Project title:	**Demonstrating strawberry powdery mildew risk forecasting and biofungicide management – on farm assessment 2020**
Project number:	SF 157
Project leader:	Scott Raffle, AHDB
Report:	Final report March 2021
Key Staff:	Angela Berrie, Plant pathologist
Location of Project:	Vicarage Nurseries, Bretforton, Worcestershire

Date project commenced: 1 April 2020

Date project completed: 30 November 2020

GROWER SUMMARY

Headline guidance from trial

- In this trial, the risk of strawberry powdery mildew infection occurring was reliably worked out using the weekly weather forecast and a simple 'look-up' table (below).

Simplified Mildew risk in relation to daily average temperature and relative humidity		
Condition		**Mildew risk**
Temperature	**Humidity**	
< 14	Not relevant	Low
≥ 14	< 82%	Moderate
≥ 14	≥ 82%	High

- Assess the risk category for each day using the weather forecast and criteria in the table. The entire week of cumulative seven days is then estimated as a low, medium or high-risk week, but take account of farm conditions such as full cover poly tunnels. (Details on how to determine the risk are included in the appendix of the main report).

- Start the spray programme as soon as temperatures and humidity start to increase, even though the risk may still fall within the 'low' category. The start can often be delayed until May or even early June. Ensure excellent spray cover to the underside of the leaves and to the young leaves and developing flowers deep in the crown.

- A conventional mildew product should always be used for the first spray of the year.

- The two biopesticides assessed in this trial (Sonata and AQ10) only worked well in periods of low risk. Sonata and AQ10 were used without wetters and at the rates advised on the label.

- Watch the crop very closely at least once a week using a hand lens and move to conventional products immediately the tiniest specks of mildew hyphae are seen and especially if the forecast risk has increased.

- Moderate and high risks need conventional mildew products, not biopesticides for reliable control.

- In this trial, a weekly programme of conventional mildewcides, starting in early April, gave reliable control through the whole season for the rest of the farm and in the control area.

- In the trial tunnel, the spray programme started on 10 June when the risk had increased to moderate, resulting in a serious outbreak of mildew in the trial area. In hindsight, the risk judgements were perhaps too optimistic and the programme should have started a week earlier when the risk started to increase. This probably would have avoided the increase in mildew. At the start, biopesticides were used too optimistically in the trial area.

- Action taken by the grower using conventional products, including four potassium bicarbonate sprays, successfully dealt with this early epidemic in the trial tunnel, such that the mildew incidence had fallen considerably by the second assessment in August and was negligible and similar to that in the routine tunnel by the final assessment in September.

Background and expected deliverables

Over 15 years ago, a computer based strawberry powdery mildew risk prediction model was developed by Xiangming Xu at NIAB EMR in Kent. The model which uses knowledge of the optimum temperature and relative humidity for mildew infection to occur, was utilised in AHDB Projects SF 62 and SF 62a and demonstrated that growers can successfully use it to determine the need for applying protective fungicides to avoid infection.

However, despite being used successfully in these projects, UK growers have been slow to adopt it on commercial strawberry farms. Some growers have found it difficult and impractical to run the computer-based model using the required data loggers in the field. Furthermore, powdery mildew infection is so common in protected strawberry crops and can be so damaging to fruit yields and quality, that the majority of growers and agronomists feel more comfortable sticking to a routine prophylactic protective fungicide spray programme.

More recently, in an Integrated Pest and Disease Management Project funded by AHDB from 2015-2020 (SF 157), a simplified model employing weather forecast data and a ‘look-up’ table was used as part of a novel management approach to controlling powdery mildew and Botrytis in a protected everbearer strawberry (cultivar Amesti). The project demonstrated the potential to cut fungicide use for mildew by half. Instead of using the computer-based model, BBC weather forecast data (predicted for the next seven days) for the site was used in combination with a simple ‘look-up’ table to calculate the risk of mildew infection for the coming week. Criteria used in deciding upon the need to spray included this mildew risk ‘look-up’ table, weekly inspections of growth stage and rate of growth and weekly monitoring

for the presence of very early signs of powdery mildew infection. In addition, when the predicted risk of infection occurring was moderate, the biopesticides ‘Sonata’ and ‘AQ10’ were relied upon rather than conventional fungicides.

To consider whether such savings could be made and if biopesticides could be relied upon in a commercial setting using a similar approach in 2021, a demonstration trial was set up at Vicarage Nurseries, Bretforton, near Evesham in Worcestershire, by kind permission of Jaswinder Singh. The trial was set up using a single multi-bay tunnel of table-top (five rows per tunnel) everbearer strawberries (cultivar Murano) within a commercial plantation of the same cultivar.

No replication or statistical analyses were applied. The trial tunnel was managed using the same approach as Project SF 157, employing BBC weather forecast data in the simplified risk prediction table to determine the need to spray, coupled with weekly crop monitoring for growth stage, rate of growth and symptoms of early mildew infection. The trial was managed by plant pathologist Angela Berrie, aided by ADAS agronomist Robert Irving and farm manager Jaswinder Singh. The trial tunnel was compared to the remainder of the Murano crop which received routine weekly preventive fungicide applications from April until September.

At the end of the season, the total number and type of fungicides used on both the trial tunnel and the remainder of the crop were compared, whilst also contrasting the level of mildew control achieved in each. In addition, grower Jaswinder Singh and agronomist Robert Irving, offered their opinion on how confident they would be to adopt this management approach for mildew control in future.

There were two basic questions that they asked at the end of this trial:

- Was the weekly risk assessment, a forecast based on BBC weather data for the post code and assessed by Angela Berrie (took an hour per week) useful?
- Were the biopesticides AQ10 and Sonata useful?

Summary of the project and main conclusions

The trial began in March 2020. The everbearer cultivar Murano was planted in peat substrate bags on standard table-tops (five rows per tunnel) on 27 March 2020. This cultivar has good resistance to disease but in the UK shows low / moderate susceptibility to powdery mildew (but now appears more susceptible to mildew than the Amesti used in the earlier trials).

Data loggers were used in the trial tunnel to record daily average temperatures and humidities so that these could be used in the computer-based mildew risk model and compared, at the end of the season, to the simplified ‘look-up’ table which was managed by plant pathologist Angela Berrie. The computer-based mildew risk model cannot be used to predict forward mildew risk until forecast temperature and

humidity data is available to input. Data loggers in the tunnel only provide historic weather information.

Every week from the start of April until the end of September, from a remote site in Kent, Angela Berrie studied the BBC weather forecast data for the postcode for Vicarage Nurseries (WR11 7HW) for the week ahead and used the predicted average daily temperatures and relative humidities to work out the risk of strawberry powdery mildew infection occurring, using the simplified 'look-up' table below:

Simplified Mildew risk in relation to daily average temperature and relative humidity		
Condition		**Mildew risk**
Temperature	**Humidity**	
< 14	Not relevant	Low
≥ 14	< 82%	Moderate
≥ 14	≥ 82%	High

In addition to studying the weather forecast and calculating the risk of infection, the crop (both trial tunnel and the remainder of the crop) was monitored every week by ADAS agronomist Robert Irving and/or farm manager Jaswinder Singh. Plant pathologist Angela Berrie also visited the site to assess the crop in July, August and September. She had planned to visit once per month, but was prevented from doing so in April, May and June due to Covid-19 lockdown restrictions, preventing her from travelling from her home in Kent to Worcestershire.

Decisions on the need to use a fungicide in the trial tunnel

Low risk: When the mildew risk was calculated as 'low', unless any new powdery mildew lesions had been found, the decision was taken not to spray any fungicide in the early part of the season or to continue with a biopesticide once the programme had started.

Moderate risk: When the mildew risk was calculated as 'moderate', if no new powdery mildew lesions had been found, the decision was taken to continue with a biofungicide product. If there were any signs of new powdery mildew lesions, the decision was taken to apply a conventional fungicide.

High risk: When the mildew risk was calculated as 'high', the decision was taken to apply a conventional fungicide with good 'protectant' properties. If there were any signs of new powdery mildew lesions, the decision was taken to apply an additional conventional fungicide with 'eradicant' properties, such as potassium bicarbonate.

Decisions on the need to use a fungicide in the remainder of the plantation

In the remainder of the plantation, a routine prophylactic fungicide spray programme was applied every week from 25 April until 16 October, under the recommendation of ADAS agronomist Robert Irving and in line with mildew management on other everbearers on the rest of the farm business.

Choice of fungicide sprays

In the trial tunnel, when a biopesticide was used, a choice was made between Sonata (*Bacillus pumilus*) and AQ10 (*Ampelomyces quisqualis*). Sonata was kindly donated free of charge to the trial by Bayer UK. AQ10 was kindly donated free of charge to the trial by Fargro.

Choice of other biopesticides and conventional fungicides used in both the trial tunnel and remainder of the plantation came from lists provided in Tables 2 and 3 in the Science Section of this report.

All products were applied as foliar sprays by the farm using an air-assisted Berthoud sprayer at 1,000 L/ha. Both Sonata and AQ10 were used at the label rates. A wetter was not included as neither label nor their associated product support claimed a decisive benefit of doing so.

Summary of results

The risk of infection at the site was generally low in April and May. From early June, the risk started to increase and remained moderate to high until October. Interestingly, the risk determined from the computer-based model, run using the data loggers in the field, especially when conditions initially became favourable in June, agreed closely with those determined from the ‘look-up’ table and the BBC weather forecast.

The first treatment to the trial tunnel was delayed until 10 June, whereas treatments to the remainder of the crop were applied at around 7-10 day intervals from 25 April. After 10 June, treatments were applied to the trial tunnel at 7-15 day intervals in response to a continued mildew risk, mainly at moderate to high levels, based on the weather and on the incidence of new mildew lesions found in the trial tunnel (see images below.

New mildew lesion on underside of leaf

Mildew colonising seeds on Murano fruit

In the trial tunnel, a total of 19 products were applied between 10 June and 16 October, 11 of which were conventional fungicides and eight biopesticides. In contrast in the remaining crop, a total of 40 products, most of which were conventional fungicides, were applied.

Mildew lesions were first identified in the trial tunnel in mid-June, when no visible mildew was present in the remainder of the crop. By mid-July, the mildew incidence in the trial tunnel was high and it was treated with potassium bicarbonate and weekly applications of conventional fungicides. By late July, both the trial tunnel (92% of leaves) and the remainder of the crop (70% of leaves) had visible symptoms of mildew. The control measures used in both successfully reduced mildew symptoms. By September, symptoms were negligible in both. Images of the mildew symptoms seen are found in Figures 3 to 7 at the end of the Science Section of this report.

Full details of how the trial was managed, how decisions on spraying choice were made, the treatments applied, along with more information, can be found in the Science Section of this report. Key information is presented in:

Table 4: Criteria for mildew management decisions

Table 6: Action calendar and example in Appendix

Table 7: Trial diary showing weather forecast for week ahead from BBC and identified risk

Table 8: Treatments applied to trial tunnel and remaining plantation at Vicarage Nurseries in 2020

Grower and agronomist's views and findings

A useful summary on what the grower Jaswinder Singh and ADAS agronomist Robert Irving learnt from the trial is listed in the Headlines listed at the top of this report. A more comprehensive summary of their views and findings are also included

in the Science Section of this report under the heading: *'End of season views by the grower and advisor'*.

Conclusions on what we learnt from this demonstration trial

- The key to success of this management approach to powdery mildew in everbearer strawberry is having the skill and experience to detect the first mildew lesions early.

- The previous work on Amesti showed it to be highly susceptible to mildew on flowers and fruits but less so on leaves. In contrast in this work, Murano appears to be more susceptible to leaf infection and was more susceptible than the farm staff had anticipated.

- In both Project SF 157 (using Amesti) and in this demonstration trial (using Murano), temperature and humidity criteria for mildew infection were not reached until June, allowing early sprays for mildew protection in April and May to be omitted.

