
31/08/2019	26 days	Nimrod	Bupirimate	8	Inhibits sporulation-targets synthesis of nucleic acids	29/07/2019	8 days	Charm	See above on 02/07	7 + 3	See above on 02/07
						10/08/2019	12 days	Luna Sensation	Fluopyram + Trifloxystobin	7 + 11	(1) Blocks succinate dehydrogenase, interferes with respiration (2) Inhibits fungal respiration (binds to cytochrome b)
						22/08/2019	12 days	Nimrod	Bupirimate	8	Inhibits sporulation-targets synthesis of nucleic acids
						03/09/2019	12 days	Luna Sensation	See above on 10/08	7 + 11	See above on 10/08
Note: 1. Spray interval indicates number of days since last fungicide application						18/09/2019	15 days	Topas	Penconazole	3	Inhibit ergosterol biosynthesis

https://doi.org/10.18745/pb.24905

Table 2: Site 2: HR9 7

Prediction System						Routine Spray Programme					
Application Date	**Spray Interval**	**Fungicide Name**	**Active Ingredient**	**FRAC Code**	**MOA**	**Application Date**	**Spray Interval**	**Fungicide Name**	**Active Ingredient**	**FRAC Code**	**MOA**
26/04/2019	N/A	Fortress	Quinoxyfen	13	Interference with signal transduction-unknown mechanism	26/04/2019	N/A	Fortress	Quinoxyfen	13	Interference with signal transduction-unknown mechanism
28/05/2019	32 days	Stroby WG	Kresoxim-methyl	11	Inhibits fungal respiration (binds to cytochrome b)	28/05/2019	32 days	Stroby WG	Kresoxim-methyl	11	Inhibits fungal respiration (binds to cytochrome b)
03/06/2019	6 days	Nimrod	Bupirimate	8	Inhibits sporulation-targets synthesis of nucleic acids	02/06/2019	5 days	Nimrod	Bupirimate	8	Inhibits sporulation-targets synthesis of nucleic acids
11/06/2019	8 days	Luna Sensation	Fluopyram + Trifloxystobin	7 + 11	(1) Blocks succinate dehydrogenase, interferes with respiration (2) Inhibits fungal respiration (binds to cytochrome b)	10/06/2019	8 days	Luna Sensation	Fluopyram + Trifloxystobin	7 + 11	(1) Blocks succinate dehydrogenase, interferes with respiration (2) Inhibits fungal respiration (binds to cytochrome b)
17/06/2019	6 days	Topas	Penconazole	3	Inhibit ergosterol biosynthesis	16/06/2019	6 days	Topas	Penconazole	3	Inhibit ergosterol biosynthesis
22/06/2019	9 days	Potassium Bicarbonate	Potassium Hydrogen Carbonate	N/A	Causes collapse of hyphal walls and shrinks conidia	23/06/2019	7 days	Potassium Bicarbonate	Potassium Hydrogen Carbonate	N/A	Causes collapse of hyphal walls and shrinks conidia
13/07/2019	21 days	Amistar Top	Azoxystrobin + difenoconazole	11 + 3	Inhibit mitochondrial respiration (binds to cytochrome b); Inhibits ergosterol biosynthesis	30/06/2019	7 days	Takumi SC	Cyflufenamid (benzamidoxime)	U6	Interference with appressorium/ conidiation
19/07/2019	6 days	Potassium Bicarbonate	See above on 22/06	N/A	See above on 22/06	14/07/2019	14 days	Amistar Top	Azoxystrobin + difenoconazole	11 + 3	Inhibit mitochondrial respiration (binds to cytochrome b); Inhibits ergosterol biosynthesis

https://doi.org/10.18745/pb.24905

04/08/2019	10 days	Signum	Boscalid + Pyraclostrobin	7 + 11	Inhibit mitochondrial respiration (binds to cytochrome b)	20/07/2019	6 days	Potassium Bicarbonate	See above on 23/06	N/A	See above on 23/06
07/08/2019	3 days	Potassium Bicarbonate	See above on 22/06	N/A	See above on 22/06	28/07/2019	8 days	Charm	fluxapyroxad + difenoconazole	7 + 3	Inhibit mitochondrial respiration; Inhibit ergosterol biosynthesis
19/08/2019	12 days	Potassium Bicarbonate	See above on 22/06	N/A	See above on 22/06	07/08/2019	10 days	Signum	Boscalid + Pyraclostrobin	7,11	Inhibit mitochondrial respiration (binds to cytochrome b)
27/08/2019	8 days	Amylo X WG	*Bacillus amyloliquefaciens* subsp. *Plantarum* strain D747	Biofungicide	Cause antibiosis and release of lytic enzymes	15/08/2019	8 days	Nimrod	See above on 02/06	8	See above on 02/06
01/09/2019	5 days	Signum	See above on 04/08	7 + 11	See above on 04/08	22/08/2019	7 days	Potassium Bicarbonate	See above on 23/06	N/A	See above on 23/06
05/09/2019	4 days	Potassium Bicarbonate	See above on 22/06	N/A	See above on 22/06	26/08/2019	4 days	Amylo X WG	*Bacillus amyloliquefaciens* subsp. *Plantarum* strain D747	Biofungicide	Cause antibiosis and release of lytic enzymes
07/09/2019	2 days	Amylo X WG	See above on 27/08	Biofungicide	See above on 27/08	29/08/2019	3 days	Amylo X WG	See above on 26/08	Biofungicide	See above on 26/08
11/09/2019	4 days	Kumulus DF	Sulphur	M02	Multi-site function	02/09/2019	4 days	Potassium Bicarbonate	See above on 23/06	N/A	See above on 23/06
17/09/2019	6 days	Potassium Bicarbonate	See above on 22/06	N/A	See above on 22/06	09/09/2019	7 days	Potassium Bicarbonate	See above on 23/06	N/A	See above on 23/06
						12/09/2019	3 days	Kumulus DF	Sulphur	M02	Multi-site function
						16/09/2019	4 days	Potassium Bicarbonate	See above on 23/06	N/A	See above on 23/06

https://doi.org/10.18745/pb.24905

Table 3: Site 3: HR4 7

Prediction System						Routine Spray Programme					
Application Date	**Spray Interval**	**Fungicide Name**	**Active Ingredient**	**FRAC Code**	**MOA**	**Application Date**	**Spray Interval**	**Fungicide Name**	**Active Ingredient**	**FRAC Code**	**MOA**
08/04/2019	N/A	Amistar	azoxystrobin	11	Inhibits mitochondrial respiration (binds to cytochrome b)	07/04/2019	8 days	Amistar	azoxystrobin	11	Inhibits mitochondrial respiration (binds to cytochrome b)
14/04/2019	6 days	Nimrod	bupirimate	8	Inhibits sporulation-targets synthesis of nucleic acids	15/04/2019	15 days	Fortress	Quinoxyfen	13	Interference with signal transduction- unknown mechanism
01/05/2019	17 days	Charm	fluxapyroxad + difenoconazole	7 + 3	Inhibit mitochondrial respiration; Inhibit ergosterol biosynthesis	30/04/2019	14 days	Charm	fluxapyroxad + difenoconazole	7 + 3	Inhibit mitochondrial respiration; Inhibit ergosterol biosynthesis
18/05/2019	17 days	Takumi	cyflufenamid (benzamidoxime)	U6	Interference with appressorium/conidiation	14/05/2019	6 days	Takumi	Cyflufenamid (benzamidoxime)	U6	Interference with appressorium/conidiation
26/05/2019	8 days	AQ10	*Ampelomyces quisqualis*	N/A	Biofungicide- penetrates hyphal wall, dehydrates cytoplasm	20/05/2019	7 days	Serenade	*Bacillus subtilis* strain QST 713	N/A	Punctures cell membranes, destroy germ tubes and mycelia
09/06/2019	14 days	Serenade	*Bacillus subtilis* strain QST 713	N/A	Punctures cell membranes, destroy germ tubes and mycelia	27/05/2019	19 days	AQ10	*Ampelomyces quisqualis*	N/A	Biofungicide- penetrates hyphal wall, dehydrates cytoplasm
14/06/2019*	5 days	Luna Sensation	fluopyram + trifloxystobin	7, 11	(1) Blocks succinate dehydrogenase, interferes with respiration (2) Inhibits fungal respiration (binds to cytochrome b)	15/06/2019	8 days	Serenade	*Bacillus subtilis* strain QST 713	N/A	Punctures cell membranes, destroy germ tubes and mycelia
22/06/2019	8 days	AQ10	See above on 26/05	N/A	See above on 26/05	23/06/2019	5 days	AQ10	See above on 27/05	N/A	See above on 27/05
28/06/2019	6 days	Takumi	See above on 18/05	U6	See above on 18/05	28/06/2019	15 days	Amistar	See above on 07/04	11	See above on 07/04

https://doi.org/10.18745/pb.24905

02/07/2019	4 days	Charm	See above on 01/05	7 + 3	See above on 01/05	13/07/2019	6 days	Amylo X WG	*Bacillus amyloliquefaciens* subsp. *Plantarum* strain D747	Biofungicide	Cause antibiosis and release of lytic enzymes
14/07/2019	12 days	Topas	Penconazole	3	Inhibit ergosterol biosynthesis	19/07/2019	9 days	Topas	Penconazole	3	Inhibit ergosterol biosynthesis
26/07/2019	12 days	Amylo X WG	*Bacillus amyloliquefaciens* subsp. *Plantarum* strain D747	Biofungicide	Cause antibiosis and release of lytic enzymes	28/07/2019	6 days	Takumi	See above on 14/05	U6	See above on 14/05
04/08/2019	9 days	Stroby WG	Kresoxim-methyl	11	Inhibits fungal respiration (binds to cytochrome b)	03/08/2019	3 days	Stroby WG	Kresoxim-methyl	11	Inhibits fungal respiration (binds to cytochrome b)
21/08/2019	17 days	Serenade	*Bacillus subtilis* strain QST 713	N/A	See above on 09/06	06/08/2019	5 days	AQ 10	See above on 27/05	N/A	See above on 27/05
28/08/2019	7 days	Charm	See above on 01/05	7 + 3	See above on 01/05	11/08/2019	5 days	Luna Sensation	Fluopyram + Trifloxystobin	7 + 11	(1) Blocks succinate dehydrogenase, interferes with respiration (2) Inhibits fungal respiration (binds to cytochrome b)
						16/08/2019	4 days	Karma	Potassium hydrogen carbonate	N/A	Inhibits mycelial growth, causes collapse of spores; disrupts the release of hydrolytic enzymes
						27/08/2019	7 days	Potassium Bicarbonate	Potassium Hydrogen Carbonate	N/A	Causes collapse of hyphal walls and shrinks conidia

