Project title	Development of fungicide treatments for sustainable control of powdery mildew on rose and herbaceous crops
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Project leader:	Dr Tim O'Neill, ADAS
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AUTHENTICATION

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

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CONTENTS

GROWER SUMMARY

Headline

- Ten fungicides covering a wide range of active ingredients gave good control of powdery mildew on aquilegia, aster, phlox or rose.
- Effective products were Cyflamid (cyflufenamid), Flexity (metrafenone), Fortress (quinoxyfen), Nativo 75WG (tebuconazole + trifloxystrobin), potassium bicarbonate + Silwet L-77 (wetter), Signum (boscalid + pyraclostrobin), Switch (cyprodinil + fludioxonil), Systhane 20EW (myclobutanil) and Thiovit Jet (sulphur) + Silwet L-77 (wetter).
- The biofungicde Serenade ASO (*Bacillus subtilis*) gave some control.
- Seven fungicide programmes, designed to be at low risk of selecting resistant strains and comply with maximum spray number limits, gave good season-long control of powdery mildew on aquilegia and phlox.

Background and expected deliverables

Powdery mildews of rose and herbaceous perennials are widespread, common and potentially very damaging diseases. Whilst fungicides still remain the primary method of control the efficacy and crop safety of individual fungicides against powdery mildew diseases on different crops is likely to vary.

Work in project HNS 156 identified new fungicides with good activity against powdery mildew on seedling crops of *Crataegus* species (*Podosphaera clandestina*) and *Quercus* species (*Erysiphe alphitoides*) and devised long-term programmes for their use.

The overall aim of this project was to devise fungicide programmes based on currently available products, used within their spray number limit, that provide sustainable, season-long control of powdery mildew on *Rosa* species and some susceptible herbaceous crop species.

Summary of the project and main conclusions

Evaluation of fungicides for control of rose powdery mildew

Twelve fungicide or biofungicide treatments were compared for control of powdery mildew on container-grown rose cv. Ruby Wishes in a shade tunnel on a nursery in Norfolk. High volume sprays were applied between April and July 2010 at approximately 14 day intervals.

Powdery mildew was first observed shortly after the third spray application, and increased to affect 23% of leaflets and 2.2% of the leaf area on untreated plants by the end of the experiment. Disease severity was significantly reduced by all treatments with no clear difference between them: Kindred (meptyldinocap), Nativo 75WG, Nimrod (bupirimate), potassium bicarbonate + Silwet L-77, potassium bicarbonate + Serenade ASO, Serenade ASO, Signum, Switch, Systhane 20EW and three coded experimental products.

The incidence of affected leaflets at the end of the trial was reduced by all treatments except for Serenade ASO and potassium bicarbonate + Serenade ASO; possibly Serenade ASO would have given better control if applied every 7 days. None of the treatments caused crop damage or left an obvious spray deposit.

Evaluation of fungicides for control of powdery mildew on aquilegia and phlox

Eleven fungicide treatments were compared for the control of powdery mildew (*Erysiphe aquilegiae* and *Podosphaera fusca*) on container-grown Aquilegia cv. Red Hobbit and Phlox cv. Blue Paradise on a nursery in Norfolk. Five high volume sprays were applied at approximately 14 day intervals between July and September 2010. Powdery mildew was first observed, on both crops, one week after the third spray.

On aquilegia powdery mildew increased to affect 40% of untreated plants and all treatments reduced disease incidence to 15% or less. No powdery mildew was found on plants treated with Cyflamid, Nativo 75WG, Signum or Thiovit Jet + Silwet L-77. Disease severity was low and there were no clear differences between treatments.

On phlox powdery mildew was severe and by 7 October 2010 affected 70% of the leaf area of untreated plants. The best treatments were Cyflamid, Nativo 75WG, potassium bicarbonate + Silwet L-77, Signum and Thiovit Jet + Silwet L-77, all of which reduced the disease to less than 7% leaf area affected. The biofungicide Serenade ASO reduced mildew severity by 50% and the treatment may have been more effective if applied weekly. Potassium bicarbonate was significantly more effective when used with the silicon based wetter Silwet L-77 (1% leaf area affected) than with Serenade ASO (8%).

No leaf scorch or other obvious adverse effects were observed immediately after treatments. However, after five sprays had been applied, the mean height of phlox plants treated with Fortress, Nativo 75WG and both of the potassium bicarbonate treatments was lower (25-26 cm) compared with the untreated (29 cm). Thiovit Jet + Silwet L-77 left an obvious pale brown spray deposit on both aquilegia and phlox.

Evaluation of fungicides for control of established powdery mildew on aster

Nine fungicide treatments were compared for control of established powdery mildew (*Golvinomyces cichoracearum*) on container-grown aster (*Aster novi-belgii*) cv. Purple Dome at ADAS Boxworth. Each treatment was applied twice as high volume sprays at a 7 day interval in October 2010. Seven days after the second treatment the leaf area affected by powdery mildew was greatest on untreated plants (37%) and was significantly reduced by all treatments (Cyflamid, Flexity, Fortress, Nativo 75WG, potassium bicarbonate + Silwet L-77, Systhane 20EW, Signum, Swift SC and Switch). Potassium bicarbonate + Silwet L-77 was the most effective, reducing powdery mildew to 11% leaf area affected. In spring 2011, a low incidence of powdery mildew occurred on new growth of plants untreated in autumn 2010, and no powdery mildew on any of the plants treated with fungicide the previous autumn.

Evaluation of fungicide programmes

Seven fungicide programmes designed to be at low risk of selecting resistant strains of mildew were devised and tested on outdoor container crops of aquilegia and phlox during summer 2011. Each programme consisted of alternate sprays of two or three products until the maximum spray number for a product was reached, when it was continued with Thiovit Jet + Silwet L-77 or Systhane 20EW, which have no restriction on spray number (Table 1). The same seven programmes were tested on rose with additional programmes of Systhane 20EW + potassium bicarbonate alternating with Nimrod and one using the EMR powdery mildew predictions model (see HNS 165). All of the programmes are suitable for use on both outdoor and protected crops except for those containing either Cyflamid or Nativo 75WG (outdoor crops only).

On aquilegia, powdery mildew first occurred on 3 August and increased to affect 43% leaf area of untreated plants at 7 days after the final spray. All of the programmes reduced the disease to 5% or less and none caused any obvious crop damage (Table 1).

