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Original article – Thematic Issue

On farm control of strawberry powdery mildew using a decision support system

A.M. Hall, B. Liu and H. Wileman
Life and Medical Sciences, University of Hertfordshire, Hatfield, U.K.

Summary

Strawberry Powdery Mildew, caused by *Podosphaera aphanis* is a serious epidemic disease of strawberries grown under protection in the U.K., with growers often spraying weekly, using 20 or more fungicide sprays in a season. The study aimed to develop a system to predict when fungicide sprays are needed, as a way of sustainable disease management. A decision support system has been developed using wi-fi enabled temperature and humidity sensors which measures risk in 'disease conducive hours'. This data is used to predict in real time when fungicide sprays are required. The use of this system has enabled the disease to be controlled whilst the number of fungicide sprays used in a season has been reduced by up to half when compared to the weekly spray programme. Growers have demonstrated increasing confidence in the system as it has been used in successive years on some farms, and the number of sites per farm has increased year by year. Delivery of the decision support system in real time onto a PC or smart device enables growers to access the benefits of the system.

Keywords
fungicide sprays, on-farm validation, pathogen conducive hours, polythene tunnels, relative humidity, temperature

Significance of this study

What is already known on this subject?
- The advance of technology on gathering on farm weather data.

What are the new findings?
- Satisfactory disease control can be achieved by using this decision support system, with reduced fungicide sprays.

What is the expected impact on horticulture?
- Growers can achieve satisfactory disease control using less fungicide sprays, which leads to reduced financial costs and less environmental impacts. The use of this decision support system can contribute to sustainable disease management in horticulture.

Introduction

Rule based prediction systems are not new in plant pathology. An early example is the use of 'Beaumont Periods' to forecast when fungicides should be used to control late blight of potatoes (Taylor, 2000). Several modifications of this programme have been studied and evaluated since the original publication (Taylor, 2000). Recently a couple of models for the management of strawberry powdery mildew have been published (Fall and Carisse, 2022; Eccel et al., 2010), but not commercialized for on farm use by growers. Strawberry powdery mildew caused by *Podosphaera aphanis* is a serious epidemic disease of strawberries grown under protection in the U.K. (Hall et al., 2017). Yield loss per annum can be worth £69.6 million (Defra, 2019). In the U.K., growers spray fungicides throughout the eight-month growing season (April–October/November), spraying every 7 to 14 days as an insurance without considering the environmental conditions, which can result in over 20 sprays a season. Everbearer strawberries grown for six months or more tend to be more severely infected. The rising cost of fungicides, the risk of the development of fungicide resistance, and environmental impact of these fungicides means that there is a need to control the disease with fewer fungicide sprays. Varieties are chosen by growers for the size, flavour, appearance, and supermarket requirements for the fruit rather than for disease resistance. In addition, there have been major advances in the development and use of wi-fi and sensor technology in the last 20 years so that on-farm data gathering is now routine. However, the use of this data to improve sustainability in disease control is not common.

The hypothesis of this study was that a decision support system which uses real time, in tunnel on-farm data to predict when fungicide sprays are needed, rather than regular insurance spraying has the potential to control the disease with fewer fungicide sprays and improve environmental performance. The aim of the work reported here was to report on the early commercialization of the decision support system. The system was designed to use the most advanced sensors and wi-fi to deliver a clear forecast in real time direct to the growers' smart device or PC.

Materials and methods

The initial work to define the pathogen conducive conditions of temperature and humidity was carried out on farms in 2004–2008 (Dodgson, 2007). This work consisted of a) monitoring epidemic development in the tunnels, and b) monitoring temperature and humidity in the tunnels at the same time as the epidemic was developing. The next stage was to use this data to define the pathogen conducive conditions of temperature and humidity needed for *P. aphanis* to develop from spore release, through spore germination to the formation of elongating secondary hyphae to sporulation and spore release (Dodgson, 2007). The pathogen conducive hours are defined as the number of hours required by the fungus for the life cycle. The pathogen conducive hours are then described as disease conducive hours and were then utilised to forecast when fungicide sprays were necessary to prevent the growth of the pathogen. The aim is to continuously keep the inoculum at the lowest possible level, so that there is no epidemic build-up (Figure 1). The pathogen conducive hours form the basis of the disease conducive hours which drive the disease development in the field.

