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

AUTHENTICATION

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

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Grower Summary

Headline

A five-spray fungicide programme (Signum, Plover, Dithane 945, Plover, Signum) at 2-3 week intervals from mid-July, was effective in reducing the incidence and severity of Stemphylium purple spot on asparagus, and resulted in increased levels of root carbohydrate at crown dormancy, compared with an untreated control.

Background and expected deliverables

Stemphylium purple spot on asparagus spears and ferns is caused by the fungus *Stemphylium vesicarium* (also known as *Pleospora herbarum*). Purple lesions can occur on spears during the harvest season but mainly develop on the asparagus ferns, affecting the needles, secondary branches and main stems. Severe infection often results in premature defoliation, with the potential to significantly reduce yields in subsequent seasons. Survival structures of the fungus can overwinter on fern debris and this is often the main source of the disease during the following harvest season.

Despite the availability of suitable fungicides, UK growers still report Stemphylium outbreaks. The sporadic nature of the disease means that it may not be cost effective to use a prophylactic spray programme. However, disease development can occur rapidly and control may be lost when the timing of specific fungicide applications is not optimised in relation to infection events.

HDC Factsheet 18/07 summarises available information on Stemphylium biology and potential management strategies. Based on knowledge gaps identified in the factsheet, experimental work is needed to develop integrated strategies for the management of Stemphylium on asparagus. The specific objectives are to:

1. Determine the efficacy of approved and potential fungicides for control of asparagus Stemphylium in inoculated pot experiments.
2. Monitor leaf wetness / temperature and record Stemphylium development in untreated crop areas, to determine the frequency of infection periods and provide the basis for setting thresholds in a disease model (Tom-Cast).
3. Evaluate fungicide programmes for Stemphylium control on asparagus ferns and effects on root carbohydrate levels.

4. Determine the efficacy of some chemical practices for reducing inoculum of Stemphylium overwintering on asparagus fern debris.
5. Prepare an updated factsheet on integrated management of asparagus Stemphylium.

Summary of the project and main conclusions

Efficacy of fungicides for Stemphylium control in an inoculated pot experiment

A pot experiment was established in 2009 at ADAS Boxworth (Cambs) to determine the efficacy of fungicides applied at different times in relation to infection, on the control of Stemphylium purple spot on asparagus. Fungicides were applied to fern in September, 3 days before or 3 days after artificial inoculation with a spore suspension of *Stemphylium vesicarium*. Fungicides used (all at full rates) were Amistar (azoxystrobin), Amistar Top (azoxystrobin + difenoconazole), Dithane 945 (mancozeb), Olympus (azoxystrobin + chlorothalonil), Plover (difenoconazole), Signum (boscalid + pyraclostrobin) and Switch (cyprodinil + fludioxonil). Following artificial inoculation, disease development occurred gradually on all plant parts; at 21 days after inoculation, mean severity scores for fungicide treatments and the untreated control were very low (less than 10 lesions). Because of the low disease levels present it was not possible to clearly discern fungicide treatment and timing effects on disease development. None of the fungicide treatments tested had phytotoxic effects on the plants during this experiment.

Development of Stemphylium purple spot

Development of Stemphylium purple spot symptoms was monitored at two commercial sites in 2009. At Warwicks, where infested debris was abundant on the soil surface, the disease commenced from stem bases (Figure 1). Although all plant parts were subsequently affected, stem bases remained most severely affected through the season. This pattern of symptom development was consistent with a series of primary infections being initiated from ascospores of *P. herbarum* released from fruiting bodies (pseudothecia) on asparagus debris. At Norfolk, infested debris was less abundant on the soil surface and disease severity remained lower throughout the season. Symptoms were also first observed at stem bases but were subsequently more prevalent on mid-stems and secondary branches, indicative of secondary spread of the disease via conidia of *S. vesicarium*, either from stem base lesions or incoming from neighbouring asparagus crops.

Figure 1. Lesions of Stemphylium purple spot on the stem base of asparagus fern.

Evaluation of fungicide programmes

A field experiment was conducted in 2009 at two commercial asparagus holdings on fields with a history of Stemphylium purple spot. The aim of the experiment was to determine the effect of fungicide programmes on the severity of Stemphylium during the fern production season using currently approved fungicides (Table 1). The effect of fungicide programmes on subsequent root carbohydrate levels was also determined by measurement of Brix% values in roots collected at crown dormancy and through use of the ***AspireUK*** decision support system.

Table 1. Fungicide spray programmes for asparagus Stemphylium at two sites, 2009

Programmes		Spray 1	Spray 2	Spray 3	Spray 4	Spray 5	Spray 6
	Spray dates:						
	Warwicks	3 Jul	16 Jul	3 Aug	18 Aug	7 Sep	21 Sep
	Norfolk	22 Jun	3 Jul	20 Jul	3 Aug	17 Aug	31 Aug
1	Untreated	-	-	-	-	-	-
2	AT/A/P/D/P/A	Amistar Top	Amistar	Plover	Dithane 945	Plover	Amistar
3	AT/S/P/D/P/S	Amistar Top	Signum	Plover	Dithane 945	Plover	Signum
4	AT/Sw/P/Sw/P/Sw	Amistar Top	Switch	Plover	Switch	Plover	Switch
5	A/P/D/P/A/-	Amistar	Plover	Dithane 945	Plover	Amistar	-
6	S/P/D/P/S/-	Signum	Plover	Dithane 945	Plover	Signum	-
7	-/A/P/D/P/S	-	Amistar	Plover	Dithane 945	Plover	Amistar
8	-/S/P/D/P/S	-	Signum	Plover	Dithane 945	Plover	Signum

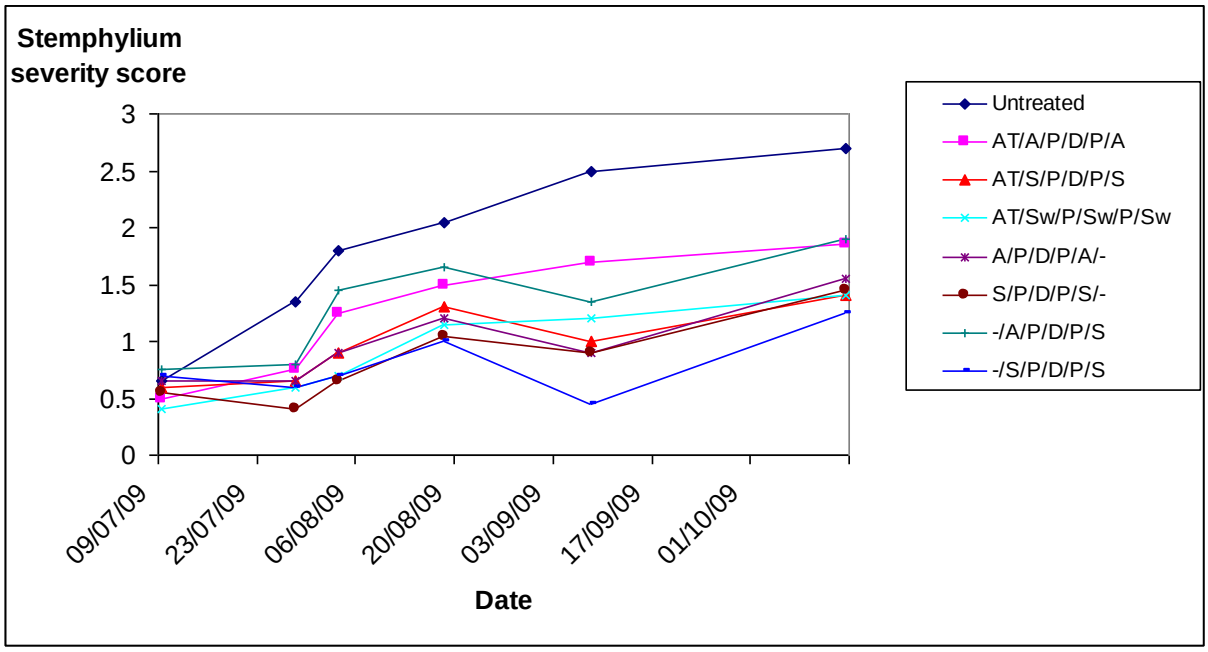
Rates:

Product	Active ingredient	Product rate/ha	Approval
Amistar	Azoxystrobin	1.0 L	On-label
Amistar Top	Azoxystrobin + difenoconazole	1.0 L	SOLA 0831/07
Dithane 945	Mancozeb	2.0 kg	SOLA 0381/06
Plover	Difenoconazole	0.5 L	SOLA 0158/05
Signum	Boscalid + pyraclostrobin	1.5 kg	SOLA 0262/08
Switch	Cyprodinil + fludioxonil	1.0 kg	SOLA 0235/07

The experiment demonstrated that under high disease pressure, there is scope for reducing the incidence and severity of Stemphylium purple spot using fungicide programmes. While there was no individual programme that performed considerably better than others, Treatment 8 (Signum / Plover / Dithane 945 / Plover / Signum, at 2-3 weeks intervals) was the most consistent (Figure 2). At the Warwicks site, this fungicide programme reduced disease incidence (Table 2) and severity, reduced % dead stems in early November, and resulted in higher root carbohydrate levels (Table 3). In addition, following this treatment, there was a trend for lower disease incidence at Norfolk (data not shown) and higher Brix% values (both sites, Table 3). Outputs from ***AspireUK*** regarding root carbohydrate (CHO) levels for treatments tested are shown below in Table 3. The fact that the most effective

programme comprised five rather than six applications (commencing around 5 weeks after close of harvest) indicates that timing of appropriate products is likely to be more important for effective control than numbers of applications.