- The predicted risk of infection calculated from the simplified 'look-up' table using BBC weather forecasts, agreed closely with the computer-based NIAB EMR model using data from loggers in the tunnel. However, the trial tunnel was well ventilated from the outset. Had it been sealed from the time of planting, then tunnel conditions would have differed more widely from the outside weather forecast and the risk based on the simplified 'look-up' table would need to have been adjusted.

- **Conditions favourable for mildew started to develop in the week beginning 1 June. The risk was deemed to be minimal so the first spray in the trial tunnel was not advised until the following week when favourable conditions had increased. This approach had been successful with the cultivar Amesti but with the greater susceptibility observed with Murano, sprays should have started a week earlier. This probably accounted for the rapid development of mildew in the trial tunnel in June and July. Had the first spray been applied one week earlier, the mildew may not have developed so rapidly.**

- The conventional fungicides applied to the trial tunnel successfully dealt with this early epidemic, reducing mildew incidence by August and September.

- Mildew incidence in the remainder of the plantation (routine spray programme) was low to moderate in July, but significantly lower than in the

trial tunnel, demonstrating that these conventional products were effective at controlling the mildew.

- The trial tunnel received less than 50% of the products applied to the routine tunnel and almost half of the products applied were biopesticides.

- We have demonstrated that this managed approach to mildew control in protected everbearer strawberries employing a simplified risk model using BBC weather data and a 'look-up' table, can work effectively on a commercial strawberry farm. However, if using this managed approach, don't be too optimistic when making judgements on the risk of infection. Err on the cautious side and be prepared to start spray programmes as soon as temperatures and humidity start to increase.

- If the predicted mildew risk is 'low' then control can be based on biopesticides such as Sonata and AQ10, but intervention is required with conventional fungicides if symptoms of mildew develop and/or predicted mildew risk increases from low to 'moderate' or 'high'.

- Crucial to success are detecting mildew symptoms early and starting the spray programme at the appropriate risk in relation to the susceptibility of the strawberry cultivar used.

Financial benefits

In Project SF 157 where the same management approach to strawberry powdery mildew control was followed, both replicated trials at NIAB EMR and a demonstration trial on a commercial farm in 2018 demonstrated the ability to reduce fungicide inputs where treatments used for SPM and fungal rots were based on the simplified 'look-up' table using BBC weather data to predict the risk of mildew infection, compared to a routine or standard farm programme. The results were confirmed in the replicated trial at NIAB EMR in 2019. In both cases in 2018, cost savings were made (£699 /ha and £443 /ha respectively) with no adverse effects on yield, fruit quality or rot incidence. In this demonstration trial, where this management approach reduced fungicide use by half compared to a routine 7-day spray programme, similar savings would have been achieved.

In this on-farm assessment, the use of the management system resulted in a saving of four sprays by delaying the start of the spray programme until weather conditions were favourable. Overall, the trial tunnel received less than 50% of the products applied to the routine tunnel and almost half of the products applied were biofungicides. However, in this study the incidence of powdery mildew was higher in

the trial tunnel at the start of harvest with obvious consequences in loss of crop and fruit quality and this must be considered in the overall cost savings.

Action points for growers

Simplified Mildew risk in relation to daily average temperature and relative humidity		
Condition		**Mildew risk**
Temperature	**Humidity**	
< 14	Not relevant	Low
≥ 14	< 82%	Moderate
≥ 14	≥ 82%	High

- You can create a simplified powdery mildew risk model using BBC weather forecast data and the 'look-up' table above to dictate whether to spray or not. Each day is assessed to its risk category using the criteria in the table. The entire week of cumulative seven days is then estimated as a low, moderate or high-risk week.

- Monitor the crop closely at least once a week and switch to conventional products immediately the tiniest specks of mildew hyphae are seen.

- Always start the spray programme on the early side and always aim for excellent crop coverage.

- Use biopesticides when the risk is 'low' and there are no visual symptoms of mildew lesions. Sonata and AQ10 can be used at the label rates with no wetters. Biopesticides are protectant, not eradicant. Our experience in project SF157 indicates that Sonata and AQ10 worked best when used in blocks of treatments rather than alternating sprays. AQ10 is not compatible with many fungicides (check label), whereas Sonata, being a bacterial product, is compatible with most fungicides.

- Moderate and high risks need conventional mildew products, instead of biopesticides for reliable control.

- Be prepared to use a weekly programme of conventional mildewcides to guarantee reliable control through the whole season as necessary. There was a serious outbreak of mildew when the biopesticides were used too optimistically in this demonstration trial.

- If you lose control when using biopesticides, it can take a month to restore control using conventional products.

- You will gain confidence by trying this management system and using biopesticides in a few tunnels at first.

- Never forget that, because mildew can increase rapidly in favourable weather, infection develops into sporing colonies in as few as four days - the system is about mildew management and initially avoids the need for sprays in the early part of the season when the mildew risk is low or absent. Once the weather becomes favourable, usually in May, then a 7-day programme of sprays must be followed on susceptible strawberry cultivars.

SCIENCE SECTION

Title: Strawberry powdery mildew risk forecasting and biofungicide management – on farm assessment 2020

Background

A system for managing strawberry powdery mildew (SPM) control in protected everbearer strawberries was developed as part of a five-year (2015-2020) project (SF157), funded by AHDB. Trials in 2015 - 2016 identified effective products for control of SPM in strawberries. The trial in 2017 combined their use in programmes and incorporated other factors such as disease risk, growth stage, type of fungicide (curative, protectant, anti-sporulant) to develop a decision-based management programme for growers. This trial demonstrated that use of biopesticides gave good control of SPM in strawberry comparable to a fungicide-based programme. The 2017 trial was conducted from late June to September, a time of year when weather conditions are usually very favourable to SPM, giving few opportunities to omit sprays. If the trial had been started in March, then there would have been more opportunities to manage the SPM during the period up to June when mildew risks are generally much lower.

In 2018 the approach for managing SPM was integrated with control of Botrytis and other fruit rots on everbearer crops. The results showed that, overall a simple decision-based system for determining treatments for SPM and rots in protected everbearer strawberries resulted in a 50 % reduction in fungicide use and a cost saving of £699 /ha compared to a routine programme with no penalties in yield, fruit quality or disease control. In addition over the 20 harvests there were no significant effects of treatments on Botrytis rot incidence compared to the untreated control, suggesting that the fungicides applied for *Botrytis* control gave no benefit. Obviously, such a result has potential for large reductions in fungicide costs and in reducing residues in fruit.

The trial in 2019 further evaluated the SPM management system and reassessed the value of fungicides for rot control. Cool chain management of the fruit post-harvest was also included as part of the fruit rot management programme. The results further demonstrated the success of the decision-based management system for control of SPM and also confirmed that control of Botrytis fruit rot could be achieved by a combination of hygiene measures at harvest to control SWD and cool chain management of the fruit post-harvest with little need for intervention with fungicides.

Until 2020, the trials were all conducted at NIAB EMR and on the cultivar Amesti. The purpose of this 2020 demonstration project was to evaluate the system on a commercial farm and on other cultivars. This is a demonstration trial and was not replicated.

Objectives

To demonstrate a managed approach to strawberry powdery mildew control in everbearers, including no specific fungicides for Botrytis control, on a commercial strawberry production unit.

Materials and methods

Site

Vicarage Nurseries, Western Road, Bretforton, near Evesham, Worcestershire, WR11 7HW. The site was provided by kind permission of the manager Jas Singh. The trial tunnel, located in Block B on the main farm, consisted of five rows of standard height table-top strawberries (Figure 1). The adjacent tunnels in the block were similar and represented the routine treated tunnels.

Overall plan

The demonstration trial (Figure 1) consisted of one tunnel (in Block B) managed for SPM control compared to disease control on the farm in tunnels receiving the standard fungicide programme. One tunnel on the commercial farm was used for the managed mildew programme, including no specific sprays for rots, and compared to mildew and rot control in adjacent tunnels on the farm following the standard farm practice. There was no replication included as this was a demonstration trial.

For the managed tunnel:

- Robert Irving (ADAS agronomist, hereafter referred to as RI) was responsible for regular disease monitoring, making control decisions, requesting specific sprays as necessary with assistance from Angela Berrie.
- Angela Berrie, trial author (hereafter referred to as AB) was responsible for monitoring the weather on the BBC website for the week ahead and providing weather-based risks for mildew and proposed decisions. In addition, AB was responsible for monthly assessments of mildew incidence in the trial and routine treatment tunnels.

- Jas Singh, technical manager, Vicarage Nurseries (hereafter referred to as JS) was responsible for agronomic management of the tunnel, applying mildew sprays as requested by Robert Irving.

Since only commercially approved products were used, all fruit picked was marketable. By including no untreated plots, the risk of severe mildew development in the tunnel was limited.

Figure1 Trial tunnel in May

Strawberry cultivar

The cultivar Murano was planted in peat substrate bags on standard table tops on 27 March 2020. This cultivar has good resistance to disease but in the UK shows low / moderate susceptibility to powdery mildew.

Treatments and spray application

The programmes evaluated are shown in Table 1. Fungicides and biopesticides used in the programmes are listed in Tables 2 and 3. All were applied as foliar sprays by the farm using an air-assisted Berthoud sprayer at 1,000 L/ha. AQ10 (provided at no charge by Fargro) and Sonata (provided at no charge by Bayer UK) were used at the label rates. A wetter was not included as neither label or product support claimed a decisive benefit of doing so.

Table 1. Treatment programmes evaluated at Vicarage Nurseries in 2020

Treatment	Type	Products	Other
1 Routine	Farm programme	Fungicides etc as in standard programme	Nutrients etc, sprays for pests same as standard farm programme
2 Managed	Mildew management programme	Fungicides, AQ10, Sonata	

Table 2. Biopesticides for disease control on strawberry applied as foliar sprays

Product	Active ingredient	Rate (ha^{-1})	Harvest interval	Maximum number of sprays
AQ10	*Ampelomyces quisqualis*	70 g	Check label	12
Sonata	*Bacillus pumilis*	10 L	Check label	6
Serenade	*Bacillus subtilis*	10 L	Check label	6

Check product label for details
AQ10 should be applied alone as it is not compatible with most fungicides

Other pests, diseases and nutrients

Treatments for control of other diseases, pests and nutrients in the managed programme were the same as applied to the other tunnels in the standard farm programme. Pest monitoring and decisions on control were carried out by the farm agronomist Robert Irving. Irrigation and nutrition were the responsibility of JS, following the standard farm programme.

Decision making in the mildew management programme

Decisions on mildew control in the managed programme were based on three factors:

1. Current disease risks from weather (BBC 7-day forecast)
2. Current plant growth
3. Current level of sporulating mildew (Tables 4-5)

These three factors were used jointly to determine the need for treatment and, if so, what types of treatments (Tables 2-3).

Table 4 is a simple lookup table for mildew risks in relation to temperature and relative humidity. This is based on historical weather data and mildew risk output from the NIAB EMR model and was used in conjunction with the forward forecast for the week ahead from the BBC weather forecast on the internet for the location of the trial (postcode WR11) to determine the weather risk.

The forward forecast for the trial location was checked weekly by AB to determine the weather risk for the week ahead. The information on weather risk was supplied to RI and JS and used in conjunction with local tunnel conditions, growth stage of the strawberries and mildew incidence to determine treatment need. An action calendar for the trial tunnel is given in Table 6.

Methods, assessments and records

Disease

Powdery mildew: A full assessment for powdery mildew on leaves as percentage leaf area infected, using a standard key on a random sample of 50 expanded leaves in the trial tunnel and in the adjacent tunnel in which the standard farm programme was used, was planned by AB for each monthly visit from April to September. However, due to Covid 19 restrictions, only three visits were made, so mildew assessments were done on three occasions in July, August and September by AB. Assessment of powdery mildew on 25 flower trusses and 25 fruitlet trusses was conducted at the same time.

Other diseases: Assessments were made for other diseases (eg leaf spots) as needed. Assessment of fruit rots was not possible in practice.