On phlox, powdery mildew affected over 70% of upper and lower leaf surfaces of untreated plants at the end of the trial. Six of the programmes gave excellent control reducing the

disease to 3% leaf area affected or less; the Serenade ASO/potassium bicarbonate programme was slightly less effective, with around 20% on the lower leaf surface (Table 1).

On rose, the level of powdery mildew infection was slight, affecting only 3% leaf area of untreated plants at the end of the trial. None of the fungicide programmes reduced disease incidence or severity. Two programmes (Signum/Cyflamid/Nativo 75WG and Serenade ASO/potassium bicarbonate + Silwet L-77) increased the proportion of plants with a high plant quality score, possibly due to control of powdery mildew.

Table 1: Efficacy of fungicide programmes against powdery mildew on aquilegia and phlox – 2011

Programme	Suitable for		Spray treatment and application week:								% leaf area affected 1 week after final spray		
	Outdoor crops	Protected crops	Week 25	Week 27	Week 29	Week 31	Week 32	Week 33	Week 34	Week 35	Aquilegia	Phlox	
												Upper surface	Lower surface
1. Untreated	-	-	-	-	-	-	-	-	-	-	45	70	81
2. Preventative	✓	✓	Thiovit[a]	Signum	Thiovit	Signum	-	Thiovit	-	Thiovit	2	<1	6
3. Preventative	✓	✓	Switch + $KHCO_3$	Signum	Switch + $KHCO_3$	Signum	-	Switch + $KHCO_3$	-	Systhane + $KHCO_3$	1	1	6
4. Preventative	✓	✓	Systhane + $KHCO_3$	Signum	Systhane + $KHCO_3$	Signum	-	Systhane + $KHCO_3$	-	Systhane + $KHCO_3$	1	2	4
5. Preventative	✓	✓	Fortress	Signum	Fortress	Signum	-	Systhane + $KHCO_3$	-	Systhane + $KHCO_3$	3	1	5
6. 'High disease risk'	✓		Signum	Cyflamid	Nativo	Signum	-	Cyflamid	-	Nativo	1	2	6
7. 'Biological'	✓	✓	Serenade	Serenade	Serenade	$KHCO_3$[b]	-	$KHCO_3$	-	$KHCO_3$	6	5	23
8. From first symptoms	✓		-	-	-	Signum[b]	Cyflamid	-	Nativo	-	4	2	8

[a]A silicon based wetter (Silwet L-77) was added to Thiovit Jet and potassium bicarbonate ($KHCO_3$) at 0.025%.

[b]Change of product (treatment 7) and start of spray programme (treatment 8) were made in response to first occurrence of powdery mildew in the crop.

Persistence of protectant sprays

An experiment was devised to compare the persistence of protection against powdery mildew provided by a single spray of different fungicides. Aster plants were sprayed with nine fungicides (Cyflamid, Flexity, Fortress, Nativo 75WG, Serenade ASO, Signum, Switch, Systhane 20EW and Thiovit Jet + Silwet L-77) at 1, 7 and 14 days before inoculation with spores of powdery mildew (*Golvinomyces cichoracearum*). Mildew developed on all treatments sprayed 14 days before inoculation, on two treatments (Cyflamid and Thiovit Jet + Silwet L-77) sprayed 7 days before inoculation and on no treatments where fungicides were sprayed 1 day before inoculation. Persistence of protection was greatest on plants treated with Systhane 20EW, Serenade ASO and Thiovit Jet + Silwet L-77 (all less than 5% leaf area affected when treated 14 days before infection) and least on plants treated with Flexity (20%).

Summary of product efficacy

The relative efficacy of products examined is summarised in Table 2. Details of products used and their approval status are given in Table 3.

Table 2. Summary of fungicide and biofungicide efficacy against powdery mildew diseases on aquilegia, phlox and rose – 2010

Product	Fungicide group codes	Level of powdery mildew control[a] on:		
		Aquilegia	Phlox	Rose
Cyflamid	U6	*****	*****	-
Flexity	U8	****	*****	-
Fortress	13	****	*****	-
Kindred	29	-	-	****
Nativo 75WG	3+11	*****	*****	*****
Nimrod		-	-	*****
Potassium bicarbonate + Silwet L-77	NC	*****	*****	*****
Potassium bicarbonate + Serenade ASO	NC	*****	**	***
Serenade ASO	NC	*****	**	****
Signum	7+11	*****	*****	*****
Switch	9+12	***	****	****
Systhane 20EW	3	*****	****	*****

Product	Fungicide group codes	Level of powdery mildew control[a] on:		
		Aquilegia	Phlox	Rose
Thiovit Jet + Silwet L-77	M2	*****	*****	-
Disease level on untreated		40% plants affected (all at low level)	70% leaf area affected	21% leaflets affected (all at low level)

[a] Disease reduced by: *, 1-20%; **, 21-40%, ***, 41-60%, ****, 61-80%; *******,** 81-100%, - not tested.

Products were applied as protectant sprays approximately every 14 days.

Fungicide group codes are taken from the Fungicide Resistance Action Committee code list. Numbers and letters are used to distinguish fungicide groups according to their cross-resistance behaviour; products with the same number are at high risk of cross-resistance. U =unknown mode of action; m=multisite inhibitor (low risk of resistance); NC = not classified.

Table 3. Details of fungicide and biofungicide products used in this work and their approval status (March 2012)

Product	Active ingredient(s)	Rate used on outdoor crops	Approval status on ornamentals:		Maximum number sprays or total dose
			Outdoor	Protected	
Cyflamid	cyflufenamid (50 g/L)	0.5 L/ha	SOLA 0512/07	Not approved	2
Flexity	metrafenone (300 g/L)	0.5 L/ha	SOLA 2850/08	Not approved	1 L/ha
Fortress	Quinoxyfen (500 g/L)	0.25 L/ha	SOLA 2852/08	SOLA 2852/08	0.5 L/ha
Nativo 75WG	tebuconazole + trifloxystrobin (50:25% w/w)	0.4 g/L	LTAEU	Not approved	2
Nimrod	bupirimate (250 g/L)	0.38 ml/L	Label (rose) and LTAEU	Label (rose) and LTAEU	none
Potassium bicarbonate + Silwet L-77	$KHCO_3$ + wetter	5 -10 g/L + 0.025%	Commodity substance	Commodity substance	60 kg/ha
Serenade ASO	*Bacillus subtilis* (13.96 g/L)	10 ml/L	EAMU 0475/12	EAMU 0475/12	20
Signum	boscalid + pyraclostrobin (26.7:6.1% w/w)	1.35 g/L	SOLA 1842/09	SOLA 1842/09	2
Swift SC	trifloxystrobin (500 g/L)	0.5 ml/L	2882/08	Not approved	2
Switch	cyprodinil + fludioxonil (37.5:5.25%	0.8 -1 g/L	Label (1 kg/ha)	Label (0.8 kg/ha)	3

Product	Active ingredient(s)	Rate used on outdoor crops	Approval status on ornamentals:		Maximum number sprays or total dose
			Outdoor	Protected	
	w/w)				
Systhane 20EW	myclobutanil (200 g/L)	0.3 ml/L	Label	Label	None stated
Thiovit Jet + Silwet L-77	sulphur + Wetter (80% w/w)	10 kg/ha + 0.025%	LTAEU	LTAEU	None stated

Treatments rates are based on a spray volume of 1,000 L/ha. Products used in mixtures were applied at the full rate.