*Prediction system used from this date

https://doi.org/10.18745/pb.24905

Table 4: Site 4: ST18 9 (a)

Prediction System						Routine Spray Programme					
Application Date	**Spray Interval**	**Fungicide Name**	**Active Ingredient**	**FRAC Code**	**MOA**	**Application Date**	**Spray Interval**	**Fungicide Name**	**Active Ingredient**	**FRAC Code**	**MOA**
18/04/2019	N/A	Fortress	Quinoxyfen	13	Interference with signal transduction- unknown mechanism	03/04/19	N/A	Fortress	Quinoxyfen	13	Interference with signal transduction- unknown mechanism
30/04/2019	12 days	Takumi	Cyflufenamid (benzamidoxime)	U6	Interference with appressorium/conidiation	17/04/2019	14 days	Takumi	Cyflufenamid (benzamidoxime)	U6	Interference with appressorium/conidiation
10/05/2019	10 days	Amistar Top	Azoxystrobin + difenoconazole	11 + 3	Inhibit mitochondrial respiration (binds to cytochrome b); Inhibits ergosterol biosynthesis	01/05/2019	14 days	Amistar Top	Azoxystrobin + difenoconazole	11 + 3	Inhibit mitochondrial respiration (binds to cytochrome b); Inhibits ergosterol biosynthesis
21/05/2019	11 days	Topas	Penconazole	3	Inhibit ergosterol biosynthesis	15/05/2019	14 days	Topas	Penconazole	3	Inhibit ergosterol biosynthesis
07/06/2019	17 days	Amylo X WG	*Bacillus amyloliquefaciens* subsp. *Plantarum* strain D747	Biofungicide	Cause antibiosis and release of lytic enzymes	29/05/2019	14 days	Amylo X WG	*Bacillus amyloliquefaciens* subsp. *Plantarum* strain D747	Biofungicide	Cause antibiosis and release of lytic enzymes
17/06/2019	10 days	Luna Sensation	Fluopyram + Trifloxystobin	7 + 11	(1) Blocks succinate dehydrogenase, interferes with respiration (2) Inhibits fungal respiration (binds to cytochrome b)	12/06/2019	14 days	Luna Sensation	Fluopyram + Trifloxystobin	7 + 11	(1) Blocks succinate dehydrogenase, interferes with respiration (2) Inhibits fungal respiration (binds to cytochrome b)
24/06/2019	7 days	Takumi	See above on 30/04	U6	See above on 30/04	26/06/2019	14 days	Takumi	See above on 17/04	U6	See above on 17/04
05/07/2019	11 days	Amistar Top	See above on 10/05	11 + 3	See above on 10/05	10/07/2019	14 days	Amistar Top	See above on 01/05	11 + 3	See above on 01/05

https://doi.org/10.18745/pb.24905

11/07/2019	6 days	Potassium Bicarbonate	Potassium Hydrogen Carbonate	N/A	Causes collapse of hyphal walls and shrinks conidia	24/07/2019	14 days	Potassium Bicarbonate	Potassium Hydrogen Carbonate	N/A	Causes collapse of hyphal walls and shrinks conidia
17/07/2019	6 days	Topas	See above on 21/05	3	See above on 21/05	31/07/2019	7 days	Topas	See above on 15/05	3	See above on 15/05
23/07/2019[1]	6 days	Karma	Potassium hydrogen carbonate	N/A	Inhibits mycelial growth, causes collapse of spores; disrupts the release of hydrolytic enzymes	07/08/2019	7 days	Karma	Potassium hydrogen carbonate	N/A	Inhibits mycelial growth, causes collapse of spores; disrupts the release of hydrolytic enzymes
01/08/2019	9 days	Amylo X WG	See above on 07/06	Biofungicide	See above on 07/06	14/08/2019	7 days	Amylo X WG	See above on 29/05	Biofungicide	See above on 29/05
14/08/2019	13 days	Systhane 20 EW	Myclobutanil	3	Inhibits ergosterol biosynthesis	21/08/2019	7 days	Systhane 20 EW	Myclobutanil	3	Inhibits ergosterol biosynthesis
24/08/2019	10 days	Luna Sensation	See above on 17/06	7 + 11	See above on 17/06	28/08/2019	7 days	Luna Sensation	See above on 12/06	7 + 11	See above on 12/06
07/09/2019	14 days	Nimrod	Bupirimate	8	Inhibits sporulation-targets synthesis of nucleic acids	04/09/2019	7 days	Potassium Bicarbonate	See above on 24/07	N/A	See above on 24/07
15/09/2019	8 days	Systhane 20 EW	See above on 14/08	3	See above on 14/08	11/09/2019	7 days	Nimrod	Bupirimate	8	Inhibits sporulation-targets synthesis of nucleic acids
24/09/2019	9 days	Potassium Bicarbonate	See above on 11/07	N/A	See above on 11/07	18/09/2019	7 days	Potassium Bicarbonate	See above on 24/07	N/A	See above on 24/07
						25/09/2019	7 days	Systhane 20 EW	See above on 21/08	3	See above on 21/08
						02/10/2019	7 days	Potassium Bicarbonate	See above on 24/07	N/A	See above on 24/07

Note: 1 (23/07/19). Up to this date, the grower acknowledged that they did not follow the prediction system precisely and sprayed approximately every week. After a meeting with the UH team on 23rd July, they started to use the system more accurately.

https://doi.org/10.18745/pb.24905

Table 5: Site 5: ST18 9 (b)

Prediction System						Routine Spray Programme					
Application Date	**Spray Interval**	**Fungicide Name**	**Active Ingredient**	**FRAC Code**	**MOA**	**Application Date**	**Spray Interval**	**Fungicide Name**	**Active Ingredient**	**FRAC Code**	**MOA**
03/04/2019	N/A	Fortress	Quinoxyfen	13	Interference with signal transduction- unknown mechanism	03/04/2019	14 days	Fortress	Quinoxyfen	13	Interference with signal transduction- unknown mechanism
17/04/2019	14 days	Fortress	See above on 03/04	13	See above on 03/04	17/04/2019	14 days	Takumi	Cyflufenamid (benzamidoxime)	U6	Interference with appressorium/conidiation
30/04/2019	13 days	Takumi	Cyflufenamid (benzamidoxime)	U6	Interference with appressorium/conidiation	01/05/2019	14 days	Amistar Top	Azoxystrobin + difenoconazole	11 + 3	Inhibit mitochondrial respiration (binds to cytochrome b); Inhibits ergosterol biosynthesis
10/05/2019	10 days	Amistar Top	Azoxystrobin + difenoconazole	11 + 3	Inhibit mitochondrial respiration (binds to cytochrome b); Inhibits ergosterol biosynthesis	15/05/2019	14 days	Topas	Penconazole	3	Inhibit ergosterol biosynthesis
21/05/2019	11 days	Topas	Penconazole	3	Inhibit ergosterol biosynthesis	29/05/2019	14 days	Amylo X WG	*Bacillus amyloliquefaciens* subsp. *Plantarum* strain D747	Biofungicide	Cause antibiosis and release of lytic enzymes
29/05/2019	8 days	Frupica[1]	Mepanipyrim	9	Inhibits protein synthesis	12/06/2019	14 days	Luna Senstaion	Fluopyram + Trifloxystobin	7 + 11	(1) Blocks succinate dehydrogenase, interferes with respiration (2) Inhibits fungal respiration (binds to cytochrome b)
07/06/2019	9 days	Amylo X WG	*Bacillus amyloliquefaciens* subsp. *Plantarum* strain D747	Biofungicide	Cause antibiosis and release of lytic enzymes	26/06/2019	14 days	Takumi	See above on 17/04	U6	See above on 17/04
17/06/2019	10 days	Luna Sensation	Fluopyram + Trifloxystobin	7 + 11	(1) Blocks succinate dehydrogenase, interferes with respiration (2) Inhibits	10/07/2019	14 days	Amistar Top	See above on 01/05	11 + 3	See above on 01/05

https://doi.org/10.18745/pb.24905

					fungal respiration (binds to cytochrome b)						
24/06/2019	7 days	Takumi	See above on 30/04	U6	See above on 30/04	24/07/2019	14 days	Potassium Bicarbonate	Potassium Hydrogen Carbonate	N/A	Causes collapse of hyphal walls and shrinks conidia
06/07/2019	12 days	Amistar Top	See above on 10/05	11 + 3	See above on 10/05	31/07/2019	7 days	Topas	See above on 15/05	3	See above on 15/05
12/07/2019	6 days	Potassium Bicarbonate	Potassium Hydrogen Carbonate	N/A	Causes collapse of hyphal walls and shrinks conidia	07/08/2019	7 days	Karma	Potassium hydrogen carbonate	N/A	Inhibits mycelial growth, causes collapse of spores; disrupts the release of hydrolytic enzymes
18/07/2019[2]	6 days	Topas	See above on 21/05	3	See above on 21/05	14/08/2019	7 days	Amylo X WG	See above on 29/05	Biofungicide	See above on 29/05
25/07/2019	7 days	Karma	Potassium hydrogen carbonate	N/A	Inhibits mycelial growth, causes collapse of spores	21/08/2019	7 days	Systhane 20 EW	Myclobutanil	3	Inhibits ergosterol biosynthesis
03/08/2019	9 days	Frupica[1]	See above on 29/05	9	See above on 29/05	28/08/2019	7 days	Luna Sensation	See above on 12/06	7 + 11	See above on 12/06
13/08/2019	10 days	Systhane 20 EW	Myclobutanil	3	Inhibits ergosterol biosynthesis	04/09/2019	7 days	Potassium Bicarbonate	See above on 24/07	N/A	See above on 24/07
22/08/2019	9 days	Luna Sensation	See above on 17/06	7 + 11	See above on 17/06	11/09/2019	7 days	Nimrod	Bupirimate	8	Inhibits sporulation-targets synthesis of nucleic acids
05/09/2019	14 days	Nimrod	Bupirimate	8	Inhibits sporulation-targets synthesis of nucleic acids	18/09/2019	7 days	Potassium Bicarbonate	See above on 24/07	N/A	See above on 24/07
12/09/2019	7 days	Systhane 20 EW	See above on 13/08	3	See above on 13/08	25/09/2019	7 days	Systhane 20 EW	See above on 21/08	3	See above on 21/08
						02/10/2019	7 days	Potassium Bicarbonate	See above on 24/07	N/A	See above on 24/07