Overall, programmes that performed well were treatments 3, 4, 6 and 8. Treatments 3, 6 and 8 each included two applications of Signum alternating with difenoconazole products, and use of Dithane 945 as a protectant mid-season. Equivalent programmes using Amistar in place of Signum were less effective, suggesting that Signum may be a stronger product for control of Stemphylium purple spot on asparagus. There were also some good results obtained with treatment 4, commencing with Amistar Top, then alternating Switch with Plover, although this programme did not contribute to delayed senescence as effectively as programmes that contained two or three strobilurin products and finished with a strobilurin.



Severity score: 0 = no symptoms, 1 = 1-10 lesions, 2 = 11-100 lesions, 3 = >100 lesions

Key:

A	Amistar
AT	Amistar Top
D	Dithane 945
P	Plover
S	Signum
Sw	Switch

Figure 2. Effect of fungicide programmes on the development of Stemphylium purple spot on asparagus stem bases (Warwicks, 2009).

Table 2. Effect of fungicide programmes on the incidence of Stemphylium purple spot on different parts of asparagus fern (18 August 2009, Warwicks)

	Fungicide programme	% incidence Stemphylium purple spot									
		Base stem		Mid stem		Top stem		Secondary branches		Tertiary branches / needles	
1	Untreated control	95	(4.1)	95	(6.0)	65	(15.0)	35	(11.6)	40	(9.6)
2	AT / A / P / D / P / A	100	(-)	85	(9.6)	65	(15.0)	40	(11.9)	25	(8.5)
3	AT / S / P / D / P / S	95	(4.1)	**55**	(12.3)	30	(14.4)	20	(9.7)	**5**	(4.3)
4	AT / Sw / P / Sw / P / Sw	90	(5.5)	60	(12.3)	20	(12.7)	10	(7.3)	**5**	(4.3)
5	A / P / D / P / A / -	85	(6.4)	85	(9.6)	25	(13.7)	30	(11.1)	15	(7.0)
6	S / P / D / P / S / -	85	(6.4)	**45**	(12.0)	**10**	(9.6)	15	(8.7)	**0**	(-)
7	- / A / P / D / P / S	100	(-)	95	(6.0)	75	(13.7)	40	(11.9)	35	(9.4)
8	- / S / P / D / P / S	**70**	(7.9)	**55**	(12.3)	20	(12.7)	10	(7.3)	**0**	(-)

Values in bold are significantly less than the untreated control at P<0.05

Table 3. Effect of treatments on Brix% values from asparagus roots at dormancy (winter 2009/2010) at two sites

	Fungicide programme	Mean Brix% value*		Root CHO content mg/g**	
		Warwicks	Norfolk	Warwicks	Norfolk
1	Untreated control	18.5	18.3	489 (450-550)	478 (450-550)
3	AT / S / P / D / P / S	19.8	-	534 (450-550)	-
4	AT / Sw / P / Sw / P / Sw	18.3	-	468 (450-550)	-
6	S / P / D / P / S / -	21.0	-	542 (450-550)	-
8	- / S / P / D / P / S	23.3	20.4	591 (550-750)	519 (450-550)

*Mean of five plants per plot, from four plots
**Determined using *AspireUK*; actual CHO content shown, with ranges for that category in parentheses
Carbohydrate analysis was done only on treatments that significantly reduced Stemphylium compared with the untreated control.

Extract from ***AspireUK*** output for Warwicks (treatments 1, 3, 4 and 6) and Norfolk (treatments 1 and 8):

> Root CHO content is satisfactory, but not as high as it could be by the end of the season. Values in this range, especially at the low end, indicate good but incomplete replenishment of CHO reserves in the roots during fern growth.

Extract from ***AspireUK*** output from Warwicks treatment 8:

> The root system is full of CHO, as it should be by the end of the season. The high CHO content means that a good harvest is likely next year, especially if the crop has a large root system. CHO content is seldom much greater than 550 mg/g in established crops with large root systems. This occurs when they have been well managed during the past year, with optimised spear harvest followed by healthy, active fern growth.

Values above 600 mg/g are more likely in crops with small root systems. However, even though these systems are about as full of CHO as they can get, spear yield can be limited by lack of total available CHO. This usually occurs in either (a) young establishing crops with small but expanding systems or (b) older crops with declining systems, indicated by a high proportion of dead roots. A high CHO level is a positive indicator for young crops because it shows that the root system is full, although it is still small and expanding. On the other hand, a high CHO content in older crops indicates that yield may be limited by the declining size of the root system.

Monitoring of leaf wetness and temperature

Research in Michigan State, USA and France has shown that use of a simple programme (Tom-Cast) can help to minimise sprays for Stemphylium control without compromising fern health, because sprays are only applied when environmental conditions are high risk for disease development. This system is being used on 75% of the asparagus tonneage in Michigan State. Experimental work is required to determine appropriate thresholds for spray timing in the UK, since results from France and the USA vary in this respect.

In the Tom-Cast programme, leaf wetness duration and the average temperature during wetness periods are used to derive Disease Severity Values (DSVs) and associated thresholds from which spray timing is determined. Researchers in Michigan State showed that fungicides applied according to Tom-Cast (DSV=15), resulted in a reduction in sprays compared with 7, 10 and 14-day programmes. Moreover, applying fungicides according to Tom-Cast or every 7 days resulted in significantly reduced lesion severity compared with 10 and 14 day programmes.

In this experiment, leaf wetness and temperatures were monitored using a sensor (SpectrumTechnologies) at two commercial sites during fern production in 2008 and 2009. Examination of the data using the Tom-Cast model established the number of sprays that would have been triggered at each site, based on different DSV thresholds. DSVs of 5 and 7 gave spray numbers comparable to commercial programmes although at different timings to grower applications. DSVs of 10 or higher would have triggered fewer sprays than commercial programmes at both sites / seasons. A field trial in 2010 will compare disease development following spray programmes based on DSVs of 5, 7 and 10. A further consideration will be whether a fungicide application soon after close of harvest to young fern could provide useful protection particularly in situations where infested debris on the soil surface is present as a primary source of inoculum.

Financial benefits

Financial losses due to Stemphylium have not been quantified in the UK but it is well known that fern damage in one season can have a deleterious effect on spear yield in subsequent seasons. Financial losses can also occur due to application of unnecessary fungicides when conditions are low risk for disease development. The expected benefit to the industry is a set of guidelines that will enable effective management of Stemphylium on asparagus with minimum fungicide usage.

Action points for growers

- Read HDC Factsheet 18/07 to be aware of Stemphylium symptoms, the disease cycle and high risk conditions for disease development.
- Be aware that Stemphylium survives on asparagus debris between seasons. Infested debris on the soil surface is an important source of the disease. Ridging-up so that debris is covered can help to reduce this risk.
- Note that premature defoliation due to Stemphylium can lead to decreased carbohydrate transfer to roots with subsequent effect on yields in subsequent seasons.
- When using fungicides for Stemphylium control, be aware of FRAG guidelines (see www.pesticides.gov.uk) and manufacturer's guidelines for minimising risk of developing fungicide resistance risk through over-use of strobilurin products.

Science Section

Introduction

Stemphylium purple spot on asparagus spears and ferns is caused by the fungus *Stemphylium vesicarium* (perfect stage: *Pleospora herbarum*). Purple lesions can occur on spears during the harvest season but mainly develop on the asparagus ferns, affecting the needles, secondary branches and main stems. Severe infection often results in premature defoliation. Results from the validation of the ***Aspire*** decision support system in New Zealand and recently in the UK (HDC project FV 271) have indicated that poor management of Stemphylium in summer/autumn can have a deleterious effect on the transfer of carbohydrates from fern to roots, with the potential to significantly reduce yields in subsequent seasons. Survival structures of the fungus can overwinter on fern debris and this is often the main source of the disease during the following harvest season. The aetiology and epidemiology of *S. vesicarium* on asparagus is described by several authors. For example, Hausbeck *et al*. (1999) and Falloon *et al*. (1987) identified high risk environmental conditions for disease development. Falloon *et al.* (1987) also developed methods for artificial inoculation of asparagus using either a spore suspension of *S. vesicarium* or infected fern debris.

Despite the availability of suitable fungicides, UK growers still report Stemphylium outbreaks. The sporadic nature of the disease means that it may not be cost effective to use a prophylactic spray programme. However, disease development can occur rapidly and control may be lost when the timing of specific fungicide applications is not optimised in relation to infection events. A range of fungicidal active ingredients currently have approval for use on asparagus as specific off-label approvals (SOLAs) and on-label approvals. Products such as Amistar (azoxystrobin), Plover (difenoconazole), Amistar Top (azoxystrobin + difenoconazole) and Dithane 945 (mancozeb) may be effective against Stemphylium, when applications are appropriately timed. Switch (fludioxonil + cyprodinil) and Signum (boscalid + pyraclostrobin) also recently received SOLAs for use on asparagus, while Olympus (azoxystrobin + chlorothalonil) now has on-label approval.

Research in Michigan State, USA and France has shown that use of a simple programme (Tom-Cast) can help to minimise sprays for Stemphylium control without compromising fern health, because sprays are only applied when environmental conditions are high risk for disease development (Meyer *et al*., 2000; Poissonier, 2005). This system is being used on 75% of the asparagus tonneage in Michigan State. Experimental work is required to

determine appropriate thresholds for spray timing in the UK, since results from France and the USA vary in this respect.