Meteorological records

Weather data for decision making was obtained from the internet. A data logger (USB-502) was placed at crop height in the tunnel to monitor temperature and humidity.

Economic appraisal

At the end of the season, all the costs associated with the two programmes were collated and a simple economic appraisal of the management programme conducted.

Trial diary

A trial diary showing weather forecast for the week ahead from BBC weather on the internet and identified risk is given in Table 7.

Table 3. Available fungicide products for disease control on strawberry in 2020							
Product	**Active ingredient**	**Rate of product / ha**	**Against SPM**	**Max number of sprays**	**Harvest interval days**	**Chemical group**	**Disease controlled**
Switch	cyprodonil + fludioxonil	1 kg	No	2	3	Anilino-pyrimidine + phenylpyrroles	*Botrytis*
Frupica	mepanipyrim	0.9 L	No	2	3	Anilino-pyrimidine	*Botrytis*
Prolectus	fenpyrazamine	1.2 kg	No	3	1	Amino-pyrazolinone (KRI fungicide)	*Botrytis*
Scala	pyrimethanil	2 L	No	2	3	Anilino-pyrimidine	*Botrytis*
Signum	pyraclostrobin + boscalid	1.5	P	2	3	QoI + SDHI	*Botrytis*
Teldor	fenhexamid	1.5 kg	No	4	1	Hydroxyanilides (KRI fungicide)	*Botrytis*
Kindred	meptyldinocap	0.6 L	P	3	3	Dinitrophenyl-crotonates	SPM
Charm	difenoconazole + fluxapyroxad	0.6 L	P	3	1	Triazole + SDHI	SPM
Fortress	quinoxyfen	0.25 L	P	2	14	Aza naphthalenes	SPM
Nimrod	bupirimate	1.4 L	AS*/C/P	3	1	Hydroxyl-pyrimidine	SPM
Amistar	azoxystrobin	1.0 L	P	4	7	QoI	SPM, *Botrytis*
Amistar Top	azoxystrobin + difenoconazole	1.0 L	P	2	3	QoI + triazole	SPM + *Botrytis*
Karma	Potassium bicarbonate	3 kg	AS	8	1	Inorganic	SPM
Luna Sensation	trifloxystrobin + fluopyram	0.8 L	AS/C/P	2	1	SDHI + QoI	SPM, *Botrytis*
	potassium bicarbonate	20 kg	AS	Max total dose of 60 kg/ha	0?	Inorganic	SPM
Stroby	kresoxim-methyl	0.3 kg	P	3	14	QoI	SPM
Takumi	cyflufenamid	150 ml	AS/C/P	2	3	Phenyl-acetamide	SPM
Kumulus	sulphur	200g/100 L	P	No limit	0	inorganic	SPM
Topas	penconazole	0.5 L	AS/C/P	4	3	DMI	SPM
Talius	proquinazid	190 ml	AS/C/P	1	3	Aza-naphthalenes	SPM
AS = Antisporulant, P = protectant, C=curative							

Table 4. Criteria for mildew management decisions			
Item	**How determined**	**Risk**	**Management options**
Disease risk Less important	Determined from forward hourly weather forecast for temperature and humidity for the next 7 days from BBC for the location on the internet. A temperature / humidity logger was placed in the tunnel for local information	More than 4 days with risk above 10% requires action	**Product choice** – Fungicide or Biofungicide **Spray interval** – 7 or 14 days **Tunnel ventilation**
Growth stage and rate of growth	Weekly inspections	Rapid leaf production, start of flowering/ fruiting indicates increased risk and possible change of product	
SPM monitoring Most important as short time between infection and visible SPM; need to spot new SPM on leaves	Weekly inspections on youngest leaves, flowers and fruits. Plants will be selected at random for each inspection, choosing a different walk through the tunnel for each visit	Scored 0-5, 0 = no SPM on leaves, 1 = <1% (new SPM lesion), 2 = 1-5 %, 3 = 5-10%, 4 = up to 20%, and 5 = > 20% Flowers and fruit scored as presence or absence	

Table 5 Simplified Mildew risk in relation to daily average temperature and relative humidity		
Condition		**Mildew risk**
Temperature ºC	**Humidity**	
< 14	Not relevant	Low
≥ 14	< 82%	Moderate
≥ 14	≥ 82%	High

Table 6. Action calendar

Growth Stage	Likely month	Plant part to examine	What to look for	Disease risk from weather monitoring	Action
Runners / modules at or soon after planting	March / April	Old leaves	**Mildew** - Creamy-coloured mycelium on leaf undersides (may have mildew sexual fruiting bodies (black dots - chasmothecia) **Botrytis** – Sporing Botrytis on dead leaves	**Usually low** as daytime humidity below 82% & nights below 14°C. Will need to check tunnel conditions if crop fleeced and tunnel sealed as risk may be higher. See Tables 1-4 below	Remove any dead leaves. Spray azoxystrobin after planting to control any carry-over of mildew and botrytis and commence weekly or fortnightly inspections.
Onset of growth	April / May	New leaves	**Mildew** - New colonies (small white specks) on underside of young leaves		Check forecast weather risk either on model or internet, adjusting for tunnel conditions if needed. Fortnightly fungicide usually un-necessary if weather not conducive to mildew or no new mildew colonies found. If weather changes then weekly applications of protectant programme against conidial infection may need to start.
New leaf growth /Flowering / fruiting	May	New leaves, flowers, fruit	**Mildew** - New white mildew colonies on underside of young leaves or on flowers, especially stalks		
New Leaf growth /Flowering / fruiting	June to Sept.	New leaves, flowers, fruit	**Mildew** - New white mildew colonies on underside of young leaves or on flowers, especially stalks or on seeds on fruit **Botrytis** – Sporing botrytis on old fruit	**Moderate / High**, as usually above 80% RH in day & night temperature 14°C to 16°C .See Tables 1-4	Start biofungicide protectant programme for mildew when weather risk increases or new mildew lesions found. Follow a 7- day programme including fungicides when weather risk high or mildew incidence increases **Botrytis –** Ensure SWD rules for harvest clean- up of fruit are followed Ventilate tunnels to reduce heat and humidity.
Leaves / Flowers / Fruit	September - November	New leaves, flowers, fruit	**Mildew** - New white mildew colonies on underside of young leaves or on flowers, especially stalks or on seeds on fruit **Botrytis** – Sporing botrytis on old fruit	**Low - Moderate**, as usually above 80% RH in day & night but temperatures are lower. See Tables 1-4	Continue biofungicide protectant programme for mildew. Follow a 7- day programme including fungicides when weather risk high or mildew incidence increases **Botrytis –** Ensure SWD rules for harvest clean- up of fruit are followed Ventilate tunnels in the daytime to reduce heat and humidity.

Table 7 Trial diary showing weather forecast for week ahead from BBC weather on the internet and identified risk

Date	Weather forecast	Temperature /RH	Risk decision
March	Visit to Vicarage Nurseries to discuss trial Strawberries planted		
2 April	Weather checked on BBC for week ahead. Day weather RH too low. Night too cold	Day temperature up to 19ºC, mean RH 57% Night temperature up to 7ºC, RH mean 80%	Low risk. No spray
6 April	Weather checked on BBC for week ahead. Day weather RH too low. Night RH<82 when temperature >14ºC	Day temperature 15-20ºC, mean RH <70% Night temperature up to 1-16ºC, RH mean 80%	Low risk. Only spray if new mildew seen on leaves
13 April	Weather checked on BBC for week ahead. Day weather RH too low. Night too cold. RI reported no mildew seen	Day temperature12-19ºC, mean RH 49-70% Night temperature <14ºC, RH 79- 85%	Low mildew risk. No spray
20 April	Weather checked on BBC for week ahead. Day weather RH too low when temperature >14ºC. Night too cold.	Day temperature 6-21ºC, mean RH 39-91% Night temperature 6-14ºC, RH 50-95%	Low mildew risk. No spray unless new mildew found
27 April	Weather checked on BBC for week ahead. Day weather RH too low when temperature >14ºC. Night too cold when RH >82%	Day temperature 6- 19ºC, mean RH 57-96% Night temperature 6-19ºC, RH 70-96%	Low mildew risk. No spray unless new mildew found on leaves or flowers
4 May	Weather checked on BBC for week ahead. Day weather RH too low when temperature >14ºC. Night too cold when RH >82%	Day temperature 6- 21ºC, mean RH <82% Night temperature 3-17ºC, RH 61-90%	Low mildew risk. No spray unless new mildew found on leaves or flowers
11 May	Weather checked on BBC for week ahead. Day weather RH too low when temperature >14ºC. Night too cold when RH >82%	Day temperature 2-20ºC, mean RH 41-89% Night temperature 1-17ºC, RH 51-91%	Low mildew risk. No spray unless new mildew found on leaves or flowers
18 May	Weather checked on BBC for week ahead. Day weather RH too low when temperature >14ºC. Night too cold when RH >82%	Day temperature 9-25ºC, mean RH 39-95% Night temperature 10-20ºC, RH 56-95%	Low mildew risk. No spray unless new mildew found on leaves or flowers
25 May	Weather checked on BBC for week ahead. Day weather RH too low when	Day temperature 10-25ºC, mean RH 36-88% Night temperature 10-22ºC, RH 43-85%	Low mildew risk. No spray unless new mildew found

	temperature >14°C. Night <14°C when RH >82%		on leaves or flowers
1 June	Weather checked on BBC for week ahead. Day weather RH too low when temperature >14°C. Night <14°C when RH >82%	Day temperature 9-26°C, mean RH 36-85% Night temperature 8-20°C, RH 43-85%	Low mildew risk. No spray unless new mildew found on leaves or flowers
8 June	**Weather checked on BBC for week ahead. Day weather temperature >14°C and RH >82% for the early morning. Night >14°C and RH >82% for most nights**	**Day temperature 10-23°C, mean RH 51-91% Night temperature 9-19°C, RH 64-93%**	**Moderate mildew risk. Spray needed, using an effective fungicide if new mildew found on leaves or flowers**
9 June	First new mildew seen on young leaf by RI		
13 June	Weather checked on BBC for week ahead. Day weather temperature <14°C when RH >82%. Night >14°C and RH >82% for most nights	Day temperature 14-23°C, mean RH 54-98% Night temperature 13-20°C, RH 67-97%	Moderate-high mildew risk for most nights. Day risk low-moderate. Spray needed, using an effective fungicide if new mildew found on leaves or flowers
15 June	New mildew noted on seeds on mature fruit by JS		
22 June	Weather checked on BBC for week ahead. Day weather temperature <14°C when RH >82%. Night >14°C and RH >82% for most nights	Day temperature 13-29°C, mean RH 47-91% Night temperature 12-25°C, RH 59-90%	Moderate-high mildew risk for most nights. Day risk low-moderate. Spray needed, use a biopesticide such as Sonata unless new mildew found on leaves or flowers
22 June	New mildew seen on young leaves and berries by RI. Not seen in conventional tunnels		
29 June	Weather checked on BBC for week ahead. In general weather cooler. Day weather temperature <14°C when RH >82%. Night >14°C and RH >82% for most nights	Day temperature 13-20°C, mean RH 59-91% Night temperature 12-17°C, RH 72-94%	Moderate-high mildew risk for most nights. Day risk low-moderate. Spray needed, use a biopesticide such as Sonata unless new mildew found on leaves or flowers