Note: 1 (29/05/19 & 03/08/19). Fungicide 'Frupica' is for the control of Grey mould (*Botrytis cinerea*);
2 (18/07/19). Up to this date, the grower acknowledged that they did not follow the prediction system precisely and sprayed approximately every week. After a meeting with the UH team on 23rd July, they started to use the system more accurately.

https://doi.org/10.18745/pb.24905

Table 6: Site 6: PH12 8

Prediction System						Routine Spray Programme					
Application Date	**Spray Interval**	**Fungicide Name**	**Active Ingredient**	**FRAC Code**	**MOA**	**Application Date**	**Spray Interval**	**Fungicide Name**	**Active Ingredient**	**FRAC Code**	**MOA**
21/06/2019	N/A	Amistar	azoxystrobin	11	Inhibits mitochondrial respiration (binds to cytochrome b)	21/06/2019	N/A	Amistar	azoxystrobin	11	Inhibits mitochondrial respiration (binds to cytochrome b)
02/07/2019	11 days	Topas	Penconazole	3	Inhibit ergosterol biosynthesis	02/07/2019	11 days	Talius	proquinazid	13	Interference with signal transduction (mechanism unknown)
10/07/2019	8 days	Topas	See above on 02/07	3	See above on 02/07	12/07/2019	10 days	Takumi	Cyflufenamid (benzamidoxime)	U6	Interference with appressorium/conidiation
23/07/2019	13 days	Luna Sensation	Fluopyram + Trifloxystobin	7 + 11	(1) Blocks succinate dehydrogenase, interferes with respiration (2) Inhibits fungal respiration (binds to cytochrome b)	22/07/2019	10 days	Topas	Penconazole	3	Inhibit ergosterol biosynthesis
02/08/2019	10 days	Serenade	*Bacillus subtilis* strain QST 713	N/A	Punctures cell membranes, destroy germ tubes and mycelia	01/08/2019	10 days	Takumi	See above on 12/07	U6	See above on 12/07
15/08/2019	13 days	Serenade	See above on 02/08	3	See above on 02/08	11/08/2019	10 days	Topas	See above on 22/07	3	See above on 22/07
						21/08/2019	10 days	Serenade	*Bacillus subtilis* strain QST 713	N/A	Punctures cell membranes, destroy germ tubes and mycelia
						31/08/2019	10 days	Charm	fluxapyroxad + difenoconazole	7 + 3	Inhibit mitochondrial respiration; Inhibit ergosterol biosynthesis
						10/09/2019	10 days	Luna Sensation	Fluopyram + Trifloxystobin	7 + 11	(1) Blocks succinate dehydrogenase, interferes with respiration (2) Inhibits fungal respiration (binds to cytochrome b)

https://doi.org/10.18745/pb.24905

Table 7: Site 7: DD11 3 (a)

Prediction System						Routine Spray Programme	
Application Date	**Spray Interval**	**Fungicide Name**	**Active Ingredient**	**FRAC Code**	**MOA**	**Application Date**	**Spray Interval**
07/05/2019	N/A	Signum	Boscalid + Pyraclostrobin	7,11	Inhibit mitochondrial respiration (binds to cytochrome b)	07/05/2019	10 days
04/06/2019	28 days	Potassium Bicarbonate	Potassium Hydrogen Carbonate	N/A	Causes collapse of hyphal walls and shrinks conidia	17/05/2019	10 days
		Kumulus DF	Sulphur	M02	Multi-site function	27/05/2019	10 days
		Serenade	*Bacillus subtilis* strain QST 713	N/A	Punctures cell membranes, destroy germ tubes and mycelia	06/06/2019	10 days
13/06/2019	9 days	Nimrod	Bupirimate	8	Inhibits sporulation-targets synthesis of nucleic acids	16/06/2019	10 days
02/07/2019	11 days	Potassium Bicarbonate	See above on 04/05/19	N/A	See above on 04/05/19	26/06/2019	10 days
		Kumulus DF	See above on 04/05/19	M02	See above on 04/05/19	06/07/2019	10 days
11/07/2019	9 days	Charm	fluxapyroxad + difenoconazole	7 + 3	Inhibit mitochondrial respiration; Inhibit ergosterol biosynthesis	16/07/2019	10 days
18/07/2019	7 days	Luna Sensation	Fluopyram + Trifloxystobin	7 + 11	(1) Blocks succinate dehydrogenase, interferes with respiration (2) Inhibits fungal respiration (binds to cytochrome b)	26/06/2019	10 days
03/08/2019	5 days	Nimrod	See above on 13/06/19	8	See above on 13/06/19	05/08/2019	10 days
		Serenade	See above on 04/05/19	N/A	See above on 04/05/19	15/08/2019	10 days
09/08/2019[1]	11 days	Luna Sensation	See above on 18/07/19	7 + 11	See above on 18/07/19	25/08/2019	10 days
16/08/2019	6 days	Serenade	See above on 04/05/19	N/A	See above on 04/05/19	04/09/2019	10 days
		Potassium Bicarbonate	See above on 04/05/19	N/A	See above on 04/05/19	14/09/2019	10 days
16/08/2019	7 days	Kumulus DF	See above on 04/05/19	M02	See above on 04/05/19	24/09/2019	10 days
24/08/2019	8 days	Charm	See above on 11/07/19	7+3	See above on 11/07/19		

https://doi.org/10.18745/pb.24905

28/08/2019	4 days	Nimrod	See above on 13/06/19	8	See above on 13/06/19		
05/09/2019	8 days	Serenade	See above on 04/05/19	N/A	See above on 04/05/19		
		Potassium Bicarbonate	See above on 04/05/19	N/A	See above on 04/05/19		
		Kumulus DF	See above on 04/05/19	M02	See above on 04/05/19		

Note: 1 From this date fungicides started to be entered into the prediction system

https://doi.org/10.18745/pb.24905

Table 8: Site 8: DD11 3 (b)

Prediction System						Routine Spray Programme	
Application Date	**Spray Interval**	**Fungicide Name**	**Active Ingredient**	**FRAC Code**	**MOA**	**Application Date**	**Spray Interval**
29/04/2019	N/A	Topas	Penconazole	3	Inhibit ergosterol biosynthesis	29/04/2019	N/A
13/05/2019	14 days	Serenade	*Bacillus subtilis* strain QST 713	N/A	Punctures cell membranes, destroy germ tubes and mycelia	09/05/2019	10 days
		Potassium Bicarbonate	Potassium Hydrogen Carbonate	N/A	Causes collapse of hyphal walls and shrinks conidia	19/05/2019	10 days
		Kumulus DF	Sulphur	M02	Multi-site function	29/05/2019	10 days
25/05/2019	12 days	Luna Sensation	Fluopyram + Trifloxystobin	7 + 11	(1) Blocks succinate dehydrogenase, interferes with respiration (2) Inhibits fungal respiration (binds to cytochrome b)	08/06/2019	10 days
05/06/2019[1]	11 days	Serenade	See above on 13/05/19	N/A	See above on 13/05/19	18/06/2019	10 days
		Potassium Bicarbonate	See above on 13/05/19	N/A	See above on 13/05/19	28/06/2019	10 days
		Kumulus DF	See above on 13/05/19	M02	See above on 13/05/19		
15/06/2019	10 days	Luna Sensation	See above on 25/05/19	7 + 11	See above on 25/05/19		
29/06/2019	14 days	Serenade	See above on 13/05/19	N/A	See above on 13/05/19		
		Potassium Bicarbonate	See above on 13/05/19	N/A	See above on 13/05/19		
		Kumulus DF	See above on 13/05/19	M02	See above on 13/05/19		

Note: 1 From this date fungicides started to be entered into the prediction system

https://doi.org/10.18745/pb.24905

Table 9: Site 9: Did not use prediction system

Grower's Spray Programme					
Application Date	**Spray Interval**	**Fungicide Name**	**Active Ingredient**	**FRAC Code**	**MOA**
09/05/2019	N/A	Potassium Bicarbonate	Potassium Hydrogen Carbonate	N/A	Causes collapse of hyphal walls and shrinks conidia
11/05/2019	2 days	Topas	Penconazole	3	Inhibit ergosterol biosynthesis
18/05/2019	7 days	Serenade	*Bacillus subtilis* strain QST 713	N/A	Punctures cell membranes, destroy germ tubes and mycelia
22/05/2019	4 days	Potassium Bicarbonate	See above on 09/05/19	N/A	See above on 09/05/19
25/05/2019	3 days	Luna Sensation	Fluopyram + Trifloxystobin	7 + 11	(1) Blocks succinate dehydrogenase, interferes with respiration (2) Inhibits fungal respiration (binds to cytochrome b)
01/06/2019	7 days	Serenade	See above on 18/05/19	N/A	See above on 18/05/19
06/06/2019	5 days	Potassium Bicarbonate	See above on 09/05/19	N/A	See above on 09/05/19
07/06/2019	1 day	Takumi SC	Cyflufenamid (benzamidoxime)	U6	Interference with appressorium/ conidiation
15/06/2019	8 days	Serenade	See above on 18/05/19	N/A	See above on 18/05/19
19/06/2019	4 days	Potassium Bicarbonate	See above on 09/05/19	N/A	See above on 09/05/19
22/06/2019	3 days	Topas	See above on 11/05/19	3	See above on 11/05/19
27/06/2019	5 days	Potassium Bicarbonate	See above on 09/05/19	N/A	See above on 09/05/19
01/07/2019	4 days	Serenade	See above on 18/05/19	N/A	See above on 18/05/19
13/07/2019	12 days	Talius	Proquinazid	13	Interference with signal transduction (mechanism unknown)
16/07/2019	3 days	Potassium Bicarbonate	See above on 09/05/19	N/A	See above on 09/05/19
19/07/2019	3 days	Charm	fluxapyroxad + difenoconazole	7 + 3	Inhibit mitochondrial respiration; Inhibit ergosterol biosynthesis
26/07/2019	7 days	Potassium Bicarbonate	See above on 09/05/19	N/A	See above on 09/05/19
29/07/2019	3 days	Nimrod	Bupirimate	8	Inhibits sporulation-targets synthesis of nucleic acids

https://doi.org/10.18745/pb.24905

03/08/2019	5 days	Systhane 20 EW	Myclobutanil	3	Inhibits ergosterol biosynthesis
09/08/2019	6 days	Luna Sensation	See above on 25/05/19	7 + 11	See above on 25/05/19
17/08/2019	8 days	Systhane 20 EW	See above on 17/08/19	3	See above on 17/08/19
23/08/2019	6 days	Topas	See above on 11/05/19	3	See above on 11/05/19