Previous research to control *Leptosphaeria maculans* on oilseed rape showed that treatment of stubble with products such as urea and certain adjuvants could reduce inoculum survival between seasons (Humpherson-Jones & Burchill, 1982; Wherrett *et al.,* 2003). A similar approach could be evaluated to reduce survival of Stemphylium on asparagus crop debris between seasons. Burial of crop debris, e.g. by ridging up, is also known to reduce Stemphylium severity by preventing ascospore release.

Experimental work is needed to develop integrated strategies for the management of Stemphylium on asparagus in the UK. Experiments done in project year 2 aimed to:

1. Determine the efficacy of approved fungicides for control of asparagus Stemphylium in inoculated pot experiments.
2. Determine the effect of fungicide programmes on development of asparagus Stemphylium and subsequent root carbohydrate levels in a field experiment at two sites.
3. Monitor leaf wetness / temperature at two commercial sites to provide the basis for setting thresholds in Tom-Cast.

Efficacy of fungicides for Stemphylium control in an inoculated pot experiment

Introduction

The aim was to determine the efficacy of single fungicides applied at different timings in relation to infection, on the control of Stemphylium purple spot on asparagus. The experiment followed on from a similar trial conducted in 2008, but with modified inoculation methods.

Materials and methods

The experiment was sited on a hard-standing area at ADAS Boxworth, Cambridgeshire, comprising a two-way factorial design with four plants per plot and four replicate blocks. There were seven fungicide treatments and a water only control, applied at two different timings, to give a total of 16 treatments and 64 plots. A plot comprised four asparagus plants, artificially inoculated with *Stemphylium vesicarium*. Data for disease incidence (proportion of plants per plot with symptoms) and disease severity scores were analysed using Generalised Linear Models in Genstat.

The plants were from Grade B crowns of the variety Gijnlim (small size 40-70 g) planted in 10 L pots in April 2008 (see Year 1 Annual Report). Slug pellets were applied as necessary in 2008 and 2009 to prevent slug damage to emerging ferns. The pots were placed on a hard standing area within rabbit fencing and wind breaks, and overhead watered by hand as necessary to maintain moist but not waterlogged compost. In 2009, the experiment was laid out on 17 August, using pots with uniform fern growth. Irrigation pipes with evenly spaced upright misters/sprinklers were positioned along the length of the trial, between blocks 1 and 2, and between blocks 3 and 4.

The method of artificial inoculation used was as follows: Sporulating cultures (approx. 200) of *S. vesicarium* were prepared on V8 agar by sub-culturing from previously prepared pure cultures (*ex* asparagus). V8 agar was prepared using 200 ml V8 juice mixed with 3 g calcium carbonate, 20 g agar and 800 ml distilled water. Plates were incubated for approximately 2 weeks at 20^{o}C in the dark before use. On the day of inoculation (14 September 2009), a spore suspension (containing 0.1% Tween 80) was prepared from the cultures (1 x 10^5 spores/ml in 45 L). The inoculum was applied to all plants evenly to the point of run-off using a hand-held sprayer. In addition to the spore suspension, dried asparagus debris (with visible structures of the overwintering stages of Stemphylium) remaining from the previous season were present on each pot surface. The asparagus foliage and debris were kept wet for 72 hours after inoculation by covering the asparagus plants with a polythene 'tent' followed by frequent mist irrigation.

Fungicides were applied 3 days before or 3 days after inoculation (depending on treatment) using a single nozzle, at 2 Bar pressure, in 1000 L water/ha (100 ml/m^2) with a spray guard to prevent spray drift between plots (Table 1).

Table 1. Fungicides applied to asparagus in pots 3 days before or 3 days after inoculation with *Stemphylium vesicarium*, ADAS Boxworth 2009

	Product	Active ingredient(s)	Rate/ha	Approval
1	Water only	-	-	-
2	Amistar	Azoxystrobin	1.0 L	On-label
3	Amistar Top	Azoxystrobin + difenoconazole	1.0 L	SOLA 0831/07
4	Dithane 945	Mancozeb	2.0 kg	SOLA 0381/06
5	Olympus	Azoxystrobin + chlorothalonil	2.5 L	On-label
6	Plover	Difenoconazole	0.5 L	SOLA 0158/05
7	Signum	Boscalid + pyraclostrobin	1.5 kg	SOLA 0262/08
8	Switch	Cyprodinil + fludioxonil	1.0 kg	SOLA 0235/07

The plants were assessed 7 days, 14 days, 21 days and 28 days after inoculation. At each assessment time, disease severity was estimated for the following parts of each plant: main stems (base, middle and top), secondary branches, and tertiary branches/cladophylls using the scale:

0 = no symptoms
1 = 1-10 lesions
2 = 11-100 lesions
3 = >100 lesions
4 = Lesions merging, defoliation and yellowing due to Stemphylium.

In addition, plants were checked for symptoms of phytotoxicity or evidence of growth benefits.

Results and discussion

At the time of experiment layout (prior to artificial inoculation) there was a trace of disease present due to natural infection, with symptoms of Stemphylium purple spot observed at stem bases (severity not exceeding score = 1). Following artificial inoculation, disease development occurred gradually on all plant parts but at 21 days after inoculation, mean severity scores for fungicide treatments still did not exceed score = 1 (Table 2). Because of the low disease levels present it was not possible to clearly discern fungicide treatment and timing effects on disease development.

None of the fungicide treatments tested had either beneficial or phytotoxic effects on the plants during this experiment. Since the number of treatments was limited to one application per plot early in the fern development season, there was no apparent effect on length of green fern retention later in the season.

A different experimental approach is planned for year 3 in order to get clearer data on the efficacy of fungicide treatments when applied at different timings in relation to infection events. To test protectant activity, spray treatments will be applied to asparagus plants before detaching fern pieces at different intervals after spraying, for artificial inoculation and incubation under controlled environment conditions. To test curative activity, detached fern pieces will be inoculated, then sprayed at fixed intervals after inoculation.

Table 2. Mean Stemphylium severity scores on asparagus (averaged across timings), 21 days after inoculation

Fungicide	Main stem			2^o branches	3^o branches /needles
	Base	Mid	Top		
Water only	0.63	0.25	0.06	0.19	0.13
Amistar	0.88	0.13	0.06	0.31	0.03
Amistar Top	0.81	0.28	0.06	0.25	0.09
Dithane 945	0.75	0.12	0.00	0.19	0.06
Olympus	0.81	0.25	0.25	0.25	0.06
Plover	0.63	0.06	0.00	0.16	0.00
Signum	0.69	0.13	0.06	0.19	0.06
Switch	0.88	0.16	0.03	0.28	0.13

Severity score: 0 = no symptoms, 1 = 1-10 lesions, 2 = 11-100 lesions, 3 = >100 lesions, 4 = Lesions merging, defoliation and yellowing due to Stemphylium.

Effect of fungicide programmes on asparagus Stemphylium and root carbohydrate levels

Introduction

A field experiment was conducted at two commercial asparagus holdings on fields with a history of Stemphylium purple spot. The aim of the experiment was to determine the effect of fungicide programmes on the severity of Stemphylium during the fern production season, (using currently approved fungicides) and on subsequent root carbohydrate levels during dormancy.

Comprehensive spear yield data is costly to collect and can be inconclusive due to variability. Therefore, in this experiment, root carbohydrate levels at crown dormancy were used rather than spear yields in the subsequent season, to determine the effect of fungicide programmes during fern production on overall crop performance. Results from the validation of the ***Aspire*** decision support system in New Zealand and the UK (HDC project FV 271), and from year 1 project results, have demonstrated that poor management of Stemphylium in summer/autumn may have a deleterious effect on the transfer of carbohydrates from fern to roots, potentially reducing yields in subsequent seasons. The effect of fungicide programmes and related levels of fern Stemphylium on subsequent root carbohydrate (CHO) levels was determined by measuring Brix% readings for selected treatments during crown dormancy. The study also made use of the ***AspireUK*** decision support system, developed in HDC project FV 271 (www.aspireuk.org). ***AspireUK*** estimates root system CHO content by assessing measurements of the Brix% of sap solution extracted from storage roots sampled from a crop. Recommendations for treated and untreated plots at the two sites were compared by entering Brix% data into the ***AspireUK*** decision support system.

Materials and methods

The experiment was set-up in a young established crop in Warwickshire (site 1; planted 2006) and in an older established asparagus crop in Norfolk (site 2; planted 2003). These sites were used previously for Stemphylium monitoring in 2008 (year 1 report).

The experiment comprised a randomised complete block design with eight treatments and four replicate blocks. A plot comprised 3 rows at 1.6 m spacing (Warwicks) and1.83 m spacing (Norfolk). Plot length was 5 m. Plant assessments were done on the central 3 m of the middle row. At Warwicks, the trial took up 6 rows plus a guard row either side of a wheeling (to fit within tractor spray boom width), with the central row in the wheeling as a discard. At Norfolk the trial took up 6 rows either side of a wheeling (to fit within tractor spray boom width), with the central row in the wheeling as a discard.