LTAEU - Long Term Arrangements for Extension of Use. Nimrod is currently permitted on ornamentals other than rose under the LTAEU.

Where a product is used under the LTAEU, a SOLA or an EAMU, growers should read and observe all the restrictions; use under a SOLA, EAMU or the LTAEU is at the grower's own risk.

Financial benefits

Each year powdery mildews affect many species of hardy nursery stock and herbaceous perennials. The diseases they cause may be slight or, in some situations, if left untreated, may cause severe economic losses. They impair photosynthesis, stunt growth and can cause premature leaf fall. They generally do not kill their hosts but extensive white fungal growth on leaf, stem and flower surfaces make plants unsightly, and thus either unsaleable or of reduced quality. Severe damage can cause death of leaves and shoots. Although numerous fungicides are available for powdery mildew control, weekly applications may be needed to maintain adequate control. The potential financial benefits to growers from this project are more reliable control of powdery mildew with reduced risk of fungicide resistance, and reduced losses and down-grading of crops due to powdery mildew.

Assuming a value for rose production in the UK of £24m (DEFRA 2011), losses directly attributed to powdery mildew are estimated at 5%. If these losses could be reduced by 50% due to improved control programmes using a range of fungicide at similar cost there would be a saving of £600,000 per annum for the rose industry. Assuming a value of container nursery stock production in the UK of £286m (DEFRA 2011) of which 15% is herbaceous stock this would give a value of £43m for container grown herbaceous stock. In addition field grown herbaceous nursery stock is valued at £14m giving a total value of herbaceous production of £57m. It is estimated that 15% of production genera are susceptible to powdery mildew and losses amount to 15% of these genera due to quality down grading and missed sales opportunities. If losses could be reduced by 50% due to improved control

programmes using a range of fungicide at similar cost there would be a saving of £640,000 per annum for the herbaceous plant industry. Total benefits from this project are therefore estimated at £1.24m per annum.

http://www.defra.gov.uk/statistics/files/defra-stats-foodfarm-landuselivestock-hottstats-bhs2011-110721.pdf

Action points for growers

- Use fungicides from a range of different fungicide groups when devising a spray programme for control of powdery mildew (see Table 2); this is important because powdery mildew pathogens are 'high risk' with regard to resistance management.
- Seek to include in the spray programme one or more fungicides which are at low risk of selecting resistant strains; such products include potassium bicarbonate and Thiovit Jet.
- Consider use of Nativo 75WG, Nimrod, Potassium bicarbonate + Silwet L-77, Signum, Switch, Systhane 20EW and the biofungicide Serenade ASO, in spray programmes for control of powdery mildew on outdoor rose.
- Consider use of: Cyflamid, Flexity, Fortress, Nativo 75WG, potassium bicarbonate + Silwet L-77, Signum, Switch, Systhane 20EW, Thiovit Jet + Silwet L-77 and the biofungicide Serenade ASO in spray programmes for powdery mildew on outdoor crops of aquilegia and phlox.
- When using potassium bicarbonate to control powdery mildew, mixing it with a silicon based wetter is likely to improve control.
- The biofungicide Serenade ASO applied every 14 days can give some control of powdery mildew, though generally it is less effective than conventional mildew fungicides applied at the same spray interval; use Serenade ASO at a shorter spray interval to increase the chance of better control.
- Note that Fortress at 0.25 L/ha, Nativo 75WG at 0.4 kg/ha and potassium bicarbonate at 10 g/L may reduce plant height. Do not use these products on very young plants or in succession where crop height is critical.
- A range of simple fungicide programmes, consisting of two or three products applied in alternation can be used to provide effective control of powdery mildew on aquilegia and phlox with reduced risk of selecting resistant strains (see Table 1).
- Consider using Systhane 20EW, Serenade ASO and Thiovit Jet + Silwet L-77 on aster where the interval to the next spray may be more than 14 days.

- Do not rely on potassium bicarbonate + Silwet L-77 to provide adequate control in crops (e.g. phlox) where powdery mildew may occur on the lower leaf surface.
- Consider using Systhane 20EW in mixture with potassium bicarbonate to increase the level of control, especially where the disease is visible in a crop.

SCIENCE SECTION

Evaluation of fungicide programmes for control of rose powdery mildew

Introduction

Powdery mildew (*Podosphaera pannosa*) is a widespread, common and potentially very damaging disease of rose. The fungus survives between seasons as dormant infections on leaves, inner bud scales and stems, and is sometimes visible as white mycelium around thorns. Roses are particularly susceptible to infection during early summer when warm days are followed by cool humid nights, and during periods of rapid growth. The objective of this work was to compare the efficacy of some fungicide programmes for control of powdery mildew (natural infection) during spring and early summer.

Materials and methods

Site and crop details

An experiment was done on a nursery in Norfolk using a compact patio rose cv. Ruby Wedding in 3L pots. Containers were stood on Mypex-type matting in a shade tunnel in a corner of the site shaded by trees. Plants were watered from overhead and maintained following normal nursery practice except that no fungicides were applied. A crop diary is given in Appendix 1. Temperature and relative humidity at the canopy base were recorded using a Tinytag logger.

Treatments

Treatments are shown in Table 1.1 and product details in Table 1.2. Five of the programmes are suitable for use on both outdoor and protected crops; four can only be used on outdoor crops. The programmes were designed to reduce the risk of selecting resistant strains of powdery mildew by alternating fungicides from different mode of action groups, by using products with multiple modes of action (i.e. Thiovit Jet and potassium bicarbonate) and by using mixtures of active ingredients in different fungicide groups. All of the programmes comply with label conditions with regard to maximum spray number; hence in treatments 2-5, for example, the spray sequence is altered when the maximum of two sprays of Signum have been used.