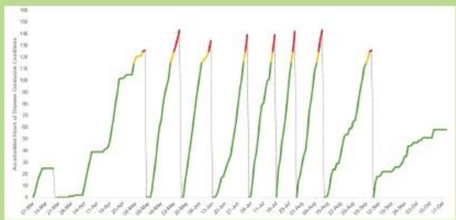
https://doi.org/10.18745/pb.24905

Appendix 3

Decision Support System for the Control of Strawberry Powdery Mildew

Uses optimum conditions for humidity and temperature to record and forecast when the disease is likely to grow, and alerts the grower when it is time to spray

- Fewer fungicide sprays by targeting with precision
- Saves cost
- Reduces pesticide residue risk
- Enables intelligent use of limited chemistry
- Quick and simple to use



Easy to view traffic light system, updated every one hour leading to quick and easy decision making

- Average cost benefit in 2018 was £250/hectare, with no detriment to the crop
- Can "talk" to three of the most popular climate loggers on the UK market
- Record your fungicide with ease from any device, creating a fungicide application report for your field
- Enables proactive rather than reactive fungicide applications, ensuring maximum benefit from limited chemistry

For further information, call us on 01462 813303 or email info@agri-tech.co.uk

ceres CONNECTED AGRI-TECH
University of Hertfordshire UH
Agri-tech SERVICES

https://doi.org/10.18745/pb.24905

Appendix 4

Agri-tech SERVICES Precision Farming Services & Solutions for Agriculture & Horticulture

University of Hertfordshire UH

With margins depleting and the cost of fungicide increasing, target your spray application with precision

We have developed a new web-based real-time prediction system for strawberry powdery mildew

Uses optimum conditions for humidity and temperature to record and forecast when the disease is likely to grow, and alerts the grower when it is time to spray.

By using the system the grower is able to use fewer fungicide sprays by targeting with precision.

- Saves cost
- Reduces pesticide residue risk
- Enables intelligent use of limited chemistry
- Quick and simple to use

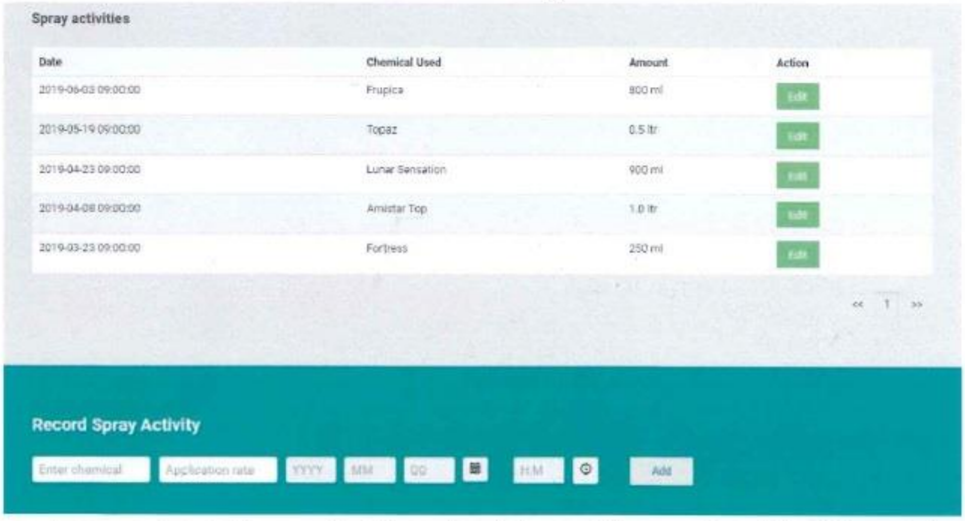
- SPM module accessible from your secure client login area
- Data easily accessible to view from your SMART device
- Easily create disease monitoring zones within your farm
- Can "talk" to three of the most popular climate loggers on the UK market
- Record your fungicide with ease from any device, creating a fungicide application report for your field
- Enables proactive rather than reactive fungicide applications, ensuring maximum benefit from limited chemistry
- Average cost benefit in 2018 was £250/hectare, with no detriment to the crop

ceres CONNECTED AGRI-TECH

https://doi.org/10.18745/pb.24905

Agri-Tech Decision Support Platform

Easy to view traffic light system, updated every one hour leading to quick and easy decision making



Simply enter your fungicide, application rate, date and time and model will reset to zero.
Auto generates fungicide record per field.
Limitless number of fields can be set up on the platform.

For further information, call us on 01462 813303, or email info@agri-tech.co.uk

Appendix 5

Optimising Growth of Strawberries under Protection

Tuesday 22nd October 2019

Bayfordbury Campus, University of Hertfordshire, Hertford, SG13 8LD

Programme

Time	Topic	Speaker
9:30 – 10:00	**Arrival, Registration & Coffee**	
10:00 – 10:15	Introduction to Bayfordbury and the Course	Dr Avice Hall: Principal Lecturer, University of Hertfordshire
10:15 – 10:50	Strawberries, Powdery Mildew and Plant Defence	Dr Avice Hall
10:50 – 11:25	Benefits of Silicon for Strawberries	Dr Avice Hall
11:25 – 11:55	**Coffee**	
11:55 – 12:30	Tools to Optimise Irrigation for Soft Fruit Production	Simon Turner: CEO, Agri-Tech Services Ltd
12:30 – 13:05	New App for in-field Data Recording for Substrate Fruit Production	Simon Turner
13:05 – 13:50	**Lunch**	
13:50 – 14:20	Introduction to the Decision Support System A Grower's Experience	Dr Avice Hall Richard Hibbard: Soft Fruit Production Manager
14:20 – 15:20	Decision Support System Interactive Session and Discussion	Dr Avice Hall & Simon Turner
15:20 – 15:30	Closing Remarks	Dr Avice Hall & Simon Turner
15:30 – 16:00	Discussion, Coffee and Feedback	

Contact

Dr Avice M Hall

Principal Lecturer, Plant Pathology

Department of Biological and Environmental Sciences

University of Hertfordshire, a.m.hall@herts.ac.uk, 07710 352786

https://doi.org/10.18745/pb.24905

Appendix 6

Cost-benefit Analyses

Table 1: Site 1: HR8 1

Prediction System				Routine Spray Programme			
Fungicide Name	Number of applications during season	Cost of fungicide per hectare (£)	Labour Cost (£)	Fungicide Name	Number of applications during season	Cost of fungicide per hectare (£)	Labour Cost (£)
AQ10	1	35.00	27.50	AQ10	2	70.00	55.00
Charm	2	239.80	55.00	Charm	2	239.80	55.00
Nimrod	1	32.00	27.50	Luna Sensation	2	238.00	55.00
				Nimrod	1	32.00	27.50
				Topas	1	46.97	27.50
Total Cost (£) per hectare		306.80	148.08			626.77	321.10
Total cost (£) (fungicide + labour) per hectare	£454.88			£947.87			
Saving per hectare when using prediction system: £492.99							

https://doi.org/10.18745/pb.24905

Table 2: Site 2: HR9 7

Prediction System				**Routine Spray Programme**			
Fungicide Name	Number of applications during season	Cost of fungicide per hectare, for all applications (£)	Labour Cost (£)	Fungicide Name	Number of applications during season	Cost of fungicide per hectare (£)	Labour Cost (£)
Amistar Top	1	41.10	27.50	Amistar Top	1	41.70	27.50
Amylo X	2	210.00	55.00	Amylo X	2	210.00	55.00
Fortress	1	14.35	27.50	Charm	1	71.07	27.50
Kumulus DF	1	1.80	27.50	Fortress	1	14.35	27.50
Luna Sensation	1	98.22	27.50	Kumulus DF	1	1.80	27.50
Nimrod	1	49.62	27.50	Luna Sensation	1	98.22	27.50
Potassium Bicarbonate	6	48.60	165.00	Nimrod	2	94.22	55.00
Signum	2	148.80	55.00	Potassium Bicarbonate	6	48.60	165.00
Stroby WG	1	42.65	27.50	Signum	1	74.40	27.50
Topas	1	22.88	27.50	Stroby WG	1	42.65	27.50
				Takumi SC	1	74.18	27.50
				Topas	1	22.88	27.50
Total Cost (£) per hectare		678.62	467.50			799.09	522.50
Total cost (£) (fungicide + labour) per hectare	1146.12			1321.59			
Saving per hectare when using prediction system: £175.47							

https://doi.org/10.18745/pb.24905

Table 3: Site 3: HR4 7

Prediction System				Routine Spray Programme			
Fungicide Name	Number of applications during season	Cost of fungicide per hectare, for all applications (£)	Labour Cost (£)	Fungicide Name	Number of applications during season	Cost of fungicide per hectare (£)	Labour Cost (£)
Amistar	1	130.00	27.50	Amistar	2	260.00	55.00
Amylo X	1	17.80	27.50	Amylo X	1	17.80	27.50
AQ10	2	4.50	55.00	AQ10	3	6.74	82.50
Charm	3	625.00	82.50	Charm	1	208.33	27.50
Luna Sensation	1	135.56	27.50	Fortress	1	14.35	27.50
Nimrod	1	32.14	27.50	Karma	1	93.17	27.50
Serenade	2	196.00	55.00	Luna Sensation	1	135.56	27.50
Stroby WG	1	11.18	27.50	Potassium Bicarbonate	1	150.00	27.50
Takumi SC	2	158.28	55.00	Serenade	3	294.00	82.50
Topas	1	104.00	27.50	Stroby WG	1	11.18	27.50
				Takumi SC	2	158.28	55.00
				Topas	1	104.00	27.50
Total Cost (£) per hectare		1414.45	412.50			1453.41	495.00
Total cost (£) (fungicide + labour) per hectare	1826.95			1948.41			
Saving per hectare when using prediction system: £121.45							

https://doi.org/10.18745/pb.24905

Table 4: Site 4: ST18 9 (a)

Prediction System				Routine Spray Programme			
Fungicide Name	Number of applications during season	Cost of fungicide per hectare, for all applications (£)	Labour Cost (£)	Fungicide Name	Number of applications during season	Cost of fungicide per hectare (£)	Labour Cost (£)[1]
Amistar Top	2	100.00	25.00	Amistar Top	2	100.00	25.00
Amylo X	2	180.00	25.00	Amylo X	2	180.00	25.00
Fortress	1	15.00	12.50	Fortress	1	15.00	12.50
Karma	1	30.00	12.50	Karma	1	30.00	12.50
Luna Sensation	2	216.00	25.00	Luna Sensation	2	216.00	25.00
Nimrod	1	50.00	12.50	Nimrod	1	50.00	12.50
Potassium Bicarbonate	2	10.00	25.00	Potassium Bicarbonate	4	20.00	50.00
Systhane 20 EW	2	40.00	25.00	Systhane 20 EW	2	40.00	25.00
Takumi SC	2	150.00	25.00	Takumi SC	2	150.00	25.00
Topas	2	190.00	25.00	Topas	2	190.00	25.00
Total Cost (£) per hectare		981.00	212.50			991.00	237.50
Total cost (£) (fungicide + labour) per hectare	1193.50			1228.50			
Saving per hectare when using prediction system: £35.00							