There were seven fungicide spray programmes and an untreated control (Table 3). Products included in the programmes were all approved for use on asparagus and were used within their label restrictions. The proportion of strobilurin product applications did not exceed 50% within any of the programmes, to minimize the risk of developing fungicide resistance. The fungicide programmes comprised either six fungicide applications spread over the fern production season (comparable to a grower programme), or five sprays commencing and finishing early, or five sprays commencing and finishing later. Close of harvest was on 11 June at Warwicks and 14 June at Norfolk. The spray programmes commenced in late June/early July with the last spray in late Aug/mid September (2-3 week intervals). Fungicides were applied using a 1.5 m spray boom (3 m for Norfolk, with outer nozzles blanked off) with F110-03 nozzles (fine/medium spray quality) at 2 bar pressure. At Warwicks, sprays were applied in 200 L water/ha; at Norfolk, spray volume was increased to 300 L/ha after an initial spray using 200 L water/ha.

Table 3. Fungicide spray programmes for asparagus Stemphylium at two sites, 2009

		Spray 1	Spray 2	Spray 3	Spray 4	Spray 5	Spray 6
	Spray dates:						
	Warwicks	3 Jul	16 Jul	3 Aug	18 Aug	7 Sep	21 Sep
	Norfolk	22 Jun	3 Jul	20 Jul	3 Aug	17 Aug	31 Aug
1	Untreated	-	-	-	-	-	-
2	AT/A/P/D/P/A	Amistar Top	Amistar	Plover	Dithane 945	Plover	Amistar
3	AT/S/P/D/P/S	Amistar Top	Signum	Plover	Dithane 945	Plover	Signum
4	AT/Sw/P/Sw/P/Sw	Amistar Top	Switch	Plover	Switch	Plover	Switch
5	A/P/D/P/A/-	Amistar	Plover	Dithane 945	Plover	Amistar	-
6	S/P/D/P/S/-	Signum	Plover	Dithane 945	Plover	Signum	-
7	-/A/P/D/P/S	-	Amistar	Plover	Dithane 945	Plover	Amistar
8	-/S/P/D/P/S	-	Signum	Plover	Dithane 945	Plover	Signum

Rates:

Product	Active ingredient	Product rate/ha	Approval
Amistar	Azoxystrobin	1.0 L	On-label
Amistar Top	Azoxystrobin + difenoconazole	1.0 L	SOLA 0831/07
Dithane 945	Mancozeb	2.0 kg	SOLA 0381/06
Plover	Difenoconazole	0.5 L	SOLA 0158/05
Signum	Boscalid + pyraclostrobin	1.5 kg	SOLA 0262/08
Switch	Cyprodinil + fludioxonil	1.0 kg	SOLA 0235/07

At each site, the crop was maintained by the host grower according to commercial practice, except that fungicide applications being applied to the field crop were excluded from the trial areas. Leaf wetness and temperature data for the duration of fern growth (June/July to October) were collected using a leaf wetness/temperature sensor (Spectrum Technologies) placed adjacent to the experimental area (see following experiment for details).

The severity of Stemphylium was assessed on seven occasions at both sites. At each assessment, five plants were selected at random from the central row of the plot. For each plant, the main stems (base, middle and top), secondary branches and tertiary branches/cladophylls (needles) were assessed for Stemphylium severity using the following scale:

0 = no symptoms
1 = 1-10 lesions
2 = 11-100 lesions
3 = >100 lesions
4 = Lesions merging, defoliation and yellowing due to Stemphylium.
5 = Foliage completely brown.

At Warwicks, where treatment differences were apparent late in the season, but difficult to discern using disease severity data, the overall health of plots was determined by i) an estimate of crop vigour (score of 1-9 where 1 indicates poor vigour) on two occasions in September, and ii) a count of dead stems (completely brown with no green or yellow tissue remaining) as a percentage of the total number of stems per plot, assessed once in October and once in November.

In addition to disease severity, plants were checked for symptoms of phytotoxicity (e.g. scorch).

Root sampling was done in December 2009 (Warwicks) and January 2010 (Norfolk) after fern senescence and at crown dormancy for selected treatments at each site. For each site, samples were collected from five locations in the central row of each plot, avoiding row ends. A spade was used to make a vertical cut about 30 cm deep into the soil, through the roots, just outside the crown area. Then a second vertical cut was made parallel to the first one, about 15-20 cm further away from the crown. The roots (10-15 cm lengths) from between the two cuts were lifted and removed, discarding any hollow asparagus roots or roots from other plants such as weeds. The roots were placed in a sealable plastic bag (labelled with site name and treatment), stored in a cool box with ice packs, and refrigerated on return to the laboratory.

The roots were prepared for Brix% measurements within 1 day of collection. The five samples from each plot were kept separate from each other throughout the procedure. The roots were washed in lukewarm tap water to remove soil and then excess water removed by laying on paper towel. Roots were then replaced in the plastic bag after it was rinsed out, then placed in a freezer. To sample for Brix%, the roots were removed from the freezer and laid on paper towel until thawed completely (free of surface moisture) but not dehydrated. The following procedure from HDC Project FV 271 was followed:

- Check that the refractometer (0-32% Brix, temperature-adjusted) reads zero with a few drops of distilled water. If not, give it time to reach room temperature (ideally about 20^{o}C). It may be necessary to adjust it to zero (see the refractometer manual).
- Cut the roots into 1-2 cm lengths with scissors.
- Place the pieces in the garlic crusher and squeeze the solution into a plastic beaker.
- Swirl the solution around until it is mixed thoroughly.
- Use the teaspoon to place about three drops onto the prism surface of the refractometer.
- Drop the cover over the juice, avoiding bubble formation.
- Read the Brix% on the refractometer scale and record the result.
- Wipe the prism surface clean with tissues between samples. The refractometer cannot be immersed in water.
- Clean the garlic crusher and plastic beakers thoroughly between samples. Rinse in water and dry carefully. Any water left on the equipment will affect subsequent readings.

Data for disease incidence (proportion of plants per plot with symptoms) and the proportion of plants with different levels of Stemphylium severity (score 2 or more) were analysed by generalised linear models in Genstat. Brix% readings from selected treatments at each site were compared statistically using ANOVA in Genstat. In addition the readings for each

treatment were entered into ***AspireUK*** to obtain root carbohydrate (CHO) values and interpretations on crop health.

Results and discussion

There were no symptoms of phytotoxicity due to fungicide programmes at either site.

At Warwicks, Stemphylium purple spot was already present at a low level on stem bases at the first disease assessment (9 July) approximately 4 weeks after the close of harvest. The severity of Stemphylium increased on all plant parts during the fern production season but stem bases were the worst affected throughout, followed by mid-stems (Figure 1). Increases in disease incidence over the season showed a similar trend (data not shown). This pattern of symptom development on asparagus plants was in agreement with data from project year 1 and is consistent with infection being initiated from ascospores of *P. herbarum* released from fruiting bodies (pseudothecia) on asparagus debris. Infested debris remaining on the soil surface was abundant at the Warwicks site.

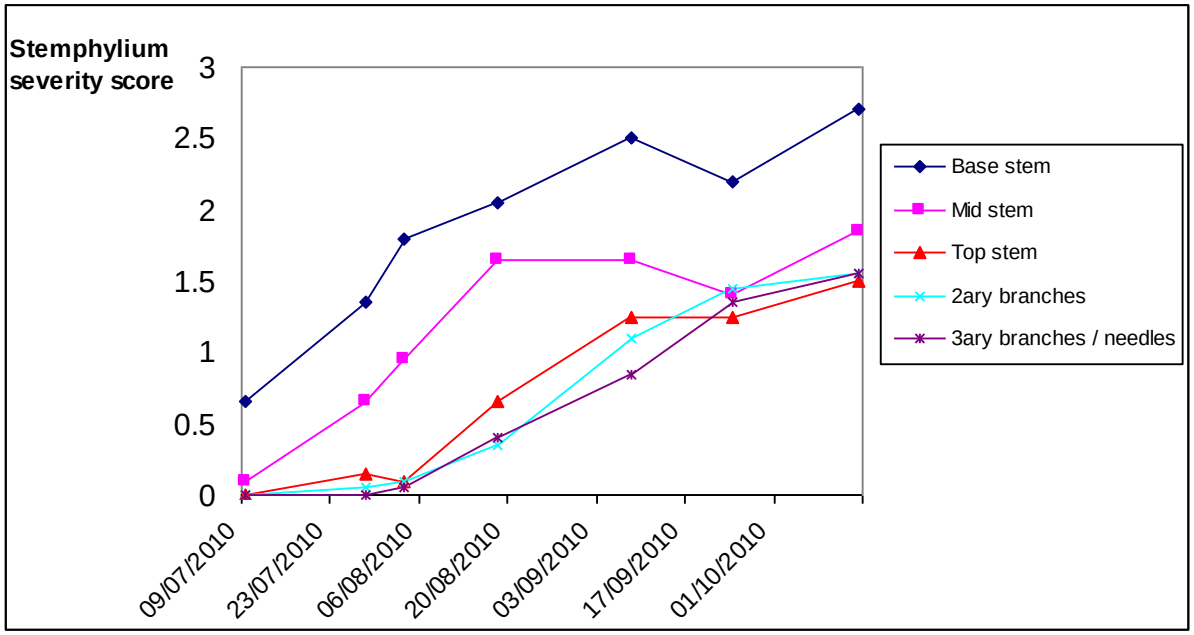
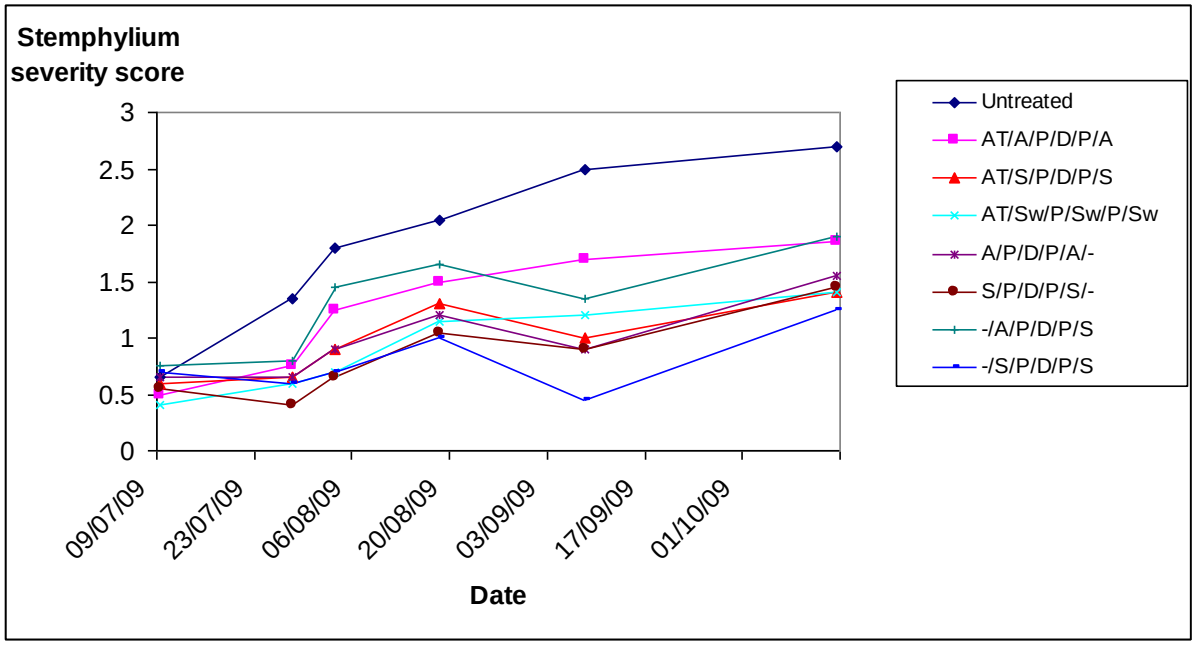