6 July	Weather checked on BBC for week ahead. In general weather cooler. Day weather temperature <14ºC when RH >82%. Night >14ºC and RH >82% for most nights	Day temperature 10-23ºC, mean RH 49-92% Night temperature 10-19ºC, RH 62-92%	Low-moderate mildew risk for most nights. Day risk low-moderate. Spray needed, use a biopesticide such as Sonata unless new mildew found on leaves or flowers
13 July	Weather checked on BBC for week ahead. In general weather warmer for week ahead. Day weather temperature <14ºC when RH >82%. Night >14ºC and RH >82% for most nights	Day temperature 12-24ºC, mean RH 54-94% Night temperature 12-20ºC, RH 58-98%	Moderate-high mildew risk for most nights. Day risk low-moderate. Spray needed, use a biopesticide such as Sonata unless new mildew found on leaves or flowers
14 July	High incidence of mildew on fruit, stalks and some leaves by RI		
20 July	Weather checked on BBC for week ahead. In general weather warmer for week ahead. Day weather temperature <14ºC when RH >82%. Night >14ºC and RH >82% for most nights and warm humid nights later in week	Day temperature 13-21ºC, mean RH 48-97% Night temperature 7-18ºC, RH 58-98%	Moderate-high mildew risk for most nights and early morning. Day risk low-moderate. Spray needed. Use an effective eradicant fungicide in view of high mildew incidence
22 July	Trial visited by AMB. Mildew easily found on leaves and fruit / flower trusses in trial tunnel. This mostly looks dead as crop has been treated with potassium bicarbonate. New mildew on runners but these will be removed. Mildew colonising seeds on mature red fruit (not seen on Amesti). It seems that cv. Murano is more susceptible to mildew on leaves than Amesti. This is an added factor in the mildew risk assessment		Mildew risk is high. Suggested 2 rounds at 7-day interval of effective fungicide such as Luna Sensation or Talius and then continue with 7 day programme of biopesticide Sonata
27 July	Weather checked on BBC for week ahead. In general weather warmer for week ahead. Day weather temperature <14ºC when RH >82%. Night >14ºC and RH >82% for most nights and early mornings	Day temperature 10-27ºC, mean RH 49-93% Night temperature 10-22ºC, RH 67-92%	Moderate-high mildew risk for most nights and early morning. Day risk low. Spray needed. Use an effective eradicant fungicide in view

			of high mildew incidence
3 August	Weather checked on BBC for week ahead. In general weather warmer for week ahead. Day weather temperature <14°C when RH >82%. Night >14°C and RH >82% for most nights and early mornings	Day temperature 13-29°C, mean RH 46-96% Night temperature 13-25°C, RH 58-95%	Moderate-high mildew risk for most nights and early morning. Day risk low. Spray needed. Use an effective eradicant fungicide in view of high mildew incidence
10 August	Weather checked on BBC for week ahead. In general weather warmer for week ahead. Day weather temperature <14°C when RH >82% except on Wednesday when RH >82% all day. Night >14°C and RH >82% for most nights and early mornings	Day temperature 13-30°C, mean RH 51-98% Night temperature 15-25°C, RH 69-98%	High mildew risk for most nights and early morning. Day risk moderate. Spray needed. Use an effective eradicant fungicide in view of high mildew incidence
17 August	Weather checked on BBC for week ahead. In general weather cooler for week ahead than last week. Day weather temperature <14°C when RH >82% except on Wednesday when RH >82% all day. Night >14°C and RH >82% for most nights and early mornings	Day temperature 12-23°C, mean RH 63-96% Night temperature 12-20°C, RH 74-96%	High mildew risk for most nights and early morning. Day risk moderate. Spray needed. Use an effective eradicant fungicide in view of high mildew incidence and high risk
19 August	Trial visited. Mildew in tunnel is mostly contained. There is still active mildew but the incidence on new leaves and flower / fruit trusses is much lower than observed on last visit. A lot of new leaf and flowers being produced. Less mildew in the adjacent standard treatment tunnel but the differences are much lower. Flower fungus visible on flowers in both tunnels, possibly associated with shrivelled fruit.		
24 August	Weather checked on BBC for week ahead. In general weather cooler for week ahead than last week and unsettled. Day weather temperature <14°C when RH >82%. Night cooler and only >14°C on 4 out of 7 nights and RH >82% for most nights and early mornings	Day temperature 13-20°C, mean RH 59-96% Night temperature 8-17°C, RH 74-95%	Low-moderate mildew risk for some nights and early morning. Day risk low. Maintain protection. A biofungicide such as Sonata should be effective as mildew incidence is much lower

31 August	Weather checked on BBC for week ahead. In general weather cooler for week ahead than last week and unsettled. Day weather temperature <14°C when RH >82%. Night cooler and only >14°C on some nights. RH >82% for most nights and early mornings	Day temperature 9-20°C, mean RH 55-98% Night temperature 9-16°C, RH 70-97%	Low-moderate mildew risk for some nights and early morning. Day risk low. Maintain protection. A biofungicide such as Sonata should be effective as mildew incidence is much lower and risk lower
4 September	Weather checked on BBC for week ahead. In general weather cooler for week ahead than last week and unsettled. Day weather temperature <14°C when RH >82%. Night cooler and only >14°C on some nights. RH >82% for most nights and early mornings	Day temperature 9-21°C, mean RH 61-97% Night temperature 9-18°C, RH 76-97%	Low-moderate mildew risk for some nights and early morning. Day risk low. Maintain protection. A biofungicide such as Sonata should be effective as mildew incidence is much lower and risk lower
14 September	Weather checked on BBC for week ahead. In general weather warmer for week ahead. Day weather temperature <14°C when RH >82%. Night warmer than previous week and only >14°C on some nights. RH >82% for most nights and early mornings	Day temperature 9-26°C, mean RH 48-98% Night temperature 10-20°C, RH 71-98%	Moderate mildew risk for some nights and early morning, mainly at start of week. Day risk low. Maintain protection. A biofungicide such as Sonata should be effective unless mildew incidence has increased
21 September	Weather checked on BBC for week ahead. In general weather warm at start of week, cooler from Wednesday onwards. Day weather temperature <14°C when RH >82%. Night cooler and only >14°C on some nights. RH >82% for most nights and early mornings	Day temperature 5-23°C, mean RH 59-98% Night temperature 5-17°C, RH 70-95%	Moderate mildew risk for first part of week, then low mainly at night and early morning. Day risk low. Maintain protection. A biofungicide such as Sonata should be effective unless mildew incidence is increasing
23 September	Visited trial. In general mildew incidence was negligible in both tunnels. Flower fungus was easily found in both tunnels		

28 September	Weather checked on BBC for week ahead. In general weather warm at start of week and cool from Wednesday onwards. Day weather temperature <14^{o}C when RH >82%. Night cooler and only >14^{o}C on some nights. RH >82% for most nights and early mornings, but generally too cool for mildew **Last forecast**	Day temperature 7-17^{o}C, mean RH 56-97% Night temperature 7-14^{o}C, RH 76-98%	Low mildew risk for week ahead. Maintain protection. A biofungicide such as Sonata should be effective as mildew incidence is very low

Results

Weather

The temperature and relative humidity data range for days and nights from April to September are given in the appendix (Table A1). Examples of the weekly weather given on the internet are shown in Figure A1-3 in the appendix. In general night temperatures did not exceed the 14^{o}C criteria until early June, although night time humidities were generally >82% for most nights. Similarly, day temperatures were generally above 14^{o}C for most of the trial period but day time humidity was generally <82% for most days until August. The usual pattern for the day was humidity >82% in the early morning up to around 10 am but with the temperature <14^{o}C. Then as the temperature increased so the humidity fell with the result that for most days the mildew risk was low. The humidity and temperatures were higher in the tunnel which was also well ventilated (Figure1). At night the humidity rose to >82% for most nights but the night time temperature did not rise above 14^{o}C until early June (Table 7).

Data for temperature and humidity were also obtained for the tunnel from a data logger placed in the crop in the trial tunnel. This is shown in Appendix Figure A4. This data was input into the NIAB EMR mildew risk model to determine the mildew risk in the trial tunnel for April to October 2020. The results are shown in Figure 2. A period of four (or more) consecutive days with risks > 10% on susceptible cultivars (the red points) is considered to need growers' intervention with a moderate to high level of inoculum (usually when the incidence of leaves with mildew is above 5%). Apart from mid-April the model predicted a 10% risk from early June onwards until October. This predicted risk, especially when the conditions initially became favourable in June, agreed closely with those determined from the look-up table (Table 5) and the BBC weather forecast.

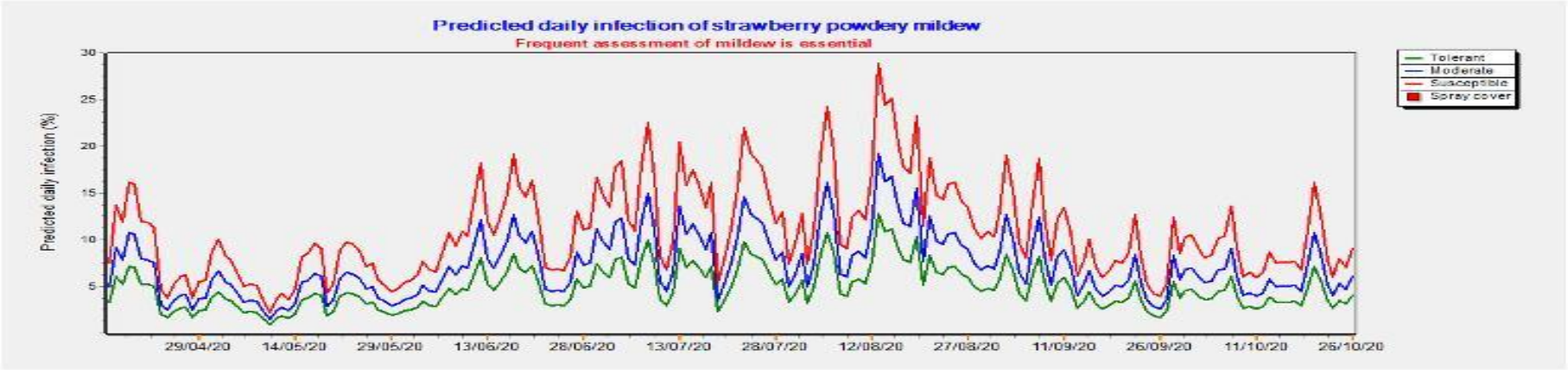

Figure 2 Predicted daily risk of powdery mildew for the Vicarage Nursery trial polytunnel site in 2020. The predictions were given by the NIAB EMR model where a period of four (or more) consecutive days with risks > 10% on susceptible cultivars (the red points) is considered to need growers' intervention with a moderate to high level of inoculum (usually when the incidence of leaves with SPM is above 5%).

Spray decisions

The spray decisions based on weather risk (Tables 4 and 5) are given in Table 7. Up until early June the weather conditions did not exceed the criteria for mildew risk, being too cool at night, despite the humidity being >82%, and less humid in the day when the temperature exceeded 14^{o}C. The treatments applied to the trial and routine tunnels are shown in Table 8. The first treatment to the trial tunnel was delayed until 10 June, whereas treatment to the routine tunnel were applied at around 7-10 day intervals from 25 April. Thereafter treatments were applied to the trial tunnel at 7-10 day intervals in response to a continued mildew risk, mainly at moderate to high levels, based on the weather and on the incidence of new mildew lesions found in the trial tunnel. A total of 40 products, most of which were fungicides, were applied to the routine tunnel. 27 of these were targeted at mildew and 21 at Botrytis. In contrast a total of 19 products were applied to the managed tunnel, of which 11 were fungicides and 8 biopesticides. Nine products were targeted at mildew and three at Botrytis.

Powdery mildew incidence

The incidence of mildew on leaves, flowers and fruits was assessed on three occasions in July, August and September (Table 9). No mildew was observed in the crop in April and May (Figure 3). New mildew lesions were first reported on leaves by RI on 9 June (Figure 4). Mildew colonising the seeds on mature fruit was reported by JS on 15 June (Figure 5). A greater incidence of mildew was reported by RI on 22 June on leaves and flowers, which was not observed in the routine tunnels. By 14 July the mildew incidence in the trial tunnel was high. This was dealt with by the grower using potassium bicarbonate applied on 16 June and on 9 and 13 July. By the time of the assessment on 22 July the high incidence of mildew on leaves had been effectively dried up by the application of the potassium bicarbonate. Actively sporing mildew was still present and this combined with a run of high risk weather resulted in fungicides applied at 7- day intervals for the next month. Mildew incidence assessed on 22 July showed 92% of leaves with mildew in the trial tunnel compared to 70% in the routine tunnel. However, infected leaves in the trial tunnel had a mean of 10% (range 0-30) leaf area mildewed compared to 3.7% (range 0-20) in the routine tunnel. Similarly, mildew was present on 42% of flowers and fruits in the trial tunnel compare to 14% in the routine tunnel.