[1] Grower reported labour cost of £12.50 per hectare, per application

https://doi.org/10.18745/pb.24905

Table 5: Site 5: ST18 9 (b)

Prediction System				Routine Spray Programme			
Fungicide Name	Number of applications during season	Cost of fungicide per hectare, for all applications (£)	Labour Cost (£)	Fungicide Name	Number of applications during season	Cost of fungicide per hectare (£)	Labour Cost (£)[1]
Amistar Top	2	100.00	25.00	Amistar Top	2	100.00	25.00
Amylo X	1	90.00	12.50	Amylo X	2	180.00	25.00
Fortress	2	30.00	25.00	Fortress	1	15.00	12.50
Karma	1	30.00	12.50	Karma	1	30.00	12.50
Luna Sensation	2	216.00	25.00	Luna Sensation	2	216.00	25.00
Nimrod	1	50.00	12.50	Nimrod	1	50.00	12.50
Potassium Bicarbonate	1	5.00	12.50	Potassium Bicarbonate	4	20.00	50.00
Systhane 20 EW	2	40.00	25.00	Systhane 20 EW	2	40.00	25.00
Takumi SC	2	150.00	25.00	Takumi SC	2	150.00	25.00
Topas	2	190.00	25.00	Topas	2	190.00	25.00
Total Cost (£) per hectare		901.00	200.00			991.00	237.50
Total cost (£) (fungicide + labour) per hectare	1101.00			1228.50			
Saving per hectare when using prediction system: £127.50							

[1] Grower reported labour cost of £12.50 per hectare, per application

https://doi.org/10.18745/pb.24905

Table 6: Site 6: PH12 8

Prediction System				Routine Spray Programme			
Fungicide Name	Number of applications during season	Cost of fungicide per hectare, for all applications (£)	Labour Cost (£)	Fungicide Name	Number of applications during season	Cost of fungicide per hectare (£)	Labour Cost (£)
Amistar	1	22.00	27.50	Amistar	1	22.00	27.50
Luna Sensation	1	115.36	27.50	Charm	1	90.00	27.50
Serenade	2	196.00	55.00	Luna Sensation	1	115.36	27.50
Topas	2	49.50	55.00	Serenade	1	98.00	27.50
				Takumi SC	2	167.00	55.00
				Talius	1	14.71	27.50
				Topas	2	49.50	55.00
Total Cost (£) per hectare		382.86	165.00			556.57	247.50
Total cost (£) (fungicide + labour) per hectare	547.86			804.07			
Saving per hectare when using prediction system: £256.21							

https://doi.org/10.18745/pb.24905

Table 7: Site 7: DD11 3 (a)

Prediction System				Routine Spray Programme		
Fungicide Name	Number of applications during season	Cost of fungicide per hectare, for all applications	Labour Cost	Total number of fungicide applications	Average cost of fungicides, per application, per hectare	Labour cost per application
Charm	2	£185.40	13 x £27.50	15	£80.83	£27.50
Kumulus DF	5	£20.25				
Luna Sensation	32	£220.94				
Nimrod	3	£98.79				
Potassium Bicarbonate	5	£61.50				
Serenade	4	£380.52				
Signum	1	£77.49				
Total Cost (£) per hectare		£1044.89	£357.50		£1205.64	£412.50
Total cost (fungicide + labour) per hectare	£1402.39			£1618.14		
Saving per hectare when using prediction system (approx.): £215.75						

Note: This grower in some instances applied more than one fungicide at one time. Labour costs are associated with each application date. Therefore, labour cost is calculated by multiplying the number of times fungicides were applied by the cost to apply a single fungicide spray. To calculate an estimated cost for a routine spray programme, the average cost of a single fungicide application per hectare (fungicide plus labour) was calculated and multiplied by the number of sprays done when following a routine spray programme.

https://doi.org/10.18745/pb.24905

Table 8: Site 8: DD11 3 (b)

Prediction System				Routine Spray Programme		
Fungicide Name	Number of applications during season	Cost of fungicide per hectare, for all applications	Labour Cost	Total number of fungicide applications	Average cost of fungicides, per application, per hectare	Labour cost per application
Kumulus DF	3	£12.15	6 x £27.50	7	£97.42	£27.50
Luna Sensation	2	£220.94				
Potassium Bicarbonate	3	£36.90				
Serenade	3	£285.39				
Topas	1	£29.14				
Total Cost (£) per hectare		£584.52	£165.00		£681.94	£192.50
Total cost (fungicide + labour) per hectare	£749.52			£874.44		
Saving per hectare when using prediction system (approx.): £124.92						

Note: This grower in some instances applied more than one fungicide at one time. Labour costs are associated with each application date. Therefore, labour cost is calculated by multiplying the number of times fungicides were applied by the cost to apply a single fungicide spray. To calculate an estimated cost for a routine spray programme, the average cost of a single fungicide application per hectare (fungicide plus labour) was calculated and multiplied by the number of sprays done when following a routine spray programme.

https://doi.org/10.18745/pb.24905

Site 9: Did not use prediction system

Prediction System			
Fungicide Name	Number of applications during season	Cost of fungicide per hectare, for all applications (£)	Labour Cost (£)
Charm	1	100.00	27.00
Luna Sensation	2	192.00	55.00
Nimrod	1	39.29	27.00
Potassium Bicarbonate	6	54.00	165.00
Serenade	3	290.00	82.50
Systhane 20 EW	2	40.00	55.00
Takumi SC	1	75.00	27.50
Talius	1	13.33	27.50
Topas	2	190.00	55.00
Total Cost (£) per hectare		993.62	522.50
Total cost (£) (fungicide + labour) per hectare	1516.12		
Saving per hectare when using prediction system:	£ -		

University of Hertfordshire UH
ceres CONNECTED AGRI-TECH
Agri-tech SERVICES

https://doi.org/10.18745/pb.24905

Appendix 7

What is the prediction system?

A decision support system (DSS) designed to support the grower for the intelligent use of fungicides, spraying only when conditions are favourable for disease development. The prediction system accumulates the number of hours needed for the fungus to grow from spores to producing the next generation of spores.

How does a disease epidemic build up?

The development of disease epidemic contains three phases (Fig 1.):

a. **Lag Phase**: Spore germination, and fungus growth to spore production. Not enough disease development to be detected by naked eye, though early symptoms (cupping) may be visible. Length of lag phase governed by the number of disease conducive hours[1]

b. **Log Phase**: Fungus grows and spreads exponentially (i.e. doubles in each time period) at a speed governed by the number of disease conducive hours; the quicker the disease conducive hours accumulate the faster the fungus grows, and the steeper the line of the exponential phase

c. **Stationary Phase**: No healthy tissue left to be infected

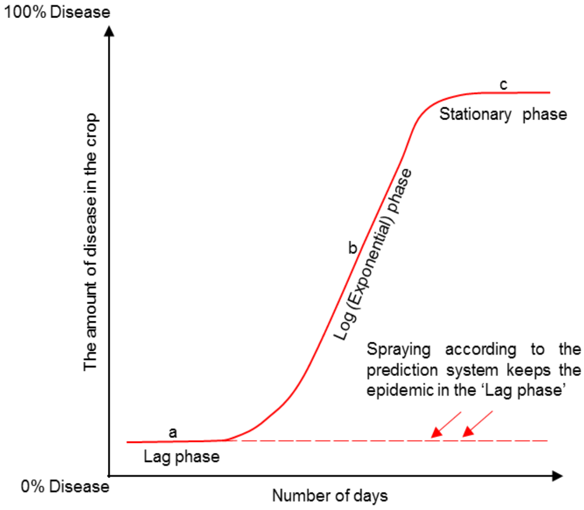


Figure 1 Epidemic growth graph

Figure 1: a typical epidemic curve, and also shows how disease levels can be kept to a minimum if spraying using the prediction system.

Figure 2: the number of disease conducive hours needed for each cycle of spore production.

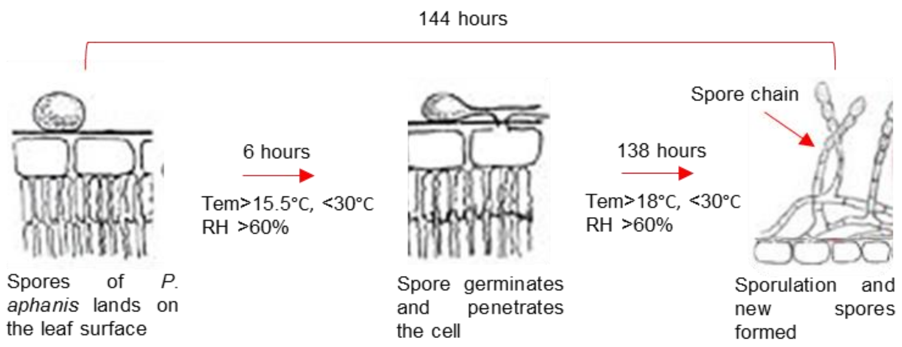


Figure 2 Asexual life cycle of *P. aphanis*)[2] (Xiaolei Jin, 2016)

[1.] **Disease conducive hours**: the number of hours of correct environmental conditions for a particular fungus to grow**.** For *Podosphaera aphanis* (Strawberry powdery mildew) the conditions are temperature >15.5°C and <30°C (15.5°C is the minimum temperature for spore germination, whereas 18°C is the minimum temperature for sporulation; see Fig. 2), with relative humidity (RH) >60%.

[2.] Full life cycle of strawberry powdery mildew, disease characteristic and controlling strategies are available on the AHDB Factsheet 29/16 **'Control of strawberry powdery mildew under protection**'.

What can the prediction graph tell the grower?