Figure 1. Development of Stemphylium purple spot on different asparagus plant parts (untreated plots), Warwicks 2009.



Key:

A	Amistar
AT	Amistar Top
D	Dithane 945
P	Plover
S	Signum
Sw	Switch

Figure 2. Effect of fungicide programmes on the development of Stemphylium purple spot on asparagus stem bases (Warwicks, 2009).

The effect of fungicide programmes on the development of Stemphylium purple spot on stem bases over time is shown in Figure 2. The disease progress curves suggest that by the end of the season, disease severity scores were reduced by the various fungicide programmes compared with the untreated control. This was analysed in more detail by determining treatment effects on i) disease incidence on 18 August after three fungicide sprays (two for treatments 7 and 8) had been applied, and on ii) disease severity on 14 October (as determined by the proportion of plants with a severity score of 2 or more) after the fungicide programme was completed.

In mid-August, treatment 8 significantly reduced the incidence of Stemphylium on stem bases, mid stems and tertiary branches/needles, despite only two fungicide applications at this stage (Table 4). Treatment 6 reduced disease incidence on mid stems, top stems and tertiary branches/needles. Treatment 3 reduced Stemphylium on mid stems and treatment 4 reduced Stemphylium on tertiary branches/needles. All of these programmes (except treatment 4) included Signum at an early stage in the programme. There were no significant

effects of the other programmes (treatments 2, 5 and 7) on the incidence of Stemphylium on different plant parts at this stage in the season.

At the end of the season, all of the fungicide programmes had significantly reduced the severity of Stemphylium on at least one plant part, compared with the untreated control (Table 5). For example treatments 3 and 6 were effective in reducing Stemphylium severity on stem bases, mid stems, top stems as well as tertiary branches / needles.

Table 4. Effect of fungicide programmes on the incidence of Stemphylium purple spot on different parts of asparagus fern (18 August 2009, Warwicks)

	Fungicide programme	% incidence Stemphylium purple spot									
		Base stem		Mid stem		Top stem		2ary branches		3ary branches / needles	
1	Untreated control	95	(4.1)	95	(6.0)	65	(15.0)	35	(11.6)	40	(9.6)
2	AT / A / P / D / P / A	100	(-)	85	(9.6)	65	(15.0)	40	(11.9)	25	(8.5)
3	AT / S / P / D / P / S	95	(4.1)	**55**	(12.3)	30	(14.4)	20	(9.7)	**5**	(4.3)
4	AT / Sw / P / Sw / P / Sw	90	(5.5)	60	(12.3)	20	(12.7)	10	(7.3)	**5**	(4.3)
5	A / P / D / P / A / -	85	(6.4)	85	(9.6)	25	(13.7)	30	(11.1)	15	(7.0)
6	S / P / D / P / S / -	85	(6.4)	**45**	(12.0)	**10**	(9.6)	15	(8.7)	**0**	(-)
7	- / A / P / D / P / S	100	(-)	95	(6.0)	75	(13.7)	40	(11.9)	35	(9.4)
8	- / S / P / D / P / S	**70**	(7.9)	**55**	(12.3)	20	(12.7)	10	(7.3)	**0**	(-)
	F. probability	0.012		0.018		0.031		NS (0.207)		<0.001	
	D.f.	31		31		31		31		31	

Standard errors in parentheses. Values in bold are significantly less than the untreated control at P<0.05.

Table 5. Effect of fungicide programmes on the severity of Stemphylium purple spot on different parts of asparagus fern (14 October 2009, Warwicks)

	Fungicide programme	% plants with Stemphylium purple spot severity ≥ score 2*									
		Base stem		Mid stem		Top stem		2ary branches		3ary branches / needles	
1	Untreated control	85	(7.1)	65	(13.2)	30	(6.3)	25	(9.2)	65	(10.6)
2	AT / A / P / D / P / A	75	(8.5)	**10**	(8.4)	**5**	(3.7)	15	(8.3)	**10**	(7.1)
3	AT / S / P / D / P / S	**50**	(9.7)	**10**	(8.4)	**5**	(3.7)	10	(7.3)	**5**	(5.3)
4	AT / Sw / P / Sw / P / Sw	**45**	(9.7)	**10**	(8.4)	0	(-)	20	(8.9)	**5**	(5.3)
5	A / P / D / P / A / -	**45**	(9.7)	30	(12.3)	15	(5.5)	40	(9.1)	**15**	(8.1)
6	S / P / D / P / S / -	**40**	(9.6)	**10**	(8.4)	**5**	(3.7)	20	(8.9)	**15**	(8.1)
7	- / A / P / D / P / S	55	(9.6)	35	(12.7)	15	(5.5)	35	(9.2)	**25**	(9.4)
8	- / S / P / D / P / S	**30**	(9.1)	25	(11.6)	10	(4.8)	35	(9.2)	**5**	(5.3)
	F. probability	0.009		0.046		0.010		Ns (0.282)		0.004	
	D.f.	31		31		31		31		31	

Standard errors in parentheses. Values in bold are significantly less than the untreated control at P<0.05
Severity score 2 indicates 11-100 lesions

There was no significant effect of fungicide programme on crop vigour assessed in mid and late September (Table 6), although there was a trend for lower vigour in the untreated control plots. There was a significant block effect at both dates indicating lower vigour in block 1, perhaps due to proximity to the field margin. Once fern had started senescing (5 November) all of the fungicide programmes except treatment 4 reduced the percentage of dead stems present, indicating delayed senescence in these treatments compared with the untreated control. Interestingly treatment 4, which had no effect on dead stems, included only one strobilurin application (first product applied) compared with at least two strobilurins in other programmes, and was the only programme which did not finish with a strobilurin product. Evidence from a range of previous horticultural and arable trials has suggested the possible physiological effects of strobilurin fungicides including retention of green leaf area.

Table 6. Effect of fungicide programmes on crop vigour and the mean number of dead asparagus stems as a percentage of total stems, at two assessment dates (Warwicks, 2009)

	Fungicide programme	Mean crop vigour (1-9 score)		Mean % dead stems	
		14 Sep	24 Sep	14 Oct	5 Nov
1	Untreated control	5.6	5.5	27.7	77.5
2	AT / A / P / D / P / A	6.5	6.6	21.3	57.1
3	AT / S / P / D / P / S	6.9	6.8	20.3	42.2
4	AT / Sw / P / Sw / P / Sw	6.3	6.5	21.3	66.5
5	A / P / D / P / A / -	6.6	6.8	19.9	54.9
6	S / P / D / P / S / -	6.3	6.0	23.6	41.3
7	- / A / P / D / P / S	6.3	6.4	23.6	58.8
8	- / S / P / D / P / S	6.3	6.5	19.4	47.8
	F. Probability	0.317	0.130	0.730	0.005
	Df	21	21	21	21
	SED	Ns (0.33)	Ns (0.45)	Ns (4.88)	8.53
	LSD	Ns (0.68)	Ns (0.93)	Ns (10.14)	17.73

At Norfolk, in contrast to results obtained in 2008 (both sites) and in 2009 at Warwicks, symptoms of Stemphylium were most prevalent on the mid stems and secondary branches of the ferns rather than stem bases (Table 7). While lesion development at stem bases is typical of primary infection from ascospores released from infested debris, symptoms higher up the plant on mid stems and secondary branches are more indicative of secondary spread (via conidia) either from stem base lesions or incoming from neighbouring asparagus crops.