Risk of disease development is measured in disease conducive hours (dch). Risk is expressed as 'dch' where, under 50 h is low risk; 50 to 100 dch described as medium risk, and over 100 to 144 dch being high risk. A spray is needed when a high risk (dch > 125) is identified. A 'traffic light system' is displayed on screen with amber showing at 100 dch, to indicate that a fungicide spray is needed and red over 144 dch denoting that the fungus life cycle will have reached sporulation.

The proof-of-concept work was carried out on commercial farms from 2016 to 2019 (Dodgson et al., 2022) and the final validation was carried out in 2019/2020, on 9 commercial farms throughout the U.K. All validation was carried out on commercial crops grown under protection and a range of varieties were used. A cost benefit analysis was carried out as part of the validation, and this showed a saving per hectare of about £200 or more per hectare depending on the farm (Dodgson et al., 2022). The system uses wi-fi enabled temperature and humidity sensors, e.g., METOS or SMS cli-

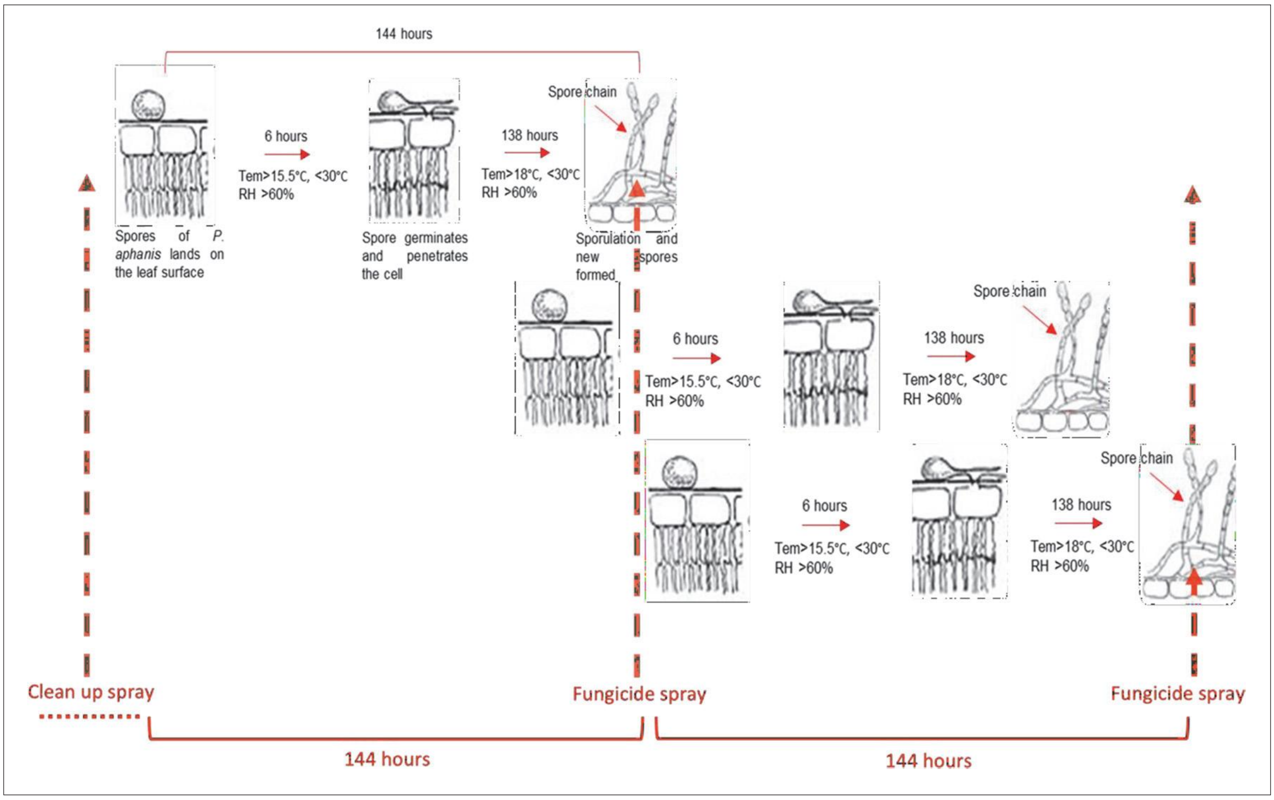

FIGURE 1. Visual representation of how the decision support system aims to kill all stages of fungal growth.