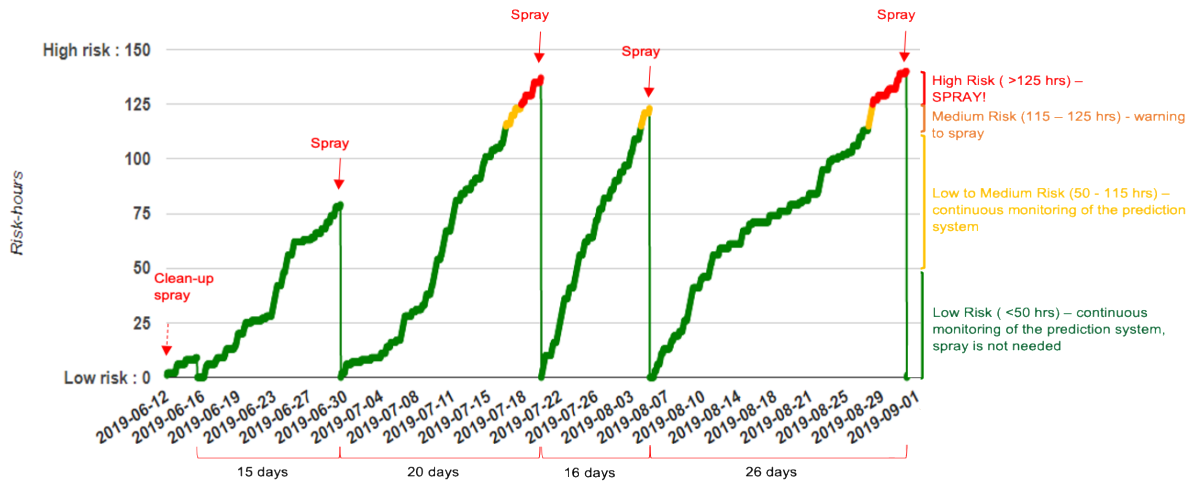


Figure 3 Prediction graph

The Y-axis of the prediction graph indicates the number of accumulated hours where both parameters are met, the X-axis showing the date. When the ascending green line turns to amber (at 115 hours), this is a warning for the grower to prepare to spray. When the line turns to red (at 125 hours), a fungicide spray is needed. At **144** hours, the fungus can start to reproduce and produce spores, i.e. initiate an epidemic if the grower has NOT sprayed. After spraying, grower enters fungicide details and resets the system, which then starts to accumulate disease conducive hours.

Points to be noted:

- At the start of the season, always assume there may be some disease, do a **clean-up spray**;

- \- **Low Risk**: <50 hours, the fungus will not have grown very much
  \- **High Risk**: >125 hours, the fungus is likely to reproduce and produce spores, fungicide sprays are needed
  \- **Continuous monitoring of the prediction system** is required even when the risk level is low;

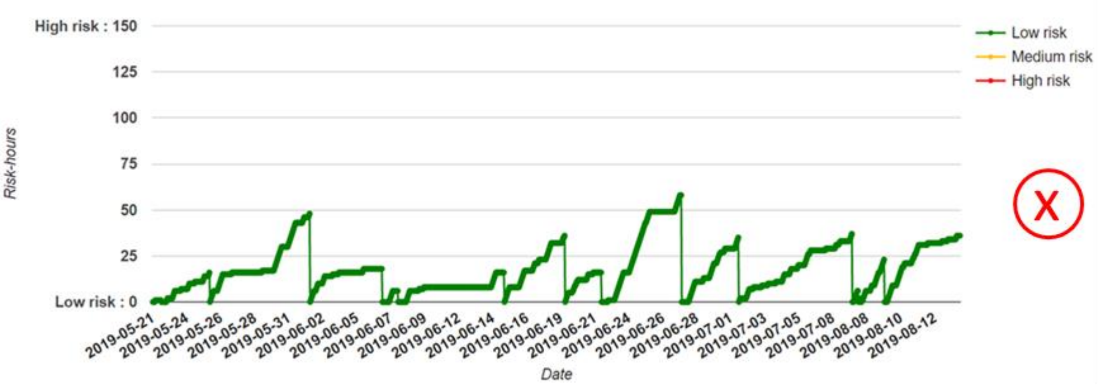
- If there is a constant accumulation (e.g. 24 hours of disease conducive conditions per day), **144** hours will be quickly reached, the grower would need to spray every 6 days; however, this is unlikely. If there is only 6 hours of disease conducive conditions per day, the grower would only need to spray every 24 days;

- The system is recording disease conducive hours, **NOT** forecasting disease levels;

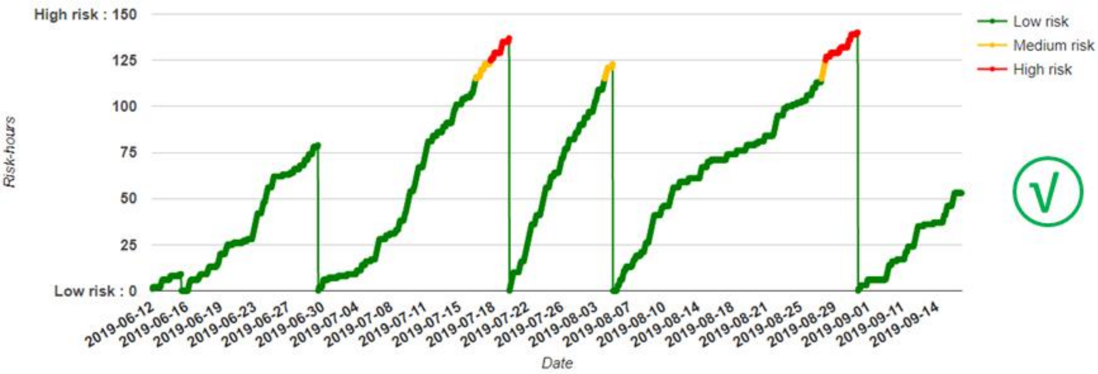
- The grower makes the decision as to what fungicides to use, using Mode of Actions (MoA) in rotation and biological controls if appropriate;

- Finally, **Spray with precision** without panicking. Weekly spray (Fig.4-a) is not needed if you follow the prediction system accordingly (Fig.4-b).

https://doi.org/10.18745/pb.24905



(a) Weekly spraying, not following the prediction system



(b) Spraying according to the prediction system

Figure 4 Examples of two sites using the prediction system

https://doi.org/10.18745/pb.24905

Prediction System User Instructions

The Prediction System is a decision support system designed to support the grower for the intelligent use of fungicide, spraying only when conditions are favourable for strawberry powdery mildew disease development.

How to use the system

1. Preform **clean up spray** at start of season to reduce initial inoculum;
2. Frequently (daily) monitor the accumulation of hours of disease conducive conditions on the graph;
3. When the line reaches amber (115 hours), **WARNING**: potential high risk of disease, prepare to spray;
4. When the line reaches red (125 hours), imminent risk of disease spread, **SPRAY!**
5. Enter the name and rate of each fungicide used against strawberry powdery mildew, as soon as it has been sprayed, reset the system to 0;
6. It may be useful to keep a note of why you made this decision to spray.

https://doi.org/10.18745/pb.24905

Appendix 8

Proceedings Crop Production in Northern Britain 2020

VALIDATION OF A REAL TIME DECISION SUPPORT SYSTEM (PREDICTION SYSTEM) TO CONTROL STRAWBERRY POWDERY MILDEW WITH THE USE OF FEWER FUNGICIDES

A. M. Hall, H. Wileman and B. Liu

Biological and Environmental Sciences, University of Hertfordshire, Hatfield AL10 9AB

Email: a.m.hall@herts.ac.uk

Summary: The parameters used to predict disease conducive conditions for strawberry powdery mildew development are described and then used in a real-time web-based system to predict when a grower should spray with fungicides. This keeps the initial inoculum to a minimum and prevents epidemic build up with the use of fewer fungicide sprays than the advised weekly or fortnightly fungicide sprays. The results of the successful 2018 and 2019 trials in Scotland are given in this paper. The cost / benefit analysis from the final validation of the system in 2019 on farms in Scotland will be presented in February 2020.

INTRODUCTION

The strawberry crop in Britain is a successful soft fruit crop, the hectarage has remained static for over 20 years, but the yield has doubled. This has been achieved using polythene tunnels, precision watering and nutrition coupled with the judicious use of cultivars, both June bearers and ever bearers. This has resulted in a lengthening of the harvest season from 6 or 8 weeks to six months. However, the environment created (temperature and relative humidity) in the polythene tunnels has resulted in strawberry powdery mildew (caused by *Podospheara aphanis*) to become the most feared disease of strawberries (Figure 1). *P. aphanis* can cause up to 70% yield loss. One grower reported a loss in one year of £750,000, due to this disease. To control strawberry powdery mildew, some growers are spraying weekly resulting in up to 24 fungicide sprays in a season. This number of sprays a season has environmental and financial consequences. Hall *et al.*, 2017 gives an overall description of integrated control of this disease, including information on clean up spraying at the start of the season and venting tunnels, however, multiple fungicide sprays are still required. The life cycle of the fungus is shown in Figure 2.

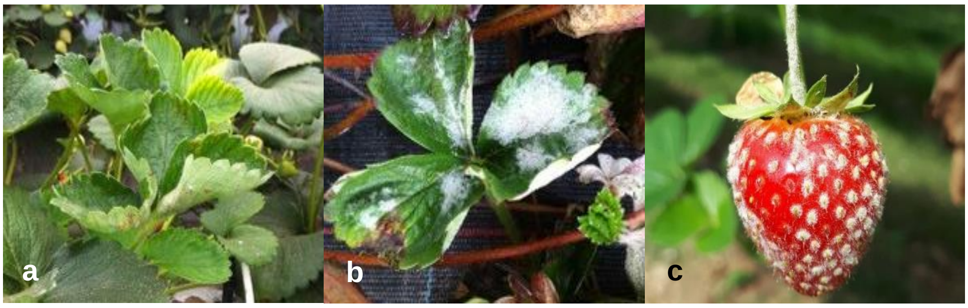


Figure 1 Symptoms of strawberry powdery mildew, caused by *Podosphaera aphanis* including leaf cupping, (a) mycelium on both leaves (b) and mycelium on ripe fruit (c).