Treatments 2-5 were all designed as preventative spray programmes, using different combinations of two or three products. Treatment 6 consists of preventative sprays of three

fungicides that have performed well in previous work and is considered suitable for situations where a high disease pressure is expected. Treatment 7 uses a biofungicide and a natural salt, and is termed 'biological'. Treatment 8 is designed to test the efficacy of applying fungicides soon after the first appearance of powdery mildew and is termed 'reactive to symptoms'; this treatment may save spray applications, provided the first spray is applied before the disease establishes extensively in a crop. In order to improve the chance of achieving effective control with this treatment, the first spray consists of an eradicant (potassium bicarbonate) mixed with a protectant fungicide (Signum); and a second spray is applied within 8 days of the first. Treatment 9, termed 'Growers' standard', consists of alternation of two fungicides (Systhane 20EW and Nimrod) that have been widely used for control of powdery mildew for several years; there is no restriction on the number of applications that may be made with these products. Treatment 10 used the East Malling powdery mildew prediction model (Xu, 2010) based on temperature and humidity to aid decisions on the need to spray. Model guidelines suggest that a spray should be considered when the predicted daily infection risk is 3% or greater, especially if no fungicides have been applied in the last 2-3 weeks; a predicted infection risk of 4% or more is considered high risk.

Table 1.1: Fungicide programmes examined for control of rose powdery mildew - 2011

Treatment	Situation(s)	Spray date and product						
	for use	25/5	7/6	21/6	5/7	13/7	22/7	5/8
1. Untreated	-	-	-	-	-	-	-	-
2. Preventative	O + P	Thi	Sig	Thi	Sig	-	Thi	Thi
3. Preventative	O + P	Swi	Sig	Swi	Sig	-	Swi	Sys
4. Preventative	O + P	Sys	Sig	Sys	Sig	-	Sys	Sys
5. Preventative	O + P	For	Sig	For	Sig	-	Sys	Sys
6. 'High disease pressure'	O	Sig	Cyf	Nat	Sig	-	Cyf	Nat
7. 'Biological'	O + P	Ser	Ser	Ser	$KHCO_3$	-	$KHCO_3$	$KHCO_3$
8. 'Reactive'	O	-	-	-	Sig+ $KHCO_3$	Cyf	Nat	Sig
9. 'Grower standard'	O	Sys	Nim	Sys	Nim	-	Sys	Nim
10. 'Model prediction'	O	-	-	Sys	-	Cyf	Sys	Nim

O – outdoor; P – protected

Cyf – Cyflamid; For – Fortress; Nat – Nativo 75WG; Nim – Nimrod; Ser – Serenade ASO; Sig – Signum; Swi – Switch + potassium bicarbonate; Sys – Systhane 20EW + potassium bicarbonate; Thi – Thiovit Jet + Silwet L-77

Treatments were applied as high volume sprays (1,000 L/ha) as commonly used on nursery stock, at a pressure range 200-300 KPa using flatfan nozzles. Six sprays were applied from 25 May to 22 July 2011 at approximately 14 day intervals from early leaf emergence to full flowering; dates of treatments are given in Appendix 1. A spray guard was used to prevent spray drift between plots.

Table 1.2: Details of products used

Product	Active ingredient(s)	Rate used
Cyflamid	50 g/L cyflufenamid	0.5 L/ha
Fortress	500 g/L quinoxyfen	0.25 L/ha
Nativo 75WG	50:25% w/w tebuconazole + trifloxystrobin	0.4 kg/ha
Nimrod	250 g/L bupirimate	0.38 L/100 L
Potassium bicarbonate	potassium bicarbonate + Silwet L-77	5 g/L + 0.025%
Serenade ASO	13.96 g/L *Bacillus subtilis*	10 L/ha
Signum	26.7:6.7 w/w boscalid + pyraclostrobin	1.35 kg/ha
Switch + potassium bicarbonate	37.5:5.25% w/w cyprodinil + fludioxonil + potassium bicarbonate	0.8 kg/ha + 5 g/L
Systhane 20EW + potassium bicarbonate	200 g/L myclobutanil + potassium bicarbonate	0.225 L/750 L + 5 g/L
Thiovit Jet + Silwet L-77	80% w/w sulphur + wetter	10 kg/ha + 0.025%

Experiment design and statistical analyses

Treatments were arranged in a randomized block design with fourfold replication; there was eightfold replication of the untreated. Each plot consisted of five plants in individual pots, with four plants arranged around a central plant. Results were examined by ANOVA and Generalised Linear Modelling as appropriate for the data.

Disease assessments

Plants were examined at each spray application for symptoms of powdery mildew on leaves, stem or flowers. Full disease assessments were done on 5 July, 26 July, 5 August and 12 August and a quality assessment on 19 August 2011.

Powdery mildew was assessed as the proportion of 50 leaflets per plot with any level of powdery mildew, and the mean % leaf area affected on these 50 leaflets assessed. Leaflets

were assessed on all faces of the inner plant and the inner faces of the four surrounding plants. Upper and lower leaf surfaces were assessed separately.

At the assessment on 16 August, the proportion of flowers or red coloured flower buds with obvious white powdery mildew was determined. Black marking on flowers was disregarded.

Plant quality

Each plant was categorized into one of five classes based on the quantity of green leaves and overall plant size:

1 - poor growth

2 - moderate growth

3 - good growth

4 - very good growth

5 - excellent growth.

Crop damage assessments

At two weeks after each spray application, plants were examined for leaf scorch, stunted growth, death of the growing point, or other possible symptoms of phytotoxicity, and for obvious spray deposit.

Results and discussion

Powdery mildew was first observed on 21 June 2011 when a total of eight leaves were found affected. The number of affected leaves on 5 July (two weeks after the third spray) was still low and ranged from 1.1 to 4.2 per plant and there were no significant differences between treatments (P >0.05). An assessment of disease severity was done one week later (26 July) (Table 1.3). Disease severity was greater on the lower leaf surface (1.8 – 6.2% leaf area affected) than the upper (0.1 – 0.7%). Treatment had no significant effect (P >0.05) on disease severity on either upper or lower leaf surfaces, or the combined data (Table 1.3).

A further disease assessment was done on 19 August, around one week after the final spray applications. Disease levels had changed little from that recorded one month earlier. There was no significant (P >0.05) treatment effect on total % leaf area affected (range 2.6 - 5.1%), the proportion of leaves affected or the proportion of flowers affected (Table 1.3).