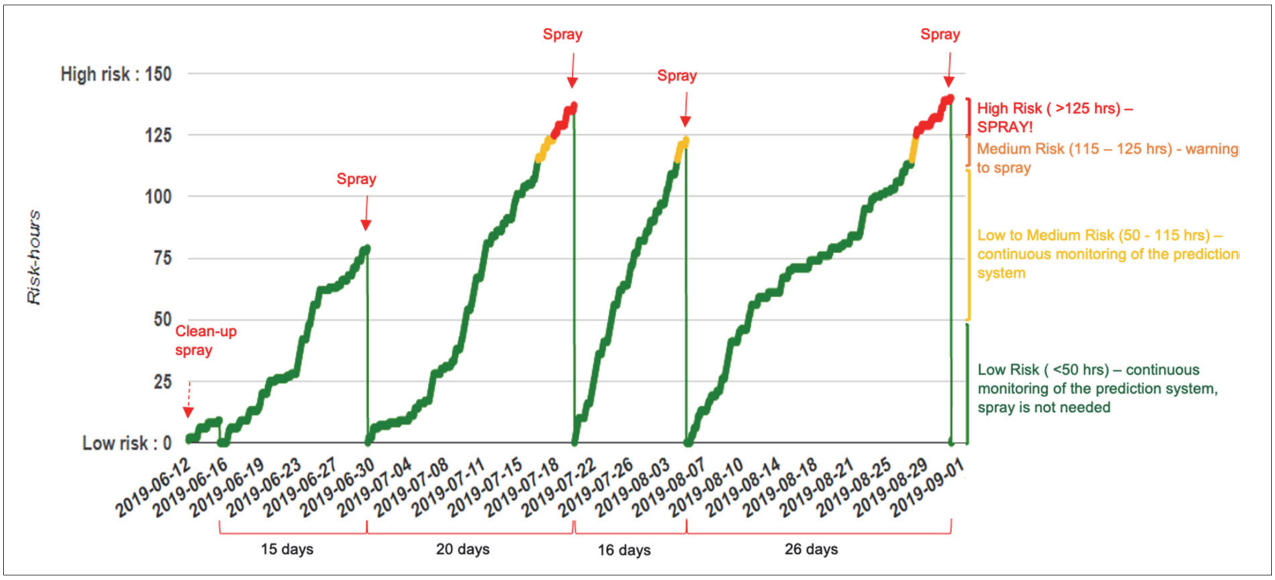

FIGURE 2. End of season screen shot showing accumulation of disease conducive hours (dch), intervals between sprays, and number of hours for low risk, medium risk and high risk of disease development.

mate sensors, with the data returned to the host web site which then displays the number of accumulated hours of dch as a graph, in real time on the device of the grower. Fungicide sprays are suggested at dch hours of 125 which define high risk of the fungus growing and so disease developing. The grower makes the decision to spray and chooses which fungicide to use. After spraying, the fungicide spray is entered onto the system and the accumulation of dch returns to zero, and accumulation of dch then re-starts. Data is viewable on any PC or smart device (Dodgson et al., 2022). Multiple sensors in different sites can be used on a single farm. From 2020 the system has been available for commercial use. The cost benefit analysis for each farm was calculated in the validation in 2019/2020 (Hall et al., 2020; Dodgson et al., 2022).

The work reported here was post validation and all in polythene tunnels on commercial farms subscribing to use the system The primary criteria used in this report of the commercial use of the decision support system was the absence of strawberry powdery mildew build up in the tunnels with sensors as reported by the growers.

Results

The results of the on-farm validation can be viewed in Hall et al. (2020) and Dodgson et al. (2022). Figure 2 shows a screen shot at the end of the season as observed by the grower, with the green ascending line signifying low to medium risk, and the amber notification of high risk and the need to spray with an appropriate fungicide. High risk represents the very high likelihood of the pathogen sporulating and leading to the build-up of an epidemic if fungicides are not applied before this point. Figure 2 also shows how the length of time between necessary sprays varies depending on the accumulation of the dch. The start of the season is shown on the left of Figure 2, where a clean-up spray is used early in the season to ensure that the crop is clean at the beginning of the season. Figure 1 showed previously gives a visual representation of how the dch mean that fungicide spray can kill all stages of the fungus development. It also visualises that the fungicide spray acts on all stages of the fungus, inhibiting germination, penetration and killing developing spores.