Table 7. Development of Stemphylium purple spot on different parts of asparagus during fern production (Norfolk, 2009)

	% stemphylium incidence				
Date	Base	Mid stem	Top stem	2ary branches	3ary branches / needles
04-Aug	45	75	15	40	25
07-Sep	15	80	0	80	40
01-Oct	20	90	20	85	60

Disease severity at Norfolk was lower throughout the season than at Warwicks with little discernible difference between treatments, perhaps due to lower disease pressure (less infested debris on the soil surface). The effect of fungicide programmes on disease incidence was most pronounced on mid stems and secondary branches (Table 8). At the mid-season assessment (4 August), disease incidence was reduced significantly by treatments 3 and 4 compared with the untreated control. Subsequently there were no significant treatment effects, although there was a trend from other assessments for lower incidence with treatments 3, 4 and 8 (sometimes approaching significance at P<0.05). There were no significant differences in crop vigour (1st October) between treatments (data not shown).

Table 8. Effect of fungicide programmes on the incidence of Stemphylium purple spot on mid-stems and secondary branches at three assessment dates (Norfolk, 2009)

	Fungicide programme	% Incidence					
		4 Aug		7 Sept		1 Oct	
		Mid-stem	2ary Branches	Mid-stem	2ary branches	Mid-stem	2ary Branches
1	Untreated control	75 (10.1)	40 (12.0)	80 (12.9)	80 (10.7)	90 (8.7)	85 (10.6)
2	AT / A / P / D / P / A	70 (10.7)	55 (12.2)	70 (14.7)	60 (13.0)	75 (12.5)	65 (14.1)
3	AT / S / P / D / P / S	**25** (10.2)	10 (7.4)	50 (16.0)	45 (13.1)	40 (14.1)	60 (14.5)
4	AT / Sw / P / Sw / P / Sw	**30** (10.8)	25 (10.6)	50 (16.0)	40 (12.9)	40 (14.1)	45 (14.7)
5	A / P / D / P / A / -	60 (11.4)	20 (9.8)	45 (15.9)	50 (13.2)	70 (13.2)	90 (8.9)
6	S / P / D / P / S / -	40 (11.5)	30 (11.1)	65 (15.3)	50 (13.2)	75 (12.5)	70 (13.6)
7	- / A / P / D / P / S	55 (11.6)	30 (11.1)	65 (15.3)	75 (11.6)	85 (10.4)	85 (10.6)
8	- / S / P / D / P / S	35 (11.2)	15 (8.8)	35 (15.3)	20 (10.7)	45 (14.3)	45 (14.7)
	F. Probability	0.038	Ns (0.16)	Ns (0.52)	Ns (0.07)	Ns (0.07)	Ns (0.16)
	Df	31	31	31	31	31	31

Standard errors in parentheses. Values in bold are significantly less than the untreated control at P<0.05.

Root monitoring was done on treatments 1, 3, 4, 6 and 8, at Warwicks, to include example programmes that had performed better than the control, with respect to Stemphylium development. Treatment differences were less apparent at Norfolk, so root samples were taken from treatments 1 and 8 only.

There was no significant effect of fungicide programmes on Brix% measurements taken during dormancy, although there was a trend for higher values for programmes commencing with Signum (treatment 8 at both sites; treatment 6 at Warwicks) (Table 9). When Brix% data was entered into the ***AspireUK*** decision support system, the untreated controls and all of the programmes (except for treatment 8 at Warwicks) were categorised as having 'satisfactory' root CHO content (450-550 mg/g). The root CHO value for Treatment 8 at Warwicks (starting and ending with Signum, late) was in a higher category (550-750 mg/g), indicating a root system full of CHO. The root CHO value for Treatment 6 (starting and ending with Signum, early) was also close to being in this higher range. Interpretations from ***AspireUK*** are shown below.

Table 9. Effect of treatments on Brix% values from asparagus roots at dormancy (winter 2009/2010) at two sites

	Fungicide programme	Mean Brix% value*		Root CHO content mg/g**	
		Warwicks	Norfolk	Warwicks	Norfolk
1	Untreated control	18.5	18.3	489 (450-550)	478 (450-550)
3	AT / S / P / D / P / S	19.8	-	534 (450-550)	-
4	AT / Sw / P / Sw / P / Sw	18.3	-	468 (450-550)	-
6	S / P / D / P / S / -	21.0	-	542 (450-550)	-
8	- / S / P / D / P / S	23.3	20.4	591 (550-750)	519 (450-550)
	F. Probability	0.187	0.054		
	Df	15	6		
	SED	Ns (2.16)	Ns (0.84)		
	LSD	Ns (4.61)	Ns (2.05)		

*Mean of five plants per plot, from four plots.
**Determined using *AspireUK*; actual CHO content shown, with ranges for that category in parentheses.

Extract from ***AspireUK*** output for Warwicks (treatments 1, 3, 4 and 6) and Norfolk (treatments 1 and 8):

> Root CHO content is satisfactory, but not as high as it could be by the end of the season. Values in this range, especially at the low end, indicate good but incomplete replenishment of CHO reserves in the roots during fern growth.

Extract from ***AspireUK*** output from Warwicks treatment 8:

> The root system is full of CHO, as it should be by the end of the season. The high CHO content means that a good harvest is likely next year, especially if the crop has a large root system. CHO content is seldom much greater than 550 mg/g in established crops with large root systems. This occurs when they have been well

managed during the past year, with optimised spear harvest followed by healthy, active fern growth.

Values above 600 mg/g are more likely in crops with small root systems. However, even though these systems are about as full of CHO as they can get, spear yield can be limited by lack of total available CHO. This usually occurs in either (a) young establishing crops with small but expanding systems or (b) older crops with declining systems, indicated by a high proportion of dead roots. A high CHO level is a positive indicator for young crops because it shows that the root system is full, although it is still small and expanding. On the other hand, a high CHO content in older crops indicates that yield may be limited by the declining size of the root system.

Monitoring leaf wetness and temperature in relation to Stemphylium development

Introduction

The Tom-Cast model was derived from a forecasting system called FAST, originally developed for *Alternaria solani* on tomato (Madden *et al*., 1978). Hausbeck (2003) describes practical use of the Tom-Cast system and associated weather equipment for management of Stemphylium in asparagus crops. Meyer *et al*. (2000) evaluated the efficacy and economics of using Tom-Cast for aiding management of Stemphylium on asparagus in Michigan State, USA using different fungicide programmes. Poissonier (2005) described use of Tom-Cast to forecast the occurrence of Stemphylium on asparagus in France. He demonstrated that disease severity value (DSV) thresholds for first symptom expression and for first and subsequent fungicide applications could vary with production region. The objectives of this study were:

- To monitor leaf wetness durations and air temperature at two asparagus field sites over two fern growing seasons (June to October, 2008 and 2009).
- To process the leaf wetness and temperature data collected using the Tom-Cast model using a range of thresholds to determine when and how many fungicide applications would have been triggered by the model.
- To use data on leaf wetness, temperature, commercial and experimental fungicide applications and disease development (from 2008 and 2009) to set Tom-Cast thresholds to be tested in fungicide experiments next season.

Materials and methods

Leaf wetness/temperature sensors (Spectrum Technologies) were placed at two sites with a history of Stemphylium purple spot, in a young crop in Warwickshire (planted 2006) and in an established asparagus crop in Norfolk (planted 2003) soon after the close of harvest. The same field was used in each season, although at Warwicks the sensor was placed in a different area of the field in 2009. At each site, the sensor was placed at a 45^{o} angle, mounted on a pole, and facing north (so that it was not in direct sunlight). The mounted sensor was placed adjacent to the crop area to be monitored but not in contact with the fern or other vegetation, or where it was going to be knocked by passing machinery. The sensor was at about ¾ the height of the top of the fern canopy at the time of set-up. Temperature and leaf wetness data were downloaded periodically from the sensors using a launched Watchdog shuttle (Spectrum Technologies). The data was run through the Tom-Cast programme (purchased from Spectrum Technologies) to determine i) the number of sprays that would have been triggered using different Tom-Cast thresholds and, ii) realistic Tom-Cast thresholds to use in 2010 field fungicide experiments.

Spray records for the commercial crops were obtained from the host growers, to determine typical numbers, products and timing of applications per season. Data on Stemphylium symptom development was also available from experimental plots established in the same fields comparing i) an untreated area versus grower programmes (2008), and ii) fungicide programmes in a randomized complete block design (2009) (see previous experiment).

Results and discussion

At both sites, growers were aware of the risk of Stemphylium development (due to a history of the disease in the fields) and each applied a fungicide programme for Stemphylium control commencing in June/July (depending on close of harvest) and finishing in early to mid-September (Tables 10 and 11). At Warwicks, there were six spray applications in both seasons, including eight single products as tank mixes in 2008 and 10 in 2009. At Norfolk, there were seven spray applications (including nine single products) in 2008 and six spray applications (eight single products) in 2009. It was noticeable that several strobilurin products were included in each programme, highlighting the need for careful programming in future to reduce resistance risk.