Each plant was assessed for overall quality on a 0-5 scale on 19 August. Although fungicide treatment had no significant effect (P >0.05) on the mean plant quality score (range 2.9 to

4.3), several of the programmes significantly increased (P <0.001) the proportion of plants with a quality score of 3 or more. These plants had a greater number of clean, bright green leaves. This effect was most evident with treatments 6 (Signum/Cyflamid/Nativo 75WG) and 7 (Serenade ASO/potassium bicarbonate); these products (except for Cyflamid which was not tested), all gave good or very good control of rose powdery mildew when examined as individual products in 2010.

None of the fungicide programmes resulted in leaf scorch, growth distortion, stunting or other obvious adverse effects.

Due to the low severity of powdery mildew that developed in this experiment, no conclusions can be drawn as to the relative efficacy of the different fungicide programmes on rose. For the same reason, it is difficult to comment on the usefulness of the powdery mildew prediction model (Appendix 2). However, powdery mildew was first observed on 21 June, over a month after the first of nine days when an infection risk score of 4% or more was recorded, suggesting no mildew inoculum was present in the trial until shortly before 21 June.

The low severity of powdery mildew was surprising as the weather during the experiment was largely warm and dry, considered favourable to powdery mildew; severe powdery mildew developed in crops of aquilegia and phlox at another site in Norfolk used in this project. Possibly the rose variety used is not as susceptible to powdery mildew as reported by growers; or possibly there was insufficient high humidity to favour mildew development. The mean daily humidity was rarely above 80% during the trial period while the mean day and night relative humidities were 66% and 76% respectively (Appendix 3), supporting this latter explanation. The high temperatures (>30°C) in late June would also have been unfavourable to powdery mildew.

Table 1.3. Effect of fungicide programmes on rose powdery mildew – 2011

Treatment		% LAI (26 July)			% LAI (19 Aug)	% leaves affected (19 Aug)	% flowers affected (19 Aug)
		Upper	Lower	Total			
1.	Untreated	0.7	4.1	4.8	3.2	48	3.3
2.	Thiovit Jet[c]/Signum[a]	<0.1	3.4	3.4	5.1	58	5.0
3.	Switch[b]/Signum[a]	0.3	1.8	2.1	2.7	42	28.2
4.	Systhane 20EW[b]/Signum[a]	0.1	2.6	2.7	3.7	55	13.9
5.	For/Sig/For/Sig/Sys/Sys	0.1	3.4	3.5	2.5	38	15.2
6.	Sig/Cyf/Nat/Sig/Cyf/Nat	0.2	4.5	4.8	4.6	55	9.7
7.	Ser[d]/Ser/Ser/$KHCO_3$[c]/ $KHCO_3$[c]/$KHCO_3$[c]	0.5	3.6	4.0	3.3	47	13.5
8.	-/-/-/Sig+ $KHCO_3$/Cyf/Nat	0.6	6.2	6.9	3.4	48	5.0
9.	Systhane 20EW/Nimrod[a]	0.4	5.4	5.8	2.6	38	12.7
10.	Model[e]	0.7	5.5	6.2	3.5	53	5.3
Significance (31 df)		NS	NS	NS	NS	NS	NS

Cyf – Cyflamid; $KHCO_3$ – potassium bicarbonate + Silwet L-77; Nat – Nativo 75WG;

For – Fortress; Sig – Signum; Sys – Systhane 20EW, LAI – leaf area infected

[a] Applied alternately, 6 sprays in total.

[b] Switch and Systhane 20EW were used in mixture with potassium bicarbonate.

[c] The adjuvant Silwet-L77 was used with potassium bicarbonate and Thiovit Jet.

[d] Serenade ASO applied until powdery mildew was confirmed in the trial; thereafter potassium bicarbonate + Silwet-L77 was used.

[e] Spray timing and product choice was aided by the rose powdery mildew prediction model devised at EMR. The treatments used were Systhane 20EW, Cyflamid, Systhane 20EW, Nimrod.

Table 1.4. Effect of fungicide programmes on rose powdery mildew – 2011 (Final assessment)

Treatment	Plant quality (0-5) on 19 August		
	Mean quality score	% with score 3 or more	% with score 4 or more
1. Untreated	3.0	72 (6.2)	33 (8.1)
2. Thiovit Jet[c]/Signum[a]	2.9	85 (6.8)	50 (5.3)
3. Switch[b]/Signum[a]	3.7	85 (6.8)	55 (12.0)
4. Systhane 20EW[b]/Signum[a]	3.7	95 (4.3)	63 (11.9)
5. For/Sig/For/Sig/Sys/Sys	3.5	80 (7.6)	60 (11.9)
6. Sig/Cyf/Nat/Sig/Cyf/Nat	4.3	100 (0.0)	95 (5.4)
7. Ser[d]/Ser/Ser/$KHCO_3$[c]/$KHCO_3$[c]/$KHCO_3$[c]	4.2	100 (0.0)	85 (8.6)
8. Ser[d]/Ser/Ser/Sig+$KHCO_3$/Cyf/Nat	3.1	80 (7.6)	35 (11.5)
9. Systhane 20EW/Nimrod[a]	3.9	90 (5.8)	70 (11.1)
10. Model[e]	3.5	85 (6.9)	50 (12.1)
Significance	NS	<0.001	<0.001

Cyf – Cyflamid; $KHCO_3$ – potassium bicarbonate + Silwet L-77; Nat – Nativo 75WG;

For – Fortress; Sig – Signum; Sys – Systhane 20EW.

() – standard errors of means.

[a] Applied alternately, 6 sprays in total.

[b] Switch and Systhane 20EW were used in mixture with potassium bicarbonate.

[c] The adjuvant Silwet-L77 was used with potassium bicarbonate and Thiovit Jet.

[d] Serenade ASO applied until powdery mildew was confirmed in the trial; thereafter potassium bicarbonate + Silwet-L77 was used.

[e] Spray timing and product choice was aided by the rose powdery mildew prediction model devised at EMR. The treatments used were Systhane 20EW, Cyflamid, Systhane 20EW, Nimrod.