https://doi.org/10.18745/pb.24905

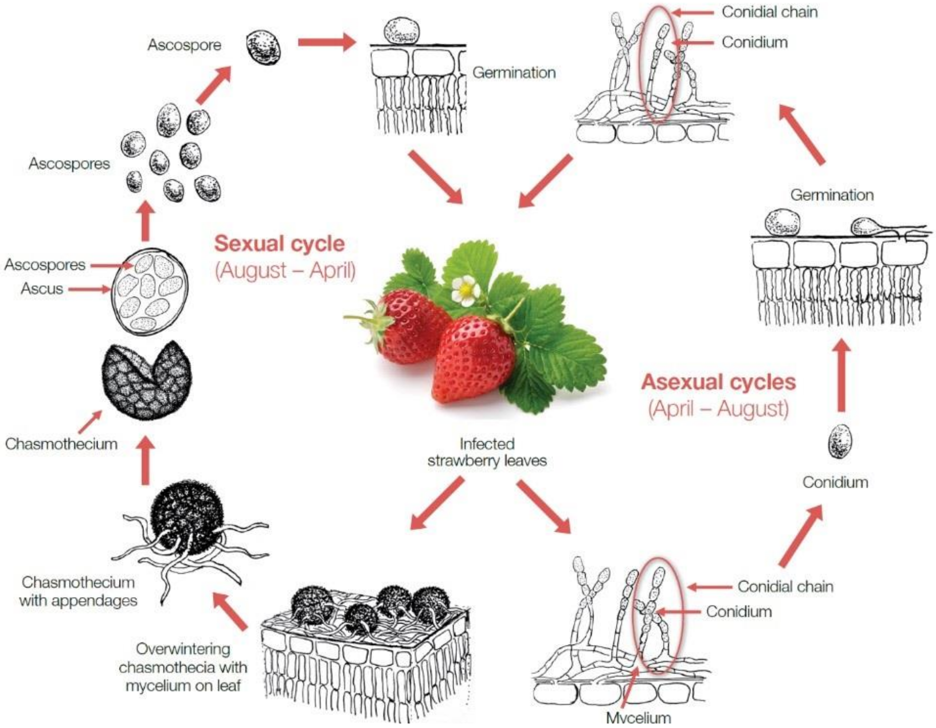


Figure 2 Life cycle of *Podosphaera aphanis,* including both an asexual and sexual cycle (Jin, 2016).

Work at the University of Hertfordshire since 2004 has resulted in the development of a decision support system based on the temperature and humidity for asexual fungal growth and sporulation that predicts when growers should spray with fungicides against strawberry powdery mildew. The aim of the system is to prevent sporulation of the fungus. The prediction system is based on the parameters shown in Figure 3, using temperature and humidity sensors within the crop. At the start of the season the grower assumes that there may be some disease and does a clean-up spray. The prediction system accumulates the hours which have the correct temperature and humidity conditions for the fungus to grow from conidiospore germination, through 'elongating secondary hyphae' to sporulation, i.e. it is accumulating 'disease conducive' hours. This appears as an ascending green line until it reaches 115 hours, when the line turns to amber, which is an indication to the grower that they should start thinking about making a fungicide application. At 125 hours the line turns to red; at 144 hours, the fungus can start to produce new spores and so initiate an epidemic if the grower has not sprayed.

After spraying, the grower enters fungicide details and resets the system which then starts to accumulate disease conducive hours again. Risk is defined by the number of disease conducive hours that have occurred. If only 50 disease conducive hours have occurred, then there is a low risk, as the fungus will not have grown very much. If 115 hours of disease conducive conditions have occurred, the fungus will be growing and there will be a high risk of disease development. When the ascending line is between 125 and 144 hours it is advised that the grower sprays a fungicide.

The work reported here is of the validation of the real time, web-based system on farms in Scotland in 2018 and 2019.

https://doi.org/10.18745/pb.24905

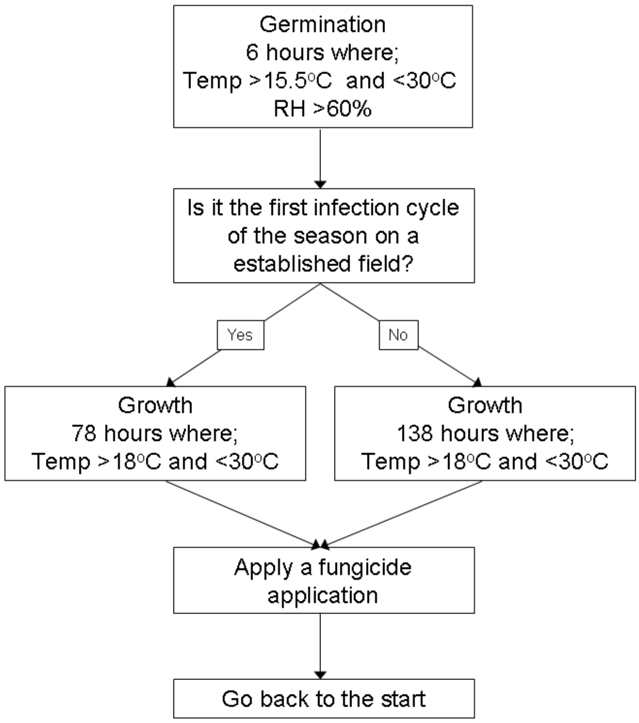


Figure 3 Flow chart showing parameters used to predict when fungicides should be sprayed (Dodgson, 2007).

MATERIALS AND METHODS

The validation criteria of the prediction system were to have a range of geographical locations (England and Scotland), a range of cultivars (June bearers and ever bearers), and a variety of growing methods i.e. the use of soil or coir, on raised beds or tabletops.

The decision support system was used on one farm in Scotland in 2018, and two farms in Scotland in 2019 (cost benefit analysis not available at time of writing for 2019). In 2018, the farm located at DD2 5 used the prediction system from March to October on an area of 15 hectares. Both ever bearer (cv. Islay and Murano) and June bearer (cv. Sonata) strawberry crops were grown in coir on tabletops in Seaton tunnels. The June bearers were grown as two successive crops, the second was planted in June and overwintered into the 2019 season. A Davis temperature and relative humidity sensor was placed within the crop. The normal routine spray programme for this farm was to apply fungicides every 14 days. Disease assessments were carried out throughout the season, to achieve commercially satisfactory disease control.

In 2019, two farms in Scotland used the prediction system. The first strawberry crop, located near PH12 8 was sprayed with fungicides guided by the prediction system from July to October 2019 on a hectare of covered everbearer crops (cv. Murano), grown in coir bags on tabletops. A second strawberry crop, located near DD11 3 was sprayed with fungicides guided by the prediction from June to July 2019 on a covered June bearer crop (cv. Malling Centenary™), grown in soil. The routine spray programmes for both farms was to apply fungicides every 10 days.

https://doi.org/10.18745/pb.24905

RESULTS

The prediction system gave commercially satisfactory disease control in 2018, confirmed by routine disease assessments. On the ever bearers, the routine spray programme used 13 fungicide sprays whereas the prediction system only used 10 fungicide sprays, thus giving a saving of three sprays. The first June bearer crops received 5 fungicide sprays, and the second crop received 3 when using the prediction system (the advised routine spray was 7 fungicide sprays on the first crop and 4 on the second). The use of the prediction system used three fewer sprays than the routine programme advised. Table 1 shows the cost benefit analysis.

Table 1. Cost benefit analysis for DD2 5 (2018)

Cultivar type	Cost for routine commercial spray programme (£ ha^{-1})	Cost for prediction system (£ ha^{-1})	Total saving (£ ha^{-1})
Ever bearer	1,194.60	918.92	275.68
June bearers	1,029.44	748.68	280.76

Table 2. Fungicide spray programmes from PH12 8: using the prediction system from 2nd July to 2nd October 2019; and routine spray programme (2019)

Prediction System			Routine Spray Programme		
Application Date	Fungicide Used	Active Ingredient	Application Date	Fungicide Used	Active Ingredient
21st Jun	Amistar	azoxystrobin	21st Jun	Amistar	azoxystrobin
2nd Jul	Topas	penconazole	2nd Jul	Talius	proquinazid
10th Jul	Topas	penconazole	12th Jul	Takumi	cyflufenamid
23rd Jul	Luna Sensation	fluopyram + trifloxystobin	22nd Jul	Topas	penconazole
			1st Aug	Takumi	cyflufenamid
			11th Aug	Topas	penconazole
			31st Aug	Charm	fluxapyroxad + difenoconazole
			10th Sep	Luna Sensation	fluopyram + trifloxystobin

https://doi.org/10.18745/pb.24905

Table 3. Fungicide spray programmes from DD11 3: using the prediction system from 5th June until mid-July. The routine spray programme is given as approximate spray dates based on a ten-day spray programme

Prediction System			Routine Spray Programme
Application Date	Fungicide Used	Active Ingredient	Approximate Application Date
29th Apr	Topas	penconazole	29th Apr
13th May	Potassium Bicarbonate	potassium hydrogen carbonate	9th May
	Kumulus DF	sulphur	19th May
25th May	Luna Sensation	fluopyram + trifloxystobin	29th May
5th Jun	Potassium Bicarbonate	potassium hydrogen carbonate	8th Jun
	Kumulus DF	sulphur	18th Jun
15th Jun	Luna Sensation	fluopyram + trifloxystobin	28th Jun
29th Jun	Potassium Bicarbonate	potassium hydrogen carbonate	
	Kumulus DF	sulphur	

In 2019, the prediction system also gave commercially satisfactory disease control on both farms. When guided by the prediction system at the farm located at PH12 8 (Table 2), four fungicide sprays were applied, whereas following the routine spray programme eight fungicide sprays were applied. The use of the prediction system has saved four fungicide sprays, on this everbearer crop. At the farm located near DD11 3 (Table 3), when guided by the prediction system six fungicide applications were made, whereas if a ten-day routine spray programme had been used seven fungicide applications would have been made (based on application dates). The use of the prediction system has saved a fungicide spray on this June bearer crop.

DISCUSSION

The results from the 2018 and 2019 trial in Scotland showed that the growers who used the prediction system had commercially satisfactory disease control (i.e. minimal amount of disease observed, and no epidemic build-up) but this was achieved with fewer fungicide sprays than the advised fortnightly spray, routine spray programme or ten-day spray programme. The growers had the confidence to not spray with fungicides when they could observe on the prediction system that the disease pressure was low (low risk). In 2018, the grower also benefited from the use of the system by making financial savings on both crops (>£200 per hectare), due to the reduced number of fungicide applications and saved labour costs. Additionally, the reduced number of fungicide sprays when using the prediction system will be beneficial to the environment. In 2018, the grower found the system to be reliable and user friendly, therefore, a final validation of the system was conducted in 2019. In 2019 validation was carried out on two farms in Scotland, which also achieving reduced fungicide applications by using the prediction system. These results of the 2019 cost-benefit analysis will be available in February 2020. Both the 2019 growers reported that the system was easy to follow and use as well as being a reliable decision support system.