The control measures applied and the subsequent treatments were effective as by the next assessment in August the mildew incidence on new leaves (those produced since 22 July) in the trial tunnel had fallen to 26% with a mean leaf area mildewed of 1.24% compared to 16% of leaves and a mean leaf area infected of 0.18% in the routine tunnel. Mildew incidence on flowers and fruit was 24% in the trial tunnel compared to 10% in the routine tunnel. By the final assessment in September the incidence of mildew on new leaves and flowers and fruits was negligible in both tunnels.

Other diseases

At the assessments in July and August the flower fungus (Figs. 6 and 7) was easily found on flowers and shrivelled fruit in both the trial and routine tunnels.

End of season views by the grower and advisor

By Grower (Jas Singh, Vicarage Nurseries) and Advisor (Robert Irving, ADAS)

The trial tunnel yield matched the conventional spray programme yield. The trial tunnel was guided by the prediction model, had a reduced total of sprays and preferred use of biopesticides. The trial tunnel came close to disaster at one point. You could have walked out of the trial tunnel at any time in the season into the neighbouring conventional crop and not seen a mildew problem on the conventional crop alongside.

Mildew Development Criteria

Simplified Mildew risk in relation to daily average temperature and relative humidity		
Condition		**Mildew risk**
Temperature	**Humidity**	
< 14	Not relevant	Low
≥ 14	< 82%	Moderate
≥ 14	≥ 82%	High

There are two basic questions in this trial:

- Was the weekly risk assessment, a forecast based on BBC weather data for the post code and assessed by Angela Berrie (took an hour per week) useful?
- Were AQ10 and Sonata useful?

Our Overall Comments

- “The weekly forecast was useful. It's a judgement call based on seven days of data. It showed that sprays through April and May were probably not needed despite a growing sense of unease at losing protection. It can be used to predict the level of threat ahead. A very useful judgement call in borderline situations, though don't push it. If you still think spray or not after this assessment, choose to spray!”

- “AQ10 and Sonata are not great firefighters. They are best as protective products. The product support literature confirms this. They are useful at times of low mildew threat not high mildew threat. They are a comparable cost to conventional fungicides”.

- “Conventional products retrieved control of the trial outbreak”.

Why did the Trial have an outbreak?

“In this demonstration trial we tested for efficacy of an alternative managed approach to powdery mildew control. Doing so required us to test the strategy to the limit. We discussed tactics ahead of the season. Angela Berrie's earlier work showed continuous use of AQ10 and Sonata could

achieve good control under small scale trial conditions in 2018. Conventional mildew sprays were rarely used".

Jas Singh (Vicarage Nurseries) and Robert Irving (ADAS) agreed to follow Angela's guidance and push no spraying and use of biologicals to the limit. "When there was a serious crop threat, we were allowed to save the crop with conventional fungicides then revert back to plan".

"Angela's trial work in 2018 used the variety Amesti. Her experience of mildew management was very focussed on this variety. Angela reckoned that Murano behaved differently to Amesti".

Key periods of the season

All dates listed below are week beginning dates rather than the actual spray dates.

All sprays were applied at 1,000 l/ha and air assisted.

March 30th – June 29th

The mildew forecast ranged from Low (all April and May) to High.

"We were told to delay the first spray until the very earliest sign of sporulation. This was quite nerve racking as two tiny leaf spots were seen on 8th June in the entire tunnel. We had looked hard all the time before. This showed that the risk model had something to offer. However, whilst the first speck of mildew may have been good enough as a spray trigger for Amesti, it wasn't for Murano. We used Systhane immediately (a convenient overlap form next door, then bicarb. We then reverted to AQ10 and Sonata in the hope of gaining control".

May	25	Week 22		
June	1	Week 23		
June	8	Week 24	Systhane 0.3L/ha + SW7 1ml/L	
June	15	Week 25	Potassium Bicarbonate 5g/L + SW7 1ml/L	
June	22	Week 26	Sonata 10L/ha	
June	29	Week 27	AQ10 70g/ha	

"In hindsight, it would have been better to have sprayed before sporulation, using AQ10 and Sonata to perhaps build up some protection. The conventional crop (never getting problem mildew throughout the season) had been sprayed four times before June 8th, the first spray date for the trial. Systhane was used as it was being applied to the conventional neighbour at the time".

July 13th to July 27th

The mildew forecast ranged from Moderate to Moderate/High.

"Sporulating mildew continued to threaten and some serious conventional spraying continued through all of July and the first week of August to tidy it up. Initially this was two sprays of conventional fungicides plus a wetter each week to clear it up".

Aug 3rd to Aug 17th

The mildew forecast ranged from Moderate/High to High.

“Mildew presence continued but had been reduced in July with the conventional products. Luna Sensation applied Aug 3rd then two weekly Sonatas. Sporulating mildew had stopped by Aug 17th”.

Aug 24th to Oct 19th

The mildew forecast ranged from Low to Low/Moderate.

“Charm was applied on August 24th, then AQ10 and Sonata thereafter. Successful mildew control achieved as low mildew risk”

Overall Level of Mildew Risk and Sprays Used

Mar	30		Mildew Risk Level	
Apr	6		Low	
Apr	13		Low-Moderate	CONVENTIONAL CROP
Apr	20		Moderate	Amistar 1L/ha + SW7 1ml/L
Apr	27		Moderate to High	
May	4		High	Signum 1.8kgs/ha + SW7 1ml/L
May	11			Systhane 0.3L/ha + SW7 1ml/L
May	18			
May	25			
Jun	1		TRIAL CROP	Signum 1.8kgs/ha + SW7 1ml/L
Jun	8		Systhane 0.3L/ha + SW7 1ml/L	Two sprays/week Systhane then Bicarb
Jun	15		Potassium Bicarbonate 5g/L + SW7 1ml/L	Amistar 1L/ha + Scala 2L/ha + SW7 1ml/L
Jun	22		Sonata 10L/ha	Switch 1kg/ha + Takumi 150ml/ha + SW7 1ml/L
Jun	29		AQ10 70g/ha	Topas 0.5L/ha + SW7 1ml/L
Jul	6		Potassium Bicarbonate 5g/L + SW7 1ml/L	Two sprays/week Bicarb then Luna Sensation
Jul	13		Two sprays/week. Bicarb then Systhane Frupica mix	Two sprays/week Bicarb then Systhane + Frupica
Jul	20		Two sprays/week. Bicarb then Talius Scala mix	Two sprays/week Bicarb then Talius + Scala 2L/ha
Jul	27			Two sprays/week Bicarb then Topas + Frupica
Aug	3		Luna Sensation 0.8L/ha + SW7 1ml/L	
Aug	10		Sonata 10L/ha	Two sprays/week Nimrod + Teldor 1.5kg/ha then Stroby + Switch
Aug	17		Sonata 10L/ha	Takumi 150ml/ha + Prolectus 1.2kg/ha
Aug	24		Charm 600ml/ha + SW7 1ml/L	
Aug	31			Charm 600ml/ha + Serenade 10L/ha
Sep	7		AQ10 70g/ha	Stroby 300g/ha + Teldor 1.5kg/ha + SW7 1ml/L
Sep	14			Nimrod 1L/ha + Serenade 10L/ha
Sep	21		AQ10 70g/ha	
Sep	28			Topas 0.5L/ha + Prolectus 1.2kg/ha
Oct	5		Sonata 10L/ha	Nimrod 1L/ha + Teldor 1.5kg/ha + SW7 1ml/L
Oct	12			Serenade 10L/ha
Oct	19		AQ10 70g/ha	

Economic appraisal

Use of the management system resulted in a saving of four sprays by delaying the start of the programme until weather conditions were favourable. Overall, the trial tunnel received less than 50% of the products applied to the routine tunnel and almost half of the products applied were biofungicides. However, in this study the incidence of powdery mildew was higher in the trial tunnel at the start of harvest with obvious consequences in loss of crop and fruit quality and this must be considered in the overall cost savings.

Discussion

- The system for management of powdery mildew in protected everbearer strawberries has been developed over five seasons as part of AHDB Project SF157. Decisions on the control of mildew are based on a combination of weather risk determined from temperature and humidity obtained from either the internet or from the NIAB EMR mildew risk model, the incidence of mildew in the crop and the amount of susceptible young tissue determined from the growth stage of the crop.
- In the earlier project it was demonstrated that in most seasons the temperature and humidity criteria for mildew were not reached until mid-June. This meant that the early sprays for mildew applied after the crop was planted in March could be omitted.
- However, key to this system is the early detection of the first new mildew lesions on leaves, which without good experience can be challenging.
- In this project the original plan was for AB to make regular monthly visits from April to the trial site to assist in the mildew monitoring to detect the first new mildew lesions. Unfortunately, with the restrictions resulting from Covid 19 this was not possible. However, JS and RI were carefully monitoring for mildew in the trial tunnel and were able to detect the first early mildew lesions which corresponded closely with the onset of favourable weather conditions (Table 7).
- The predicted daily mildew risk given by the NIAB EMR model (Figure 2), using data from loggers in the trial tunnel, also agreed closely with the risk determined from the internet weather forecast. The trial tunnel was well ventilated from the outset. Had the tunnel been sealed from time of planting then tunnel conditions would have differed more widely from the outside weather forecast and the risk based on the latter would need to have been adjusted.
- In addition, the previous project had used the cultivar Amesti which, although very susceptible to mildew on flowers and fruit, appeared to be much less susceptible to foliar mildew. Mildew incidence on the leaves rarely exceeded 5-10% leaf area mildewed even in a high mildew risk season when 100% fruit infection was recorded.
- The cultivar Murano used on this farm is reported to have low-moderate susceptibility to mildew, but appears to be more susceptible to foliar mildew with up to 30% leaf area mildewe recorded in the trial tunnel at the first assessment in July.
- Conditions favourable for mildew started to develop in the week beginning 1 June. The risk was deemed to be minimal so the first spray in the trial tunnel was not advised until the following week when favourable conditions had increased. This approach had been successful with the cultivar Amesti but with the greater susceptibility observed with Murano, sprays should have started a week earlier.
- This probably accounted for the rapid development of mildew in the trial tunnel.
- Action taken by the grower successfully dealt with this early epidemic, such that the mildew incidence had fallen considerably by the second assessment and was negligible and similar to that in the routine tunnel by the final assessment in September.
- Mildew incidence in the routine tunnel was low-moderate at the first assessment but significantly lower than in the trial tunnel.
- This demonstrates that the actual products used in the trial tunnel were successful in controlling the mildew, the main problem lying with timing of the first spray and the initial control.
- The trial tunnel received less than 50% of the products applied to the routine tunnel and almost half of the products applied were biopesticides.

- This shows that this managed approach to mildew control in protected everbearer strawberries, making use of weather information from the internet, is possible in practice on a commercial farm.
- The key points are detecting the early mildew and starting the spray programme at the appropriate risk in relation to the susceptibility of the strawberry cultivar used.