Evaluation of fungicide programmes for control of powdery mildew on aquilegia and phlox

Introduction

A large number of herbaceous plant species are commonly affected by powdery mildew diseases including *Erysiphe aquilegiae* on aquilegia and *Podosphaera fusca* on phlox. The suitability of treatments for use on herbaceous species to control powdery mildew depends on various factors including efficacy, crop-safety and product attributes (e.g. eradicant/protectant; non-systemic/systemic). Crop architecture may influence treatment efficacy according to the ease with which good spray coverage is achieved. For example, aquilegia has layers of leaves close together near the ground, a difficult spray target, whereas phlox has more evenly spaced leaves with plant height. Several new fungicides used on cereals and some major horticultural crops offer potential for improved control of powdery mildew diseases on herbaceous plants. However, many herbaceous plants have 'soft growth' and consequently may be susceptible to scorch or other damage from certain treatments. In Year 1, the efficacy and crop-safety of individual products was determined. The aim of the work in Year 2 was to devise and test the efficacy of a range of fungicide programmes under conditions of natural infection.

Materials and methods

Site and crop details

Two experiments were done on a nursery in Norfolk using *Aquilegia* cv. Red Hobbit and *Phlox paniculata* cv. Blue Paradise in 9 cm pots. The aquilegia was a dense, low growing variety and the phlox a tall, open variety. Containers were stood on Mypex matting outside. Plants were watered from overhead and maintained following normal nursery practice, except that no fungicides were applied. A crop diary is given in Appendix 4. Temperature and humidity were recorded using a Tinytag logger positioned close to plants.

Treatments

Details of treatment programmes (Table 2.1) are shown below. Details of individual products are given in Table 1.2. The programmes tested were identical to Treatments 1 to 7 used on rose (see section 1).

Table 2.1: Fungicide programmes examined for control of powdery mildew on aquilegia and phlox - 2011

Treatment	Situation(s) for use	Spray date and product							
		21/6	5/7	22/7	5/8	12/8	19/8	25/8	1/9
1. Untreated	-	-	-	-	-	-	-	-	-
2. Preventative	O + P	Thi	Sig	Thi	Sig	-	Thi	-	Thi
3. Preventative	O + P	Swi	Sig	Swi	Sig	-	Swi	-	Sys
4. Preventative	O + P	Sys	Sig	Sys	Sig	-	Sys	-	Sys
5. Preventative	O + P	For	Sig	For	Sig	-	Sys	-	Sys
6. 'High disease pressure'	O	Sig	Cyf	Nat	Sig	-	Cyf	-	Nat
7. 'Biological'	O + P	Ser	Ser	Ser	$KHCO_3$	-	$KHCO_3$	-	$KHCO_3$
8. 'Reactive'	O	-	-	-	Sig	Cyf	-	Nat	-

O – outdoor; P – protected.

Cyf – Cyflamid; For – Fortress; $KHCO_3$ – potassium bicarbonate; Nat – Nativo 75WG; Nim – Nimrod; Ser – Serenade ASO; Sig – Signum; Swi – Switch + potassium bicarbonate; Sys – Systhane 20EW + potassium bicarbonate; Thi – Thiovit Jet + Silwet L-77. A silicon based wetter (Silwet L-77) was added to Thiovit Jet and potassium bicarbonate (KHCO3)) at 0.025%

Treatments were applied as high volume sprays (1,000 L/ha) at a pressure range of 200-300 KPa using flatfan nozzles. Five sprays were applied at approximately 14 day intervals from 21 June to 19 August.

Experiment design and statistical analysis

In both experiments, treatments were arranged in a randomised block design with fourfold replication. Each plot consisted of 10 plants. Results were examined by ANOVA and Generalised Linear Modelling.

Disease assessment

Plants were examined at each spray application for symptoms of powdery mildew. Full disease assessments were done on 19 August, 9 September and 16 September. Powdery mildew incidence was assessed as the number of plants affected; disease severity was assessed as % leaf area affected on each plant. For aquilegia powdery mildew, disease severity was assessed both as leaf browning directly associated with mildew pustules, and

as leaf browning plus associated yellowing. For phlox powdery mildew, infection on upper and lower leaf surfaces was assessed separately.

Crop damage assessment

Immediately before each spray application, plants were examined for leaf scorch, stunted growth or other evidence of phytotoxicity, and for presence of obvious spray deposit. Spray deposit was assessed on a 0-3 scale (nil, slight, moderate, obvious) at 1 week after the final spray.

On aquilegia, the number of plants with obvious purpling, possibly a sign of low vigour, was assessed on 3 August. A mean plant vigour score was calculated for both aquilegia and phlox using the index: 0 – dead; 1 – poor growth; 2 – moderate growth; 3 – good growth; 4 – very good growth; 5 – excellent growth.

Results and discussion

Experiment 1: Fungicide programmes for control of powdery mildew on aquilegia - 2011

Powdery mildew was first observed on untreated plants, on 3 August. The disease occurred at a relatively high incidence, with 40% of untreated plants affected. All programmes except the reactive programme (treatment 8) significantly reduced disease incidence to 13% or less ($P<0.005$), but there were no significant differences between these fungicide programmes (Table 2.2). The reactive programme in treatment 8 gave no improvement over the untreated control, as no sprays had yet been applied in this treatment

Disease severity increased steadily over the next month, with 23% leaf area affected on untreated plants by 19 August and 51% by 9 September, one week after the final spray (Table 2.3).

At the assessment on 19 August, disease severity was reduced ($P <0.001$) by all treatments except for the 'reactive' spray programme, where only one spray had been applied at this time.

At the assessment on 9 September, one week after the final spray, all treatments were giving good control (including the 'reactive' spray programme), with no difference between them. Disease severity was reduced from 51% to 3-9% leaf area affected. At two weeks after the final spray application, disease levels had increased slightly but all treatments were still giving good control. Treatment 3 (Swi/Sig/Swi/Sig/Swi/Sys) resulted in the least disease (2.6% leaf area affected). This was closely followed by Treatments 2, 4, 5, 6, and 8. All of

these programmes were significantly better than Treatment 7 (Serenade ASO/potassium bicarbonate), which had 9.6% leaf area affected at this stage (Table 2.3). Apart from the untreated and Treatment 7 (Serenade ASO/potassium bicarbonate), the % leaf area affected by powdery mildew decreased between 19 August and 9 September. This is possibly because of plant growth over this period (new leaves and/or leaf expansion) which remained free of powdery mildew; the potassium bicarbonate was less effective than the other fungicides at protecting the new growth.

No adverse effects on crop growth were observed with any of the treatments. When assessed on 3 August, no significant treatment effect was detected on either plant vigour (score range 3.3 to 4.5) or leaf purpling (Table 2.2).