Table 1 shows from one farm the reduction in fungicide

TABLE 1. Reduction in fungicide use with use of the decision support system, 2018–2020.

Year	Field experiment results
2018	No use of the decision support system; 22 fungicide sprays to control strawberry powdery mildew.
2019	Use of the decision support system on one block of tunnels in the validation; reduction to 17 fungicide sprays to control strawberry powdery mildew.
2020	Use on all everbearer crops throughout the farm; reduction to 11 fungicide sprays to control strawberry powdery mildew.
Summary	Reduction in number of fungicide sprays from 22 in a season to 11 in a season.

TABLE 2. Number of farms using the decision support system in 2020, 2021 and 2022.

Year	Farm code	County	Number of sites	Total number of farms
2020	LRF	Staffordshire	7	5
	ECD	Herefordshire	6	
	JAP	Herefordshire	2	
	GBBH	Herefordshire	4	
	WFF	Herefordshire	4	
2021	AJCIS	Herefordshire	3	13
	BP	Derbyshire	5	
	ECD	Herefordshire	6	
	ES	Angus	2	
	GBBH	Herefordshire	5	
	GBL	Perthshire	2	
	JAP	Herefordshire	2	
	LRF	Staffordshire	7	
	RH	Angus	2	
	SF	Nottinghamshire	2	
	W	Angus	2	
	WS	Suffolk	2	
	WFF	Herefordshire	5	
2022	WPB	Perthshire	2	8
	ES	Angus	2	
	WFF	Herefordshire	5	
	AJCIS	Herefordshire	2	
	ECD	Herefordshire	6	
	PW	Suffolk	2	
	SF	Nottinghamshire	4	
	BP	Derbyshire	5	
Number of farms present in all three years				4

use that can be obtained by using the decision support system to guide when sprays are needed. In 2018, the number of sprays is typical of many growers in the U.K. who are spraying every 7 to 10 days to control strawberry powdery mildew. In 2019 this grower took part in the validation study and then in 2020 the grower started to use the system with increased confidence each year, halving the number of fungicide sprays used in a season. This grower reported no epidemic build-up of strawberry powdery mildew in the years and tunnels where the system was used.

The strawberry powdery mildew decision support system has been available commercially since the 2020 growing season. Table 2 shows the number of farms that have used the system each year, and the number of sensors/sites on each farm. Four farms have used the system in all three years (Table 2). In addition, there has been an increase in the number of sites/sensors per farm, with there being a total of 23 sites in 2020, 38 sites in 2021 and 27 in 2022. There were no reports of disease build up on farms/sites using the decision support system. Growers using the system are able to adjust it to their own situation, including how many sensors are used on a particular farm and choosing the product to spray.

Discussion

Unique features of the system include the use of a clean-up spray at the start of the season. This is because small amounts of disease enter most crops on the plants from the propagators rather than waiting to see the disease (Figure 2). Another unique feature is the measurement of risk in disease conducive hours which indicate to the grower the speed the fungus would be growing in the prevailing environmental conditions (Figure 2). In contrast, other decision support systems predict disease risk as a disease percentage. Table 1 demonstrates on a single farm how it is possible to use this decision support system to reduce the number of fungicide sprays and control the disease satisfactorily. In the U.K., most sprays are saved early in the season when the dch are accumulating slowly (Figure 2). The use of this decision support system facilitates the grower to assess risk in real time and control strawberry powdery mildew with fewer fungicide sprays, thus making better use of fungicide chemistry, saving money, reducing environmental impact by use of fewer sprays (Table 1) (Hall et al., 2020). Table 2 demonstrates increasing confidence from some growers to use the system in successive years and on an increasing number of sites on these farms.

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Address of authors:
A.M. Hall*, B. Liu and H. Wileman
Life and Medical Sciences, University of Hertfordshire, Hatfield, AL10 9AB, U.K.
* Corresponding author; E-mail: a.m.hall@herts.ac.uk