Table 8 Treatments applied to trial tunnel and routine treatment at Vicarage Nurseries in 2020

Date of application	Routine programme		Managed programme (Trial)	
	Product (rate/ha)	Type	Product (rate/ha)	Type
25 April	Amistar (1.0L) + SW7 1ml/L	fungicide		
4 May	Signum (1.8kg) + SW7 1ml/L	fungicide		
14 May	Signum (1.5kg) Systhane (0.3L) SW7 1ml/L	fungicide		
2 June	Signum (1.8kg) SW7 1ml/L	fungicide		
10 June	Systhane (0.3 L) Scala (2.0L) SW7 1ml/L	fungicide fungicide	Systhane (0.3 L) SW7 1ml/L	fungicide
13 June	Potassium bicarbonate (5g/L) SW7 1ml/L	fungicide		
16 June			Potassium bicarbonate (5g/L) SW7 1ml/L	fungicide
17 June	Amistar (1.0) Scala (2.0L) SW7 1ml/L	fungicide fungicide		
25 June	Switch (1.0kg) Takumi (0.15L) SW7 1ml/L	fungicide fungicide	Sonata (10L)	biofungicide
1 July	Topas (0.5L) SW7 1ml/L	fungicide		
2 July			AQ10 (70g)	biofungicide
6 July	Potassium bicarbonate (5g/L) SW7 1ml/L	fungicide		
9 July			Potassium bicarbonate (5g/L) SW7 1ml/L	fungicide
10 July	Luna Sensation (0.8L) SW7 1ml/L	fungicide		
13 July			Potassium bicarbonate (5g/L)	fungicide

			SW7 1ml/L	
14 July	Potassium bicarbonate (5g/L) SW7 1ml/L	fungicide		
17 July	Systhane (0.3 L) Frupica (0.9L) SW7 1ml/L	fungicide fungicide	Systhane (0.3 L) Frupica (0.9L) SW7 1ml/L	fungicide fungicide
20 July	Potassium bicarbonate (5g/L) SW7 1ml/L	fungicide	Potassium bicarbonate (5g/L) SW7 1ml/L	fungicide
23 July	Talius (0.19L) Scala (2.0L) SW7 1ml/L	fungicide fungicide	Talius (0.19L) Scala (2.0L) SW7 1ml/L	fungicide fungicide
30 July	Potassium bicarbonate (5g/L) SW7 1ml/L	fungicide		
1 August	Topas (0.5L) Frupica (0.9L) SW7 1ml/L	fungicide fungicide		
3 August			Luna Sensation (0.8L) SW7 1ml/L	fungicide
10 August	Nimrod (1.0L) Teldor (1.5kg) SW7 1ml/L	fungicide fungicide		
11 August			Sonata (10L)	biofungicide
16 August	Stroby (0.3kg) Switch (1.0kg) SW7 1ml/L	fungicide fungicide		
18 August			Sonata (10L)	biofungicide
23 August	Takumi (0.15L) Prolectus (1.2kg)	fungicide fungicide		
30 August			Charm (0.6L) SW7 1ml/L	fungicide
3 September	Charm (0.6L) Serenade (10L)	fungicide biofungicide		
10 September	Stroby (0.3kg) Teldor (1.5kg) SW7 1ml/L	fungicide fungicide		
11 September			AQ10 (70g)	biofungicide
19 September	Nimrod (1.4L) Serenade (10L)	fungicide biofungicide		
26 September			AQ10 (70g)	biofungicide
28 September	Topas (0.5L) Prolectus (1.2kg)	fungicide fungicide		

7 October	Nimrod (1.4L) Teldor (1.5kg) SW7 1ml/L	fungicide fungicide	Sonata (10L)	biofungicide
16 October	Serenade (10L)	biofungicide	AQ10 (70g)	biofungicide
Total products applied	41		19	
Total fungicides	39		11	
Total fungicide mildew	28		9	
Total fungicide Botrytis	19		3	
Total biofungicide	3		8	

Table 9. Assessment of powdery mildew on leaves, flowers and fruit in trial and routine tunnels of strawberry cv Murano at Vicarage Nurseries in 2020

Date assessed	Item	Mildew on leaves		Mean % fruit / flower trusses with mildew
		Mean % leaves with mildew	Mean % leaf area mildewed (range)	
22 July	Trial	92.0	10.0 (0-30)	42.0
	Control	70.0	3.7 (0-20)	14.0
19 August	Trial	26.0	1.24 (0-20)	24.0
	Control	16.0	0.18 (0-2)	10.0
23 September	Trial	2.0	0.1 (0-5)	0
	Control	0	0	0

Conclusions

- Weather risk based on the BBC weather forecast for temperature and relative humidity for the week ahead used in conjunction with the look up table gave a good indication for mildew risk at the start of the season indicating when to start spraying for mildew and enabling four sprays to be saved in this study.
- The predicted daily mildew risk given by the NIAB EMR model (Figure 2), using data from loggers in the trial tunnel, also agreed closely with the risk determined from the internet weather forecast.
- Once the weather became favourable for mildew in early June, it remained so for the rest of the season and therefore on a susceptible cultivar required a 7-day programme to be followed thereafter.

- If mildew incidence in the crop is low, control can be based on a biopesticide such as Sonata, intervening with a conventional fungicide if mildew incidence increases or the mildew risk is high.

References

Anon, 1976. Strawberry powdery mildew ADAS Key No 8.1.1. MAFF, Plant Pathology Laboratory, Harpenden, Herts.

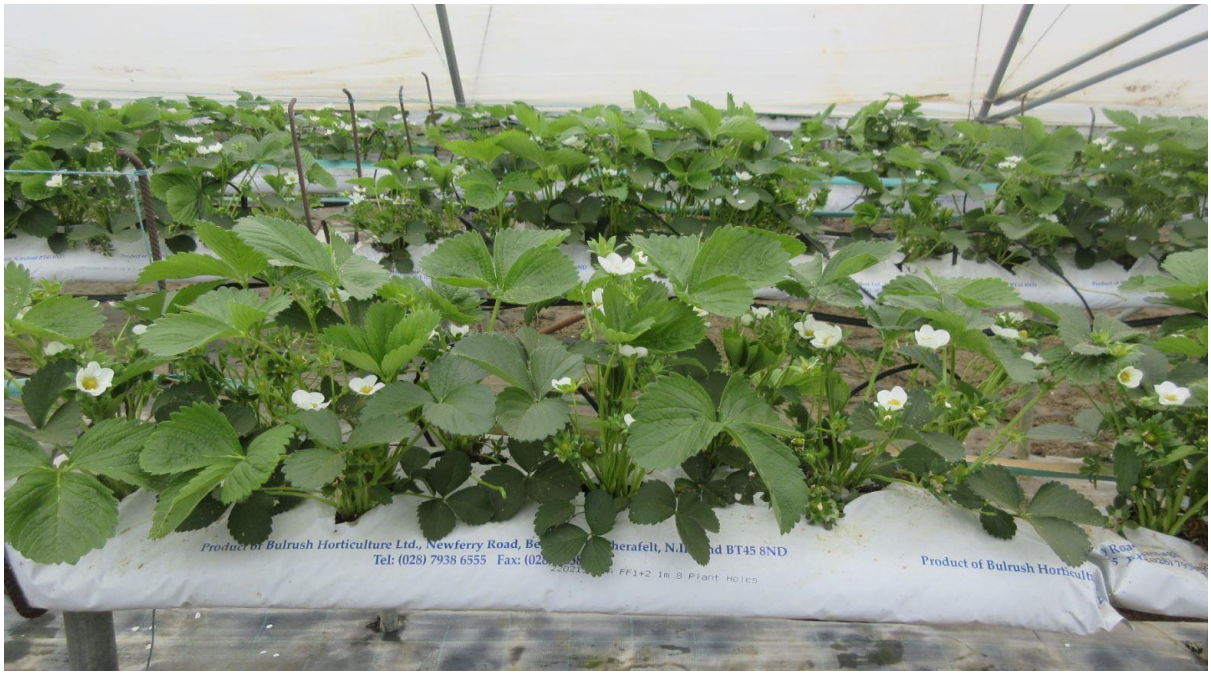

Figure 3 Plants in trial tunnel in May with no obvious mildew

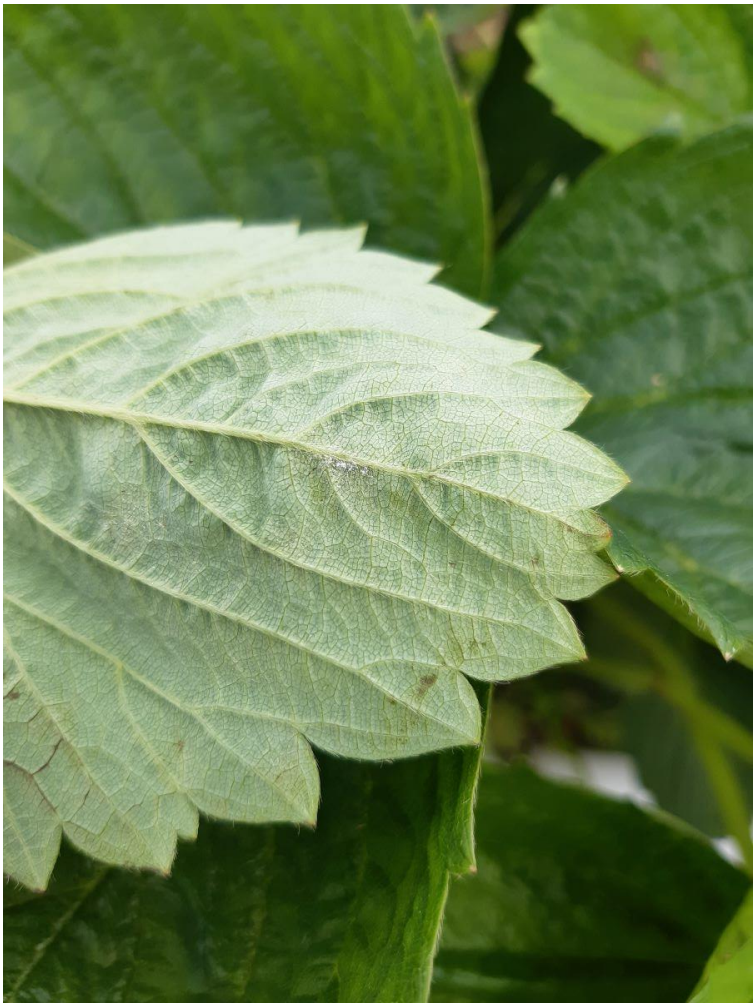

Figure 4. New mildew lesion on leaf underside reported on 9 June

Figure 5 Mildew colonising seeds on mature fruit on Murano as fluffy white growths reported on 15 June

Figure 6 Flower fungus on young flower in September showing as slight purpling to the stigmas

Figure 7 Shrivelled fruit possibly resulting from flower fungus infection

Appendix

Table A1 Weather data from BBC weather website for post code WR11 – Bretforton, Worcestershire							
Date	**Day temp range**		**Day RH range**		**Night temp range**		**Night RH range**
13-Apr	12		49		5		84
14	12		86		7		85
15	17		50		7		85
16	19		49-65		9 to 14		74-84
17	16		56-84		13		79-84
18	14		60-70		7 to 12		85
19	17		55-75		8 to 13		80-87
20	12 to 17		39-56		6 to 10		71-78
21	6 to 18		50-76		7 to 14		50-88
22	7 to 19		40-81		6 to 14		55-94
23	6 to 21		43-95		8 to 14		50-87
24	8 to 20		58-88		9 to 15		64-90
25	9 to 17		55-89		8 to 13		69-91
26	8 to 16		54-91		7 to 12		67-87
27	7 to 14		56-74		7 to 13		60-89
28	7 t0 9		83-94		6 to 8		87-96
29	6 to 13		73-96		7 to 10		78-91
30	7 to 13		64-92		6 to 9		78-92
01-May	6 to 15		57-92		7 to 11		75-93
2	7 to 16		63-93		10 to 14		70-88
3	10 to 18		67-88		12 to 15		79-89
4	12 to 17		58-63		5 to 12		68-89
5	6 to 15		44-88		6 to 11		56-83
6	6 to 19		49-82		7 to 14		61-84
7	7 to 21		55-85		10 to 16		66-90
8	10 to 21		53-91		11 to 17		67-92
9	11 to 18		60- 92		7 to 13		72-82
10	7 to 10		54-82		3 to 6		67-82
11	3 to 10		43-47		1 to 8		52-84
12	2 to 13		59-78		4 to 9		65-91
13	5 to 12		49-89		3 to 9		53-81
14	3 to 14		41-69		5 to 10		54-83
15	6 to 17		47-84		7 to 11		60-85
16	7 to 17		47-86		8 to 14		60-85
17	8 to 20		44-85		9 to 17		51-85
18	9 to 21		49-68		11 to 16		75-92