ACKNOWLEDGEMENTS

We are very grateful to all the farms participating in the validation of the prediction system in both 2018 and 2019. Many thanks for present funding from Ceres. Many thanks to Kisanhub for their work in proof of concept in 2016 to 2018 and Agri-tech Services for seeing the great potential of a web-based prediction system and for their partnership in the Ceres grant.

REFERENCES

Dodgson JLA, 2007. Epidemiology and sustainable control of *Podosphaera aphanis* (strawberry powdery mildew). Hatfield, United Kingdom: University of Hertfordshire, PhD thesis.

Hall AM, Dodgson J, Jin X, 2017. Control of strawberry powdery mildew under protection. AHDB Factsheet (29/16). On-line [http://horticulture.ahdb.org.uk/publication/2916-contol-strawberry-powdery-mildew-under-protection]

Jin X, 2016. Epidemiology and Control of Powdery Mildew (*Podosphaera aphanis*) on strawberry. Hatfield, United Kingdom: University of Hertfordshire, PhD thesis

https://doi.org/10.18745/pb.24905

Appendix 9

New exhibitors present new products and technologies at Fruit Focus

New products and technologies are continually being developed for horticulture and this year's Fruit Focus event presented some of these innovations to fruit growers. Rachel Anderson reports.

"Zensie can also ingest other important data that the grower may already collect – from manual data collection like pest-scouting and flower counts, to climate control data. In addition to connecting growers to their crops, growers can connect with team members and trusted experts outside of their business. A pest expert from the USA can now diagnose and advise, in real-time, problems from customers around the world. Digital knowledge sharing is now possible, thus removing one of the largest barriers in agriculture - proximity and distance."

Agri-Tech Services and the University of Hertfordshire

The University of Hertfordshire has developed a Strawberry Powdery Mildew prediction model that is available only on Agri-Tech's soft-fruit platform. Dr Avice Hall, principal lecturer at the University, revealed that the development of the web-based, real-time prediction model is currently being funded by a grant from the Ceres Trust. She added that it is being trialled on nine farms this year. "The aim is to control the disease substantially with fewer fungicide sprays, and it enables people to make better use of available chemistry. On average, we have [helped growers] to save five or six sprays per year." She added that the cost benefit in 2018 was £250/ha.

Agri-Tech Services' managing director, Simon Turner, told *The Fruit Grower* that the firm has a new app developed specifically for substrate irrigation management. "We think this is the first of its kind." He noted that the app is not sensor-based. Rather, growers simply log any data relating to the plant, such as run-off, water, feed and climate, into the app. They can then view the collected data on their smart phones and analyse it before making any decision relating to their crop.

Furthermore, the University of Hertfordshire's [redacted] revealed that the University has been carrying out work over the last ten years on the use of bio-available silicon nutrients. The research has highlighted the beneficial effects of silicon on strawberries, including the fact that it reduces the fruit's susceptibility to strawberry powdery mildew. The use of silicon delays the start of an epidemic by eight to 14 days when regularly used as a nutrient via the fertigation tubes or foliar application. Growers wishing to see the effects of silicon on their fruit crops can purchase the product - Sion - from Engage Agro Europe.

The University's representatives were also keen to promote its new MSc in Sustainable Planning and Environmental management, which starts this September.

https://doi.org/10.18745/pb.24905

Appendix 10

Optimising the growth of strawberries under protection

It was appropriate that the 'Optimising Growth of Strawberries Under Protection' event took place on the sunny autumn day of 22 October when there wasn't a cloud in the sky; it has been the 'blue sky thinking' of scientists at the University of Hertfordshire that has led to the development of a new system that could help soft-fruit growers save £200 to £400/ha. Rachel Anderson reports.

Strawberries, powdery mildew and plant defence mechanisms

Members of the soft-fruit industry gathered at the University's picturesque, 40ha Bayfordbury campus and began their day listening to Dr Avice Hall MBE, of the Department of Biological and Environmental Sciences, discussing the perils of powdery mildew, which she described as being "the most feared disease in strawberries." She also discussed the research that she and her team have been carrying out on silicon, an element whose application to protected strawberry crops has been found to have many positive effects.

Dr Avice Hall MBE.

Avice explained that powdery mildew, which can potentially destroy up to 70% of a grower's strawberry crop, has become a problem in polytunnels because their warmer temperature and humidity levels make for an ideal environment for the disease's development. She warned growers that the disease arrives on plants from propagators and can also overwinter and be spread between cultivars, and tunnel to tunnel. In short, she advised growers that they should never think that they haven't got the disease.

Fortunately, the situation is not all 'doom and gloom' as, explained Avice, plants have built-in defence pathways, both active and passive. Active resistance is a molecular, physiological response to infection involving the plant's resistance genes. This type of resistance is relatively easy for breeders to work with because it involves working with single or few genes, with very noticeable effects. However, "the pathogen gets so clever that it can then overcome the resistance," warned Avice. She therefore advocated plants' passive resistance, which includes structural features, such as the cuticle and cell wall thickness, that are already present in the plant. She asked: "How do these physical barriers work? In general, they make it physically more difficult for a germ tube, penetration peg, or insect stylus to get through the actual plant cell." Avice noted that, unfortunately, those characteristics that offer passive defence are often overlooked in breeding programmes. The focus tends to be on more popular traits, such as colour and sweetness. She added: "I think this passive type of resistance could provide a useful piece of armour against plant disease, particularly in strawberries." With this point in mind, she then went on to discuss the benefits of silicon for strawberry crops.

The benefits of silicon for strawberries

Avice and her team have been investigating the benefits of silicon since 2008, when they were asked by the industry, "Why is

https://doi.org/10.18745/pb.24905

there better disease control if potassium bicarbonate is applied with a silicon-based wetter?" Since then, the University of Hertfordshire team has been examining what happens to the strawberry plants when silicon is applied as a nutrient. Avice explained that silicon is an interesting element, as most of the silicon on the planet is not available for plant uptake, but plants benefit from its bio-available form. Silicon, the second most abundant element on the planet, has been proven to have many benefits, including improving plants' response to biotic stresses such as disease. Perhaps unsurprisingly, trials run by the University have found that the use of a silicon nutrient, whether applied as a spray or through the fertigation tubes, has "a real effect."

Happily, trials carried out on a commercial strawberry farm for five consecutive years showed that the silicon reduced the strawberry plants' susceptibility to strawberry powdery mildew. Avice confirmed: "Use in the fertigation tubes retards the start of an epidemic by eight to 12 days, and spraying gives a similar result." Moreover, an inadvertent result of the research, which has been supported by AHDB Horticulture and Orion Future Technology, has been the discovery that the average number of two-spotted spider mites in the crop was also reduced. This was possibly because the silicon made the plants' phytoliths too crunchy for the mites.


Richard Hibbard, soft-fruit production manager at EC Drummond

Avice concluded: "The use of bio-available silicon nutrient throughout the season enhances the passive defence pathway and so reduces susceptibility to powdery mildew and two-spotted spider mite." Furthermore, an experiment carried out on campus in hydroponically grown strawberry plants found evidence that silicon offers many other advantages to the crop, including increased biomass, increased numbers of runners, early flowering, increased chlorophyll, increased Brix and increased yield.

Avice concluded her presentation on silicon by advising growers to treat the element like a nutrient and should be given to the crop regularly throughout the growing season, preferably through the roots.

Strawberry Powdery Mildew prediction system

Having learned about the many positive effects of silicon application, growers were also no doubt pleased to learn that the team has developed a new, user-friendly decision-support system that can help them to control strawberry powdery mildew with fewer fungicide applications. The web-based system has steadily been in development since 2003/4, when the team first started plotting the number of disease-conducive hours that allow the


Above and below: Growers were given an interactive demonstration of the system at the event, which saw them try it out for themselves by inputting their own data into a computer.

fungus to grow. During 2018 and 2019, and with support from Ceres Trust, the system entered its final stage of development. This season it was validated on 10 commercial farms throughout the UK and is now available to purchase from Agri-Tech Services.

Avice revealed that the 'traffic light' prediction system sees sensors deployed in the crop to accumulate the hours in which the polytunnel's temperature and humidity levels offer the ideal conditions in which the fungus can grow. Once the tunnel has experienced 115 hours of these conditions, the green line on the graph displayed on the grower's smartphone or computer turns amber; at 125 hours, the line alerts growers that it is time to spray by turning red and, at 144 hours, the fungus can start to produce new spores, meaning that an epidemic will be initiated if the grower has not yet sprayed the crop. Avice explained: "After spraying, the grower enters the fungicide details and resets the system, which then starts to again accumulate disease-conducive hours."

Richard Hibbard, soft-fruit production manager at EC Drummond, revealed that 2019 was his third year of trialling the system. He noted that he trialled it on one field that received just 15 mildew sprays compared to the control field, which received 18 sprays. In fact, Avice pointed out that financial savings are

https://doi.org/10.18745/pb.24905

amongst the many benefits of the system. She said: "The average cost benefit in 2018 was £250/ha, with no detriment to the crop." Richard added: "The plan next year is to roll the system out to all our fields. If we can keep strawberry powdery mildew to a manageable level until October, then it's done its job." Growers were given an interactive demonstration of the system at the event, which saw them try it out for themselves by inputting their own data into a computer.

Optimising irrigation for soft fruit production

Avice and her team observed that weekly root applications resulted in a more even distribution of silicon for the plant. Considering this, Agri-Tech Services' CEO Simon Turner took the opportunity to remind growers of the importance of good irrigation practice. He said: "In too many of today's businesses, irrigation is not taken seriously enough. But irrigation is one of the most important tasks conducted on soft-fruit farms and an important part of the growing process. And it starts with an irrigation team that has the best staff in the business."

Simon advised his audience to start with good planning, ensuring that they have the right team in place and have checked every aspect of the irrigation system, from its water source to its dripper specifications. He also discussed the importance of determining the appropriate shot length for the good distribution of water and feed within the pot, bag or trough. He advised, for example, that new coir will need irrigating little and often, and that changing weather patterns will determine the number of shots per day rather than the length of the shots.

To help irrigation teams fine-tune their irrigation programmes, Agri-Tech has developed a Substrate Irrigation Management App for fruit production that will be available in November. The app

Agri-Tech Services' CEO Simon Turner took the opportunity to remind growers of the importance of good irrigation practice.

enables growers to record the substrates' pH (in and out), electrical conductivity (in and out) and run off. The data is then synchronised to growers' phones to help them build up a helpful picture of their irrigation trends. And so, as the soft-fruit industry continues to face tighter margins, this innovation, along with the new SPM prediction system and the latest research on silicon, no doubt provides the sector with some handy new tools. ◆