Table 2.2. Effect of fungicide programmes on aquilegia disease incidence and growth – 3 August, 2011

Treatment	% plants affected	Vigour (0-5)	Purpling (%)
1. Untreated	40 (9.9)	4.5	1.3
2. Thiovit/Signum	5 (4.7)	3.8	1.5
3. Switch/Signum	5 (4.7)	4.5	1.5
4. Systhane 20EW/Signum	5 (4.7)	3.3	2.3
5. Fortress/Signum	8 (5.7)	3.8	2.0
6. Signum/Cyflamid/Nativo 75WG	10 (6.5)	3.5	1.5
7. Serenade ASO/bicarbonate	13 (7.1)	4.0	2.0
8. Reactive to mildew	48 (9.9)	4.5	1.5
Significance (21 df)	0.005	NS	NS
LSD	-	-	-

(standard errors in parentheses)

Table 2.3. Effect of fungicide programmes on severity of aquilegia powdery mildew – 2011

Treatment		19 Aug		9 Sep*		16 Sep**	
		% brown	% brown + yellow	% brown	% brown + yellow	% brown	% brown + yellow
1.	Untreated	15.6	23.1	45.1	50.5	43.4	52.4
2.	Thiovit/Signum	8.6	13.1	2.0	4.3	3.1	5.2
3.	Switch/Signum	8.1	11.1	1.3	2.8	1.2	2.6
4.	Systhane 20EW/Signum	7.1	9.9	1.4	3.1	1.6	3.2
5.	Fortress/Signum	10.0	14.4	2.6	5.0	2.4	4.2
6.	Signum/Cyflamid/ Nativo 75WG	7.6	11.5	1.4	3.5	2.2	4.2
7.	Serenade ASO/bicarbonate	5.7	8.5	5.5	8.7	6.5	9.6
8.	Reactive to mildew	16.7	27.0	4.0	7.2	3.0	5.5
Significance (21 df)		0.002	<0.001	<0.001	<0.001	<0.001	<0.001
LSD		5.26	6.43	6.61	7.37	3.49	4.01

*1 week after final spray application

**2 weeks after final spray application

Experiment 2: Fungicide programmes for control of phlox powdery mildew – 2011

Phlox powdery mildew was first observed on 3 August at the same time as aquilegia powdery mildew. At this time, over 70% of untreated plants were affected by one or more spots of mildew, while levels on treated plants were nil (Treatments 3, 4 and 6), or 5% or less (Thiovit/Signum; Fortress/Signum; Serenade ASO/potassium bicarbonate) (Table 2.4).

Powdery mildew increased to affect 31% leaf area of untreated plants (upper leaf surface) by 19 August and 70% by 9 September. Disease severity was consistently greater on the lower leaf surface (Table 2.5).

All fungicide programmes significantly and greatly reduced disease severity. The 'reactive to mildew' programme was initially (19 August) less effective than other programmes, but was not inferior by the end of the trial (16 September) and required three fewer treatments than the other programmes. There was no difference between Treatments 2, 3, 4, 5, 6 or 8, all reducing the area affected on the upper leaf surface from 53% to 2% or less, and on the lower leaf surface from 75% to 7% or less. Treatment 7 (Serenade ASO/potassium

bicarbonate) was significantly less effective than other programmes, notably on the lower leaf surface where there was 27% leaf area affected on 16 September.

None of the fungicide programmes resulted in visible crop damage. When assessed on 3 August, after the application of three sprays, plant vigour (on a 0-5 scale) was significantly reduced (P = 0.012) from 3.8 (untreated) to 2.3 by Switch/Signum and to 2.8 by Serenade ASO/potassium bicarbonate (Table 2.4). There is no obvious explanation for this effect. It is possible that the differences recorded in plant vigour occurred by chance as the statistical significance was not very high (P = 0.012).

Table 2.4. Effect of fungicide programme on early growth and disease incidence on phlox - 2011

Treatment	3 Aug	
	Vigour (0-5)	% plant affected
1. Untreated	3.8	70 (4.5)
2. Thiovit/Signum	3.3	5 (2.4)
3. Switch/Signum	2.3	0 (0)
4. Systhane 20EW/Signum	3.8	0 (0)
5. Fortress/Signum	3.5	3 (1.7)
6. Signum/Cyflamid/Nativo 75WG	3.0	0 (0)
7. Serenade ASO/bicarbonate	2.8	5 (2.4)
8. Reactive to mildew	3.8	73 (4.4)
Significance (21 df)	0.012	-
LSD	0.86	-

standard errors in parentheses

Table 2.5. Effect of fungicide programmes on severity of phlox powdery mildew – 2011

Treatment		% leaf area affected					
		19 August		9 September		16 September	
		Upper	Lower	Upper	Lower	Upper	Lower
1.	Untreated	30.5	59.1	69.8	81.4	53.3	75.0
2.	Thiovit/Signum	0.5	3.7	0.3	5.7	0.2	4.5
3.	Switch/Signum	0.8	2.8	0.7	6.1	0.6	5.3
4.	Systhane 20EW/Signum	0.2	2.2	2.1	3.9	1.1	1.7
5.	Fortress/Signum	0.4	6.2	1.3	4.9	0.6	2.9
6.	Signum/Cyflamid/ Nativo 75WG	0.5	1.8	1.9	5.9	1.0	3.8
7.	Serenade ASO/bicarbonate	7.2	16.5	5.2	22.8	6.4	26.9
8.	Reactive to mildew	2.3	9.2	2.0	7.9	1.7	6.8
Significance (21 df)		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
LSD		9.30	10.11	1.49	2.48	5.45	4.11

Evaluation of fungicides for duration of protection against aster powdery mildew

Introduction

Information on the relative duration of preventative activity provided by different fungicides against powdery mildew is limited. Such information can be used to help determine an appropriate interval between fungicide treatments. Work in HNS 156 on hawthorn powdery mildew, where a single spray was applied to field-grown seedlings visibly affected by powdery mildew (c. 5% leaf area affected), showed that up to three weeks protection from disease spread was provided according to the fungicide used; Thiovit Jet + Silwet L-77, Signum and Flexity provided the greatest duration of protection. The aim in the current work was to compare the duration of protection against powdery mildew when fungicides are applied to plants unaffected by powdery mildew. An experiment was done on aster to compare the protection afforded by different fungicides applied 1, 7 or 14 days before artificial inoculation with powdery mildew (*Golvinomyces cichoracearum*).