19	11 to 23		49-91		10 to 18		61-95
20	10 to 25		39-95		12 to 20		64-82
21	12 to 23		46-82		14 to 19		56-81
22	14 to 17		58-83		10 to 13		64-81
23	10 to 16		58-81		10 to 13		66-86
24	11 to 19		50-86		11 to 15		63-88
25	11 to 23		38-88		10 to 17		56-82
26	10 to 21		59-65		10 to 15		61-80
27	11 to 24		40-83		12 to 21		46-82
28	12 to 24		37-82		12 to 21		45-72
29	12 to 24		36-73		13 to 21		43-74
30	13 to 25		39-75		12 to 22		52-80
31	13 to 24		42-80		10 to 22		52-80
01-Jun	12 to 26		37-82		11 to 20		43-85
2	11 to 24		36-87		13 to 20		46-75
3	13 to 18		61-81		9 to 14		69-82
4	9 to 15		55-82		9 to 13		68-85
5	9 to 17		52-85		9 to 13		64-83
6	9 to 15		51-82		8 to 13		65-80
7	9 to 15		54-80		8 to 13		66-84
8	10 to 17		51-85		9 to 14		64-86
9	10 to 19		51-79		10 to 15		66-86
10	10 to 16		64-73		10 to 14		77-90
11	10 to 16		70 -91		11 to 14		83-93
12	11 to 20		64-86		14 to 17		73-90
13	14 to 22		62-91		14 to 18		76-92
14	14 to 23		58-91		14 to 19		70-90
15	14 to 22		78-90		13 to 19		69-91
16	13 to 21		60-97		13 to 19		76-96
17	13 to 21		69-98		14 to 17		81-95
18	14 to 20		67-95		13 to 17		78-96
19	14 to 21		63=95		13 to 18		76-92
20	13 to 22		57-92		14 to 19		69-87
21	14 to 22		55-87		13 to 18		68-91
22	13 to 23		54-91		12 to 17		69 -90
23	12 to 26		50-89		14 to 21		65-87
24	14 to 29		47-87		16 to 25		59-88
25	17 to 29		48-88		17 to 25		59-86
26	17 to 26		60-86		15 to 21		73-88
27	15 to 22		61-87		14 to 18		73-89
28	15 to 20		61-89		13 to 16		73-88
29	13 to 16		64-77		12 to 14		79-84
30	12 to 18		69-87		14 to 17		79-89
01-Jul	14 to 19		67-90		12 to 15		85-94

2	13 to 20		65-93		12 to 16		78-91
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4	15 to 19		68-89		13 to 17		77-87
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6	13 to 20		48-57		12 to 15		60-84
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28	12 to 18		53-86		10 to 15		67-90
29	10 to 19		57-90		12 to 17		69-91
30	13 to 24		53-92		15 to 21		62-84
31	15 to 27		49-84		15 to 22		63-91
01-Aug	15 to 23		56-92		12 to 17		83-92
2	13 to 20		61-92		13 to 17		76-93
3	13 to 20		48-60		9 to 15		60-92
4	9 to 20		54-92		16 to 19		68-86
5	16 to 22		65-87		15 to 19		77-94
6	16 to 25		55-94		15 to 22		67-94
7	15 to 29		46-93		16 to 25		58-91
8	16 to 27		49-92		14 to 22		64-95
9	14 to 25		48-96		13 to 21		61-90
10	13 to 30		51-91		18 to 25		69-87
11	18 to 29		53-94		19 to 24		76-98
12	19 to 29		59-98		19 to 24		74-96
13	19 to 26		71-97		17 to 22		86-96
14	17 to 23		70-96		15 to 20		80-95

15	15 to 23		63-96		15 to 19		75-94
16	15 to 21		69-94		15 to 18		82-94
17	15 to 21		71-85		15 to 18		89-93
18	15 to 22		69-94		16 to 18		83-93
19	15 to 21		80-94		17 to 20		88-92
20	17 to 22		61-92		16 to 19		74-86
21	16 to 21		70-87		14 to 17		82-91
22	14 to 19		66-91		12 to 16		77-93
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24	13 to 19		68-79		15 to 16		83-94
25	15 to 20		73-93		14 to 17		75-81
26	14 to 20		59-83		11 to 16		74-96
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30	8 to 16		61-95		8 to 13		76-94
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01-Sep	10 to 18		55-91		11 to 15		70-88
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27	8 to 16		71-82		11 to 13		84-94

28	11 to 16		69-90		9 to 14		94-97
29	9 to 17		56-96		10 to 12		76-90
30	10 to 15		81-97		8 to 12		95-98
01-Oct	8 to 13		65-95		7 to 9		85-95
2	7 to 12		78-95		9 to 9		93-96
3	9 to 13		79-96		9 to 10		93-95
4	9 to 13		78-95		9 to 10		93-95
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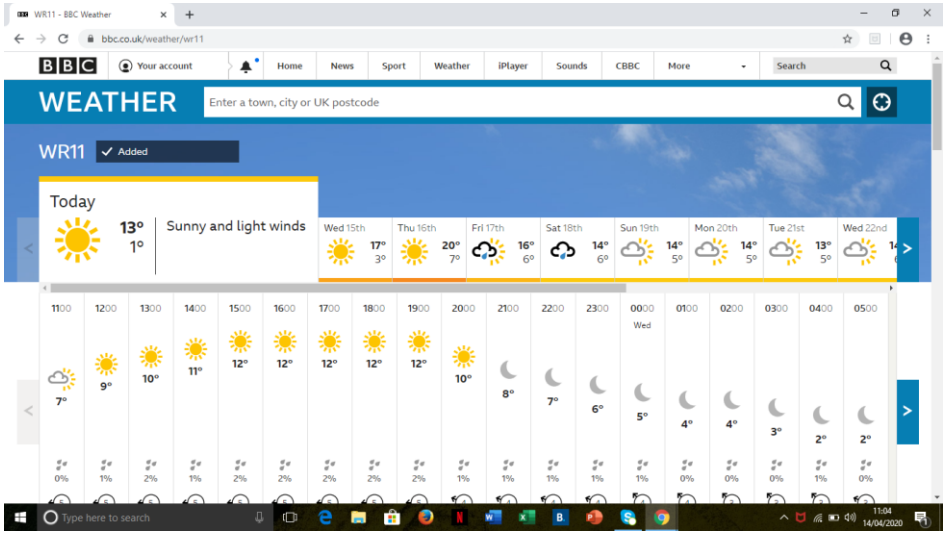
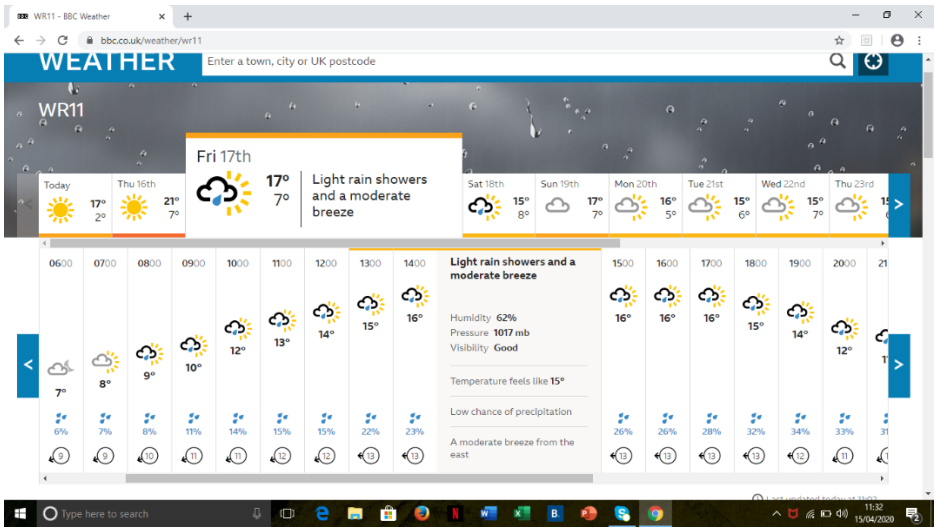
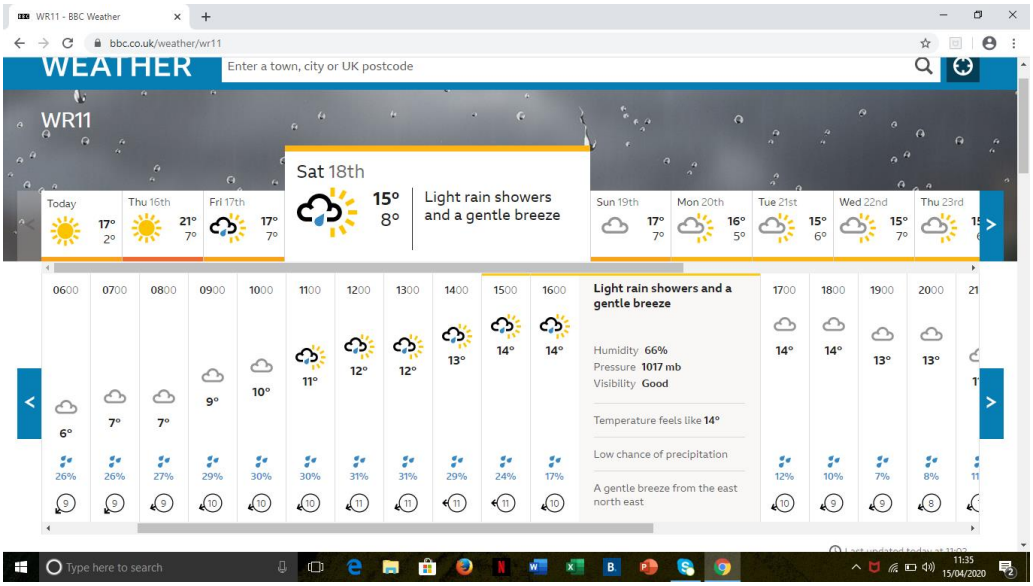
Figure A1-3 Examples of forecast for week ahead for postcode WR11 from BBC weather






WR11 - BBC Weather
bbc.co.uk/weather/wr11
WEATHER
Enter a town, city or UK postcode
WR11
Sat 18th
15° 8°
Light rain showers and a gentle breeze
Today 17° 2°
Thu 16th 21° 7°
Fri 17th 17° 7°
Sun 19th 17° 7°
Mon 20th 16° 5°
Tue 21st 15° 6°
Wed 22nd 15° 7°
Thu 23rd
0600 6° 26% 9
0700 7° 26% 9
0800 7° 27% 9
0900 9° 29% 10
1000 10° 30% 10
1100 11° 30% 10
1200 12° 31% 11
1300 12° 31% 11
1400 13° 29% 11
1500 14° 24% 11
1600 14° 17% 10
Light rain showers and a gentle breeze
Humidity 66%
Pressure 1017 mb
Visibility Good
Temperature feels like 14°
Low chance of precipitation
A gentle breeze from the east north east
1700 14° 12% 10
1800 14° 10% 9
1900 13° 7% 9
2000 13° 8% 8
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15/04/2020