In 2008, Stemphylium severity was high at both sites; although the grower programmes did not completely control the disease, fungicide applications significantly reduced disease incidence and severity compared with untreated control areas within the fields (see Year 1 Annual Report). In 2009, Stemphylium severity was moderate at Warwicks and low at Norfolk; data from the previous experiment (using comparable fungicide programmes to

commercial practice) indicated that at Warwicks, disease incidence and severity was reduced by certain 5- and 6-spray programmes, while at Norfolk, there was little difference between sprayed and untreated plots.

In the Tom-Cast programme, leaf wetness duration and the average temperature during wetness periods are used to derive disease severity values (DSVs) and associated thresholds from which spray timing is determined. Accumulation of DSVs and leaf wetness periods at the two sites during the fern production period in 2008 and 2009 is shown graphically in Figures 3 and 4. Based on outputs from Tom-Cast, the number and dates of spray applications that would have been triggered at the two sites using different DSV thresholds, are summarised in Tables 12 and 13.

This summary shows that if the Tom-Cast programme had been used to schedule sprays in 2008, an equal number of sprays would have been recommended at each site (with the actual number of applications dependant on DSV threshold). However, the optimum timing would have been different at each site. Closer spray intervals would have been triggered at the Norfolk site compared with the Warwicks site, because of a particularly rapid accumulation of disease DSVs in late July / early August (Figure 4). In 2009, for each Tom-Cast threshold, fewer spray applications would have been triggered at Warwicks compared with Norfolk due to a lower accumulation of DSVs.

Meyer *et al.* (2000) in Michigan State showed that fungicides applied according to Tom-Cast (DSV=15), resulted in a reduction in sprays compared with 7, 10 and 14-day programmes. Moreover, applying fungicides according to Tom-Cast or every 7 days resulted in significantly reduced lesion severity compared with 10 and 14 day programmes. From our monitoring in 2008, applications at DSV=7 would have given similar numbers of applications to the grower programmes (Tables 10-13), although with a closer timetabling of spray events in late July/early August, which might have been difficult (particularly for Norfolk) given continuous rain at this time. In 2009, a DSV of 5 was comparable to spray numbers at Norfolk, while under apparently drier conditions at Warwicks, commercial sprays exceeded the number of applications suggested by Tom-Cast even at DSV=5. A threshold of DSV=15, as used in the USA, would have triggered only one or two spray applications, depending on site and season. A field experiment in project year 3 will investigate further the effects of fungicide programmes (product choice) and timing on Stemphylium development. The efficacy of 14 day programmes will be compared with programmes applied according to DSV thresholds (DSV = 5, 7 and 10). A further consideration will be whether a fungicide application soon after close of harvest to young fern could provide useful protection

particularly in situations where infested debris on the soil surface is present as a primary source of inoculum.

A recent study in Michigan State, USA (Granke & Hausbeck, 2010) looked in more detail at the influence of environment on airborne spore concentrations and severity of asparagus purple spot. Leaf wetness appeared to be the most important environmental factor influencing disease development on the fern, but temperature, vapour pressure deficit and rainfall also appeared significant. The paper concluded that simplifications to the Tom-Cast model to include fewer factors were not warranted, but that the addition of rainfall to the model might be helpful.

Table 10. Fungicides applied to a commercial asparagus crop after close of harvest, Warwicks 2008 and 2009

Date	Product	Active (s)	Rate/ha
2008			
28/06/2008	Amistar Top	Azoxystrobin, difenoconazole	1.0 L
14/07/2008	Signum	Boscalid, pyraclostrobin	1.5 kg
04/08/2008	Difcor 250 EC	Difenoconazole	0.4 L
	+ Switch	Cyprodinil, fludioxonil	1.0 kg
15/08/2008	Amistar Top	Azoxystrobin, difenoconazole	1.0 L
30/08/2008	Difcor 250 EC	difenoconazole	0.5 L
	+ Switch	Cyprodinil, fludioxonil	0.773 kg
19/09/2008	Signum	Boscalid, pyraclostrobin	1.0 kg
No. spray events	6		
No. single product applications	8		
2009			
10/07/2009	Amistar Top	Azoxystrobin, difenoconazole	0.76 L
23/07/2009	Difcor 250 EC	Difenoconazole	0.5 L
	+ Signum	Boscalid, pyraclostrobin	1.0 kg
31/07/2009	Difcor 250 EC	Difenoconazole	0.49 L
	+ Switch	Cyprodinil, fludioxonil	1 kg
12/08/2009	Plover	Difenoconazole	0.4 L
	+ Olympus	Azoxystrobin, chlorothalonil	2.25 L
24/08/2009	Amistar Top	Azoxystrobin, difenoconazole	1 L
	+ Dithane 945	Mancozeb	2 kg
08/09/2009	Signum	Boscalid, pyraclostrobin	1 kg
No. spray events	6		
No. single product applications	10		

Table 11. Fungicides applied to a commercial asparagus crop after close of harvest, Norfolk 2008 and 2009

Date	Product	Active (s)	Rate/ha
2008			
27/06/2008	Plover	Difenoconazole	0.5 L
	+ Amistar	Azoxystrobin	1.0 L
04/07/2008	Plover	Difenoconazole	0.5 L
	+ Amistar	Azoxystrobin	1.0 L
14/07/2008	Signum	Boscalid, pyraclostrobin	1.5 kg
25/07/2008	Switch	Cyprodinil, fludioxonil	1.0 kg
31/07/2008	Signum	Boscalid, pyraclostrobin	1.5 kg
14/08/2008	Olympus	Azoxystrobin, chlorothalonil	2.5 L
04/09/2008	Olympus	Azoxystrobin, chlorothalonil	2.5 L
No. spray events	7		
No. single product applications	9		
2009			
07/06/2009	Signum	Boscalid, pyraclostrobin	1 kg
30/06/2009	Switch	Cyprodinil, fludioxonil	1 kg
22/07/2009	Olympus	Azoxystrobin, chlorothalonil	2.5 L
31/07/2009	Signum	Boscalid, pyraclostrobin	1 kg
14/08/2009	Olympus	Azoxystrobin, chlorothalonil	2.5 L
	Plover	Difenoconazole	0.25 L
08/09/2009	Plover	Difenoconazole	0.25 L
	Amistar	Azoxystrobin	0.5 L
No. spray events	6		
No. single product applications	8		

Table 12. Summary of suggested spray dates at Warwicks (2008 and 2009), based on Tom-Cast set at different Disease Severity Value (DSV) thresholds

Selected DSV Thresholds	No. sprays triggered Warwicks 2008*	Spray dates Warwicks 2008	No. sprays triggered Warwicks 2009*	Spray dates Warwicks 2009
5	8	10/07/08	4	03/07/09
		27/07/08		17/07/09
		30/07/08		30/07/09
		06/08/08		07/08/09
		16/08/08		
		22/08/08		
		02/09/08		
		07/09/08		
7	6	19/07/08	3	06/07/09
		29/07/08		27/07/09
		07/08/08		13/08/09
		21/08/08		
		02/09/08		
		05/10/08		
10	4	27/07/08	2	17/07/09
		06/08/08		07/08/09
		22/08/08		
		07/09/08		
12	3	28/07/08	1	21/07/09
		12/08/08		
		05/09/08		
15	2	30/07/08	1	30/07/09
		22/08/08		
20	2	06/08/08	1	07/08/09
		07/09/08		

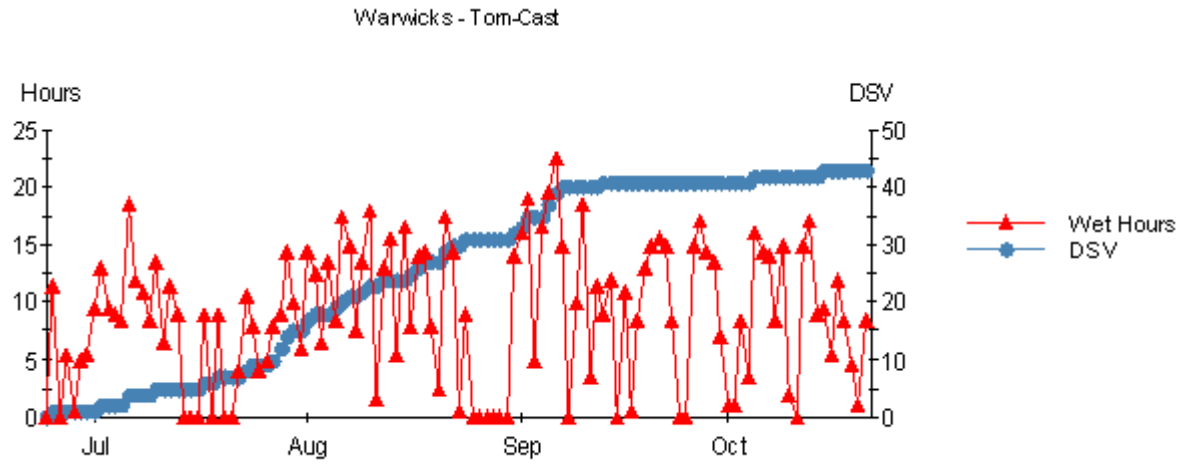
*Does not include a spray at close of harvest.