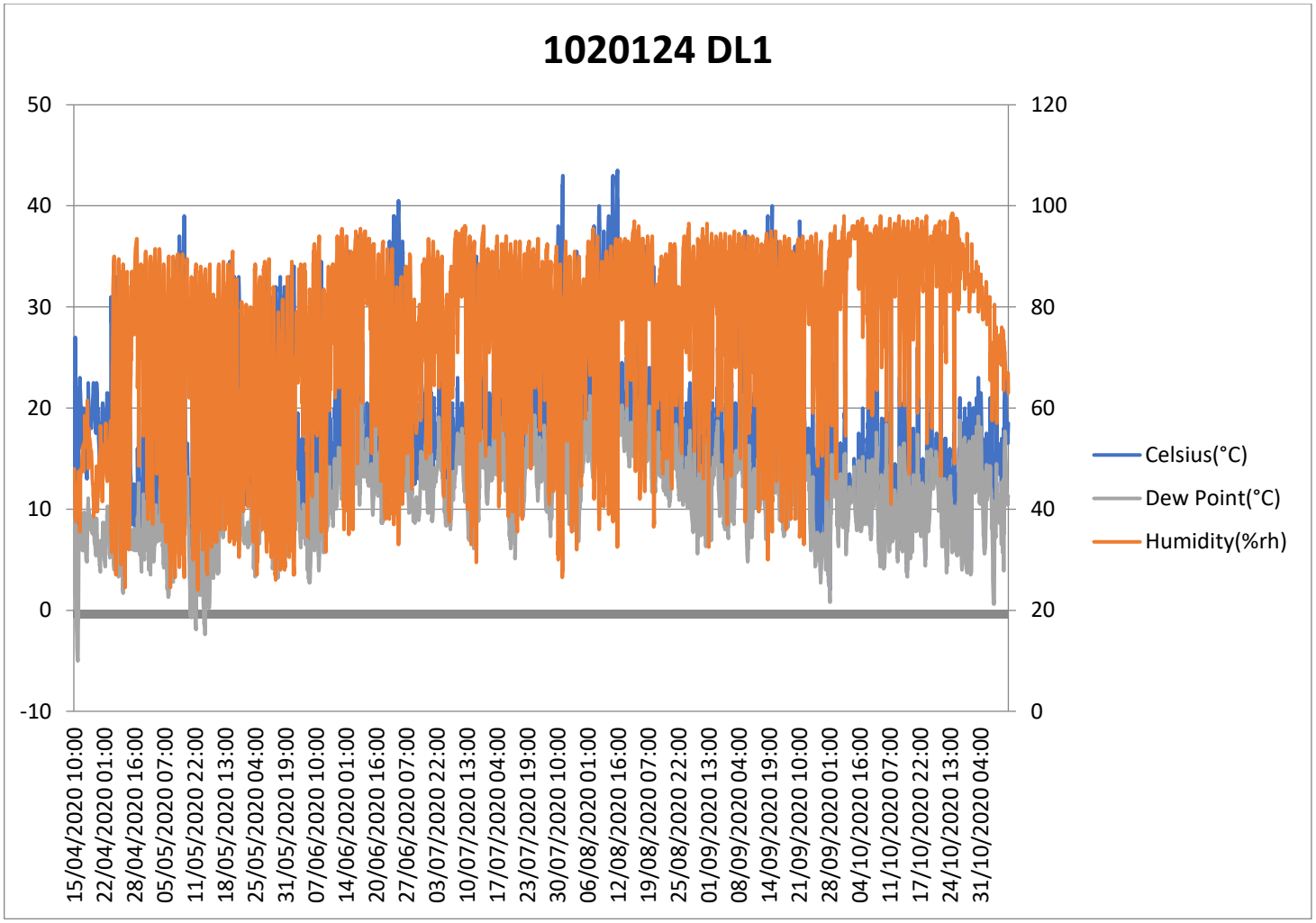
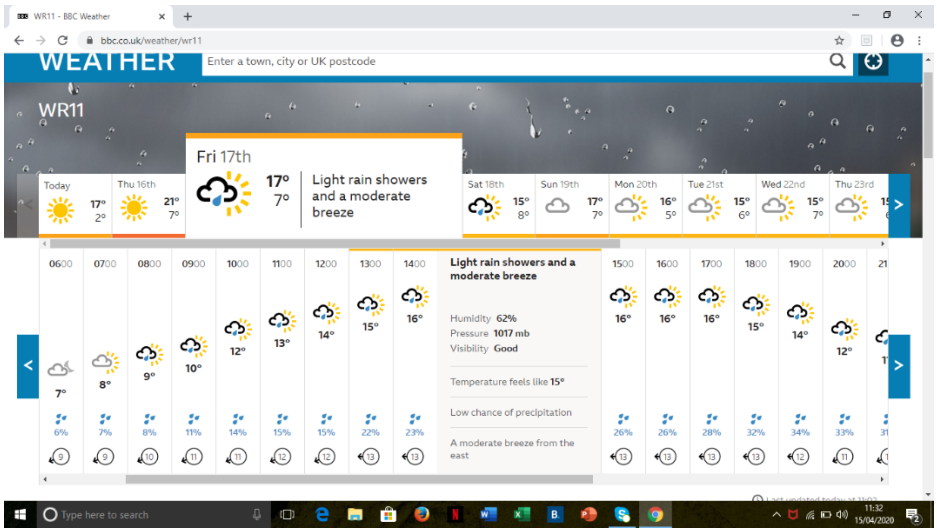


Fig. A4 Data from logger in Trial tunnel at Vicarage Nurseries

How to determine the weekly powdery mildew category using the BBC website and the risk table

- Soon after planting inspect plants for mildew mycelium on over-wintered leaves. These are a source of inoculum for the new crop.
- Apply a broad-spectrum conventional fungicide for control soon after planting.
- From March / April, on a Monday look up BBC weather forecast for the week ahead for post code area of farm. This will give hourly temperatures for each day in the week ahead and also humidity if you click on windspeed button.



- Compare data to that in the red, yellow and green risk ‘look up’ table for powdery mildew below to determine the weather risk for the week ahead. This will need to be adjusted if a tunnel is sealed up, as humidity and temperatures will be higher within. For instance, under a tunnel, you could increase the temperature and humidity readings by 15%, so that a BBC reading of 10ºC would be increased to 11.5ºC and relative humidity of 50% would be increased to 57.5% under a closed tunnel.

- Make a judgement on which category of risk the data best fits (Low, Moderate or High).

Table 5 Simplified Mildew risk in relation to daily average temperature and relative humidity

Condition		Mildew risk
Temperature ºC	Humidity	
< 14	Not relevant	Low
≥ 14	< 82%	Moderate
≥ 14	≥ 82%	High

- Generally, the weather up to June is above threshold for humidity at night but too cold, and above threshold for day temperature but not humid enough meaning that sprays for powdery mildew can be delayed.
- The risk will also need to be adjusted if new mildew lesions are found during the weekly inspections.

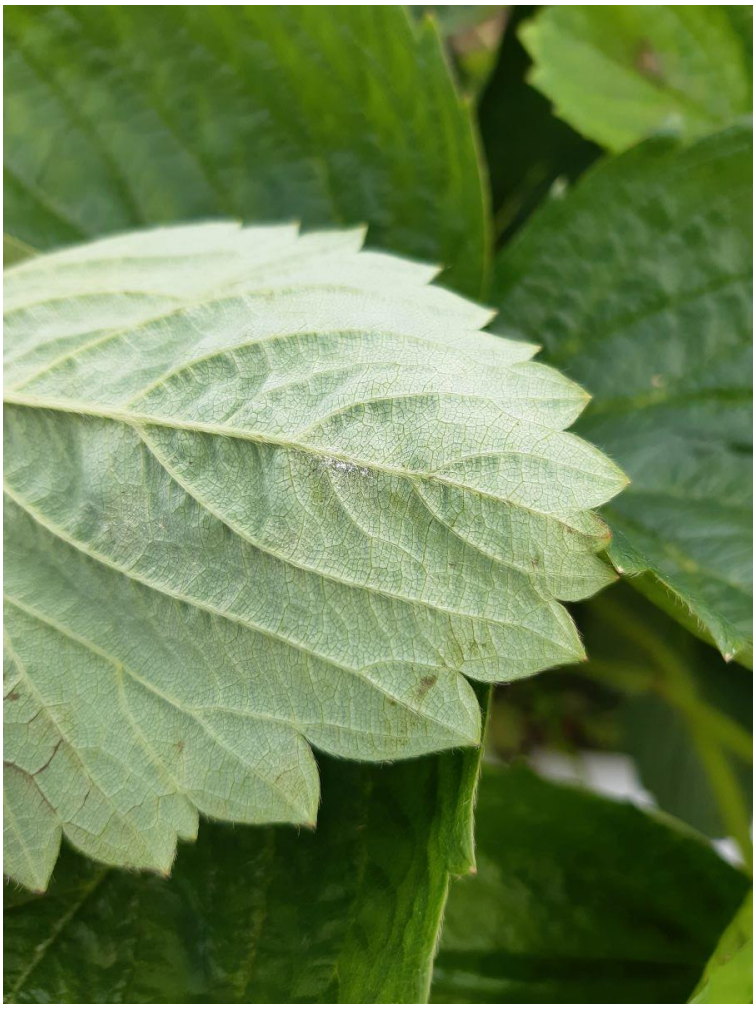


Fig. 4. New mildew lesion on leaf underside

- Continue with this procedure weekly through the season.
- Once the weather reaches threshold, generally in June, the favourable conditions continue for rest of the season.
- Once new mildew lesions are found (or before this if conditions are very favourable) then start the 7-day programme.
- Start with a conventional effective mildew fungicide to deal with any missed new mildew lesions. Then continue with programme based on biopesticides,

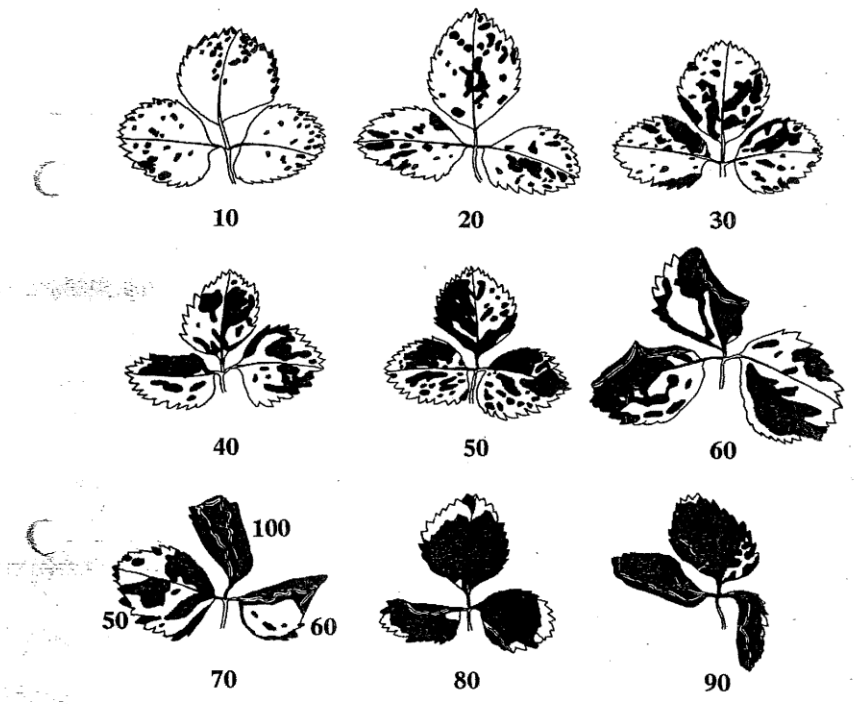
switching to conventional fungicides if the weather risk is very high or mildew incidence is increasing.

- **Spray decisions for mildew are not a question of spraying or not spraying but how often to spray and with which product. Once weather becomes favourable for mildew then, on a susceptible cultivar, treatment for mildew will need to continue as a regular programme, usually at 7 day intervals.**

AGRICULTURAL DEVELOPMENT AND ADVISORY SERVICE

Strawberry Powdery Mildew — Key No. 8·1·1

Sphaerotheca alchemillae Grev.



Percentage of leaf area affected

Black shaded areas represent red/yellow blotches and brown dead tissue

Fig. A5 Assessment key for strawberry powdery mildew