Table 13. Summary of suggested spray dates at Norfolk (2008 and 2009), based on Tom-Cast set at different Disease Severity Value (DSV) thresholds

DSV Threshold	No. sprays triggered Norfolk 2008*	Spray dates Norfolk 2008	No. sprays triggered Norfolk 2009*	Spray dates Norfolk
5	8	17/07/08	6	30/06/09
		26/07/08		08/07/09
		28/07/08		23/07/09
		29/07/08		06/08/09
		05/08/08		20/08/09
		10/08/08		20/09/09
		30/08/08		
		10/09/08		
7	6	24/07/08	4	03/07/09
		27/07/08		21/07/09
		31/07/08		07/08/09
		07/08/08		03/09/09
		30/08/08		
		05/10/08		
10	4	26/07/08	3	08/07/09
		29/07/08		06/08/09
		10/08/08		20/09/09
		10/09/08		
12	3	27/07/08	2	17/07/09
		04/08/08		15/08/09
		01/09/08		
15	2	28/07/08	2	23/07/09
		10/08/08		20/09/09
20	2	29/07/08	1	06/08/09
		10/09/08		

*Does not include a spray at close of harvest.

A



B

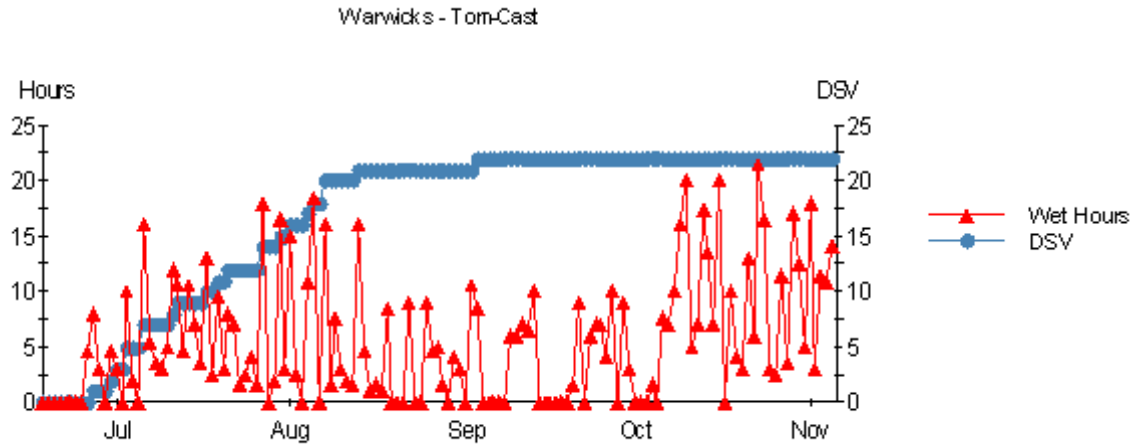
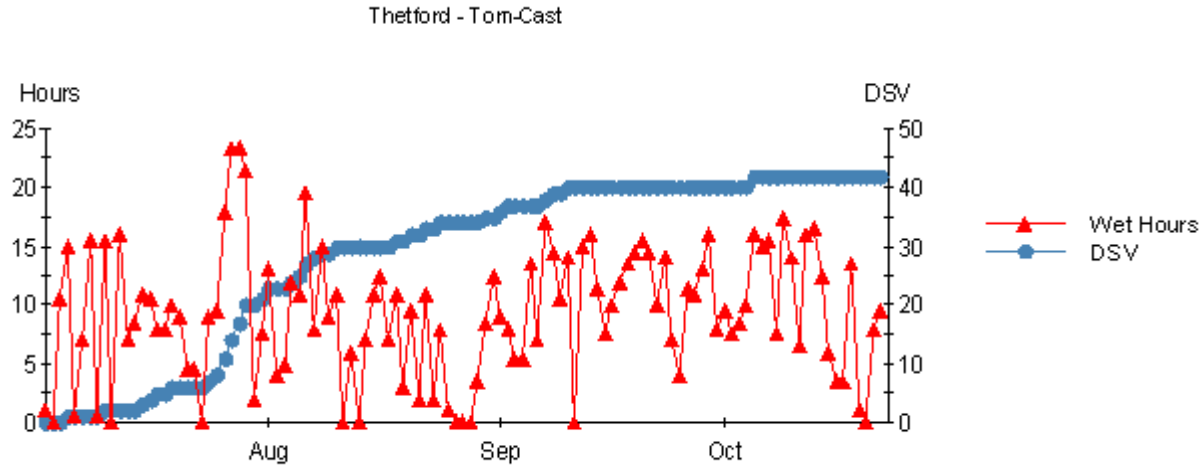


Figure 3. Output from Tom-Cast model for a commercial asparagus field, Warwicks in 2008 (A) and 2009 (B) showing accumulation of Disease Severity Values (DSVs) that can be used to schedule spray timing.

A



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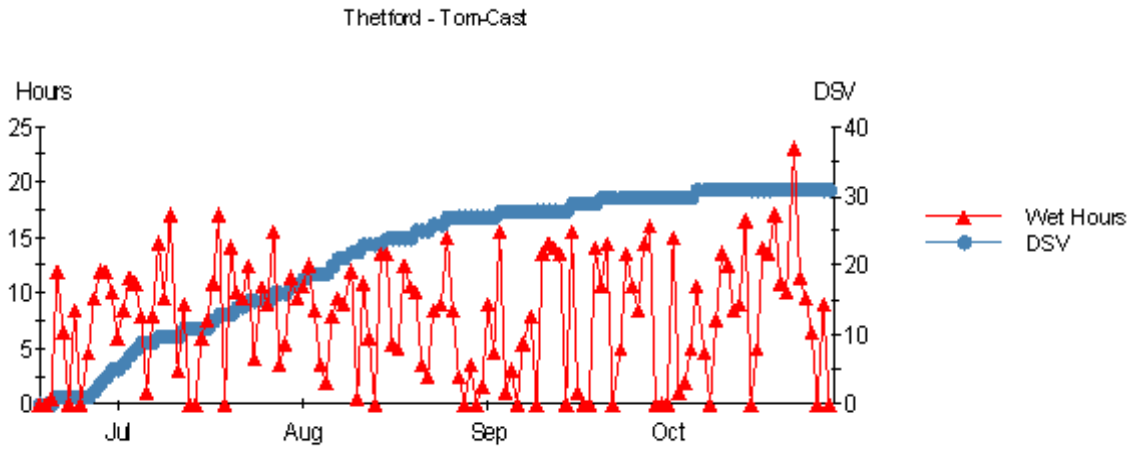

Figure 4. Output from Tom-Cast model for a commercial asparagus field, Norfolk in 2008 (A) and 2009 (B) showing accumulation of Disease Severity Values (DSVs) that can be used to schedule spray timing.

Conclusions

Development of Stemphylium purple spot

Development of Stemphylium purple spot symptoms was monitored at two commercial sites. At Warwicks, where infested debris was abundant on the soil surface, the disease

commenced from stem bases. Although all plant parts were subsequently affected, stem bases remained most severely affected through the season. This pattern of symptom development was consistent with a series of primary infections being initiated from ascospores of *P. herbarum* released from fruiting bodies (pseudothecia) on asparagus debris. At Norfolk, infested debris was less abundant on the soil surface and disease severity remained lower throughout the season. Symptoms were also first observed at stem bases but were subsequently more prevalent on mid-stems and secondary branches, indicative of secondary spread of the disease via conidia of *S. vesicarium*, either from stem base lesions or incoming from neighbouring asparagus crops.

Evaluation of fungicide programmes

Fungicide programmes were evaluated for their effect on Stemphylium purple spot during fern production at two commercial sites. The experiment demonstrated that under high disease pressure, fungicide programmes can reduce the incidence and severity of Stemphylium purple spot. While there was no individual programme that performed considerably better than others, Treatment 8 (Signum / Plover / Dithane 945 / Plover / Signum, at 2-3 weeks intervals) was perhaps the most consistent. At the Warwicks site, this fungicide programme reduced disease incidence and severity, reduced % dead stems and resulted in higher root carbohydrate levels. In addition, following this treatment, there was a trend for lower disease incidence (Norfolk) and higher Brix% values (both sites). The fact that this programme comprised five rather than six applications (commencing around 5 weeks after close of harvest) indicates that timing of appropriate products is likely to be more important for effective control than numbers of applications.

Overall, programmes that performed well were treatments 3, 4, 6 and 8. Treatments 3, 6 and 8 each included two applications of Signum alternating with difenoconazole products, and use of Dithane 945 as a protectant mid-season. Equivalent programmes using Amistar in place of Signum were less effective, suggesting that Signum may be a stronger product for control of Stemphylium purple spot on asparagus. There were also some good results obtained with treatment 4, commencing with Amistar Top, then alternating Switch with Plover, although this programme did not contribute to delayed senescence as effectively as programmes that contained two or three strobilurin products and finished with a strobilurin.

Monitoring of leaf wetness and temperature

Leaf wetness and temperatures were monitored at two commercial sites during fern production in 2008 and 2009. Examination of the data using the Tom-Cast model established the number of sprays that would have been triggered at each site, based on different Disease Severity Value (DSV) thresholds). DSVs of 5 and 7 gave spray numbers

comparable to commercial programmes although at different timings. DSVs of 10 or higher would have triggered fewer sprays than commercial programmes at both sites / seasons. A field trial in 2010 will compare disease development following spray programmes based on DSVs of 5, 7 and 10.

Technology transfer

- Update on project progress provided for a technical meeting of the AGA and the Field Vegetable Panel meeting, September 2009.
- 'Treatments to clear up asparagus purple spot' – Summary project article in Field Vegetables Review – HDC News, 2010.
- Presentation on 'Diseases and pests of asparagus', including project results at EuroAsper Conference, March 2010, Coventry.

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