Materials and methods

Experiment details

The experiment was done on detached shoots of aster cv. Purple Dome in the Plant Pathology Laboratory at ADAS Boxworth. Shoots around 15 cm in length were cut from container-grown aster plants (unaffected by powdery mildew) that had been treated with fungicides 1, 7 or 14 days previously and placed in small plastic tubes (3cm diameter) with the cut end in water. Each shoot was artificially inoculated within a few hours of cutting and then enclosed from the top in a perforated clear plastic bag, secured around the plastic tube with tape, to prevent contact between adjacent shoots, then trays of shoots were placed in a propagation tray covered with a Perspex top to maintain high humidity (Figure 3.1).

Figure 3.1: Incubation of aster shoots following dry spore inoculation with powdery mildew (Perspex top removed).

Treatments

Fungicide sprays were applied to whole plants grown in 2L pots at ADAS Boxworth at,14, 7 or 1 day before inoculation with aster powdery mildew. Nine fungicides and an untreated control were examined (Table 3.1), resulting in 30 treatment x timing combinations.

Table 3.1: Fungicides examined for duration of protectant activity against aster powdery mildew - 2011

Product	Active ingredients	Rate used	Approval
1. Untreated	-	-	-
2. Cyflamid	50 g/L cyflufenamid	0.5 ml/L	SOLA 0512/07
3. Flexity	300 g/L metrafenone	0.5 ml/L	SOLA 2850/08
4. Fortress	500 g/L quinoxyfen	0.25 ml/L	SOLA 2852/08
5. Nativo 75WG	50:25% w/w tebuconazole + trifloxystrobin	0.4 g/L	LTAEU*
6. Serenade ASO	13.96 g/L *Bacillus subtilis*	10 ml/L	SOLA 0246/09
7. Signum	26.7:6.7% w/w boscalid + pyraclostrobin	1.35 g/L	SOLA 1842/09
8. Switch	37.5:5.25% w/w cyprodinil + fludioxonil	1 g/L	Label
9. Systhane 20EW	200 g/L myclobutanil	0.3 ml/L	Label
10. Thiovit Jet + Silwet L-77	80% w/w sulphur + wetter	10 g/L + 0.025%	LTAEU*

* Used under the Long Term Arrangement for Extension of Use while a SOLA application is being assessed by CRD.

Treatments were applied as high volume sprays (1,000 L/ha) at a pressure range of 200-300 KPa using flatfan nozzles.

Inoculation

Plants were dry spore inoculated by tapping an aster leaf affected by powdery mildew over each shoot.

As a check against natural infection by powdery mildew occurring after artificial inoculation, or arising from latent infection, aster shoots from the same plants but untreated with fungicides and not inoculated were also set up.

The trays of inoculated shoots were maintained in the laboratory close to a window at ambient temperature (18-23ºC).

Assessments

Plants were examined every 3-5 days for 21 days after inoculation for presence of powdery mildew. The number of affected shoots and % leaf area affected were assessed.

Experiment design and statistical analysis

The experiment was arranged in factorial designs with two factors (delay between fungicide treatment and inoculation, and fungicide product) at three and 10 levels respectively. Treatments (30) were arranged in fully randomised blocks with fourfold replication. Each plot consisted of three shoots. Data from the three untreated controls was combined for comparison with the fungicide treatments. The experiment was repeated once. Results were examined by analysis of variance in Genstat.

Results and discussion

No powdery mildew developed on the uninoculated control shoots in either experiment. In Experiment 1, powdery mildew was found on a few leaves at 14 days after inoculation and on more leaves at 21 days after inoculation, when disease incidence and severity were assessed. The disease developed on no treatments where shoots were treated with fungicides 1 day previously, and on only three treatments (Cyflamid, Systhane 20EW and Thiovit Jet + Silwet L-77) where shoots were treated 7 days previously (Table 3.2); these infections were all at a low level (<5%).

On shoots from plants that had been sprayed with fungicides 14 days previously (i.e. 5 weeks before assessment), powdery mildew occurred in all treatments except for Systhane 20EW. The severity of mildew was 38% leaf area affected on untreated shoots, and was reduced by all the fungicide treatments ($P = 0.03$). Serenade ASO, Systhane 20EW and Thiovit Jet + Silwet L-77 had the least powdery mildew (3% or less), significantly less than that of most of the other fungicides (Table 3.2). Flexity was the least effective treatment when mildew was inoculated at 14 days after spray application, with 21% leaf area affected.

These results clearly show that the protectant effect of a single fungicide spray to aster plants declines over 14 days. When the results of all fungicide products are combined, the increase in mildew severity is tenfold between day 1 and day 7 and a further tenfold between day 7 and day 14 (Table 3.2). When the results of the three spray timings are combined, there was no significant effect of product on mildew severity ($P = 0.210$) (Table 3.3).

In Experiment 2, levels of powdery mildew on fungicide treated shoots were low with less than 1% leaf area affected (Table 3.4). There was a significant effect of fungicide treatment ($P < 0.001$), but no effect of fungicide timing or product (Table 3.5).

In Experiment 1, differences between individual products on plants treated 14 days previously were only just significant ($P = 0.03$) and should be treated with caution. It was noted that shoots treated with Thiovit Jet + Silwet L-77 had a greater number of fallen lower leaves than other treatments; possibly the persistence of control provided by Thiovit Jet + Silwet L-77 is an artifact if these leaves were more affected by mildew than the remaining attached leaves. The persistence of control provided by Serenade ASO may reflect multiplication of *Bacillus subtilis* on treated leaves under the particular conditions of this experiment, which contributed to continued protection. However, it is noted that the product label for Serenade ASO recommends treatment every 7 days which implies poor persistence.

In a previous field experiment on hawthorn to determine the persistence of control of powdery mildew by a single spray of various fungicides (HNS 156), the most effective treatment was Thiovit Jet + Silwet L-77, supporting the results of the current laboratory experiment. In contrast to the current work, Flexity also provided persistent protection on hawthorn, with little increase in disease over a 3-week period. The laboratory experiment described above tested products over a longer period, of up to 5 weeks (two weeks before inoculation and three weeks incubation), which, together with the different crop and experimental procedure, may explain the differing results for Flexity between the two experiments.

Table 3.2. Persistence of various fungicides and a biofungicide as protectant treatments against aster powdery mildew (Experiment 1) - 2011

Treatment	Mean % leaf area affected* on plants treated at intervals before inoculation:		
	1 day	7 days	14 days
1. Untreated	- [a]	- [a]	38[a]
2. Cyflamid	0	3	12
3. Flexity	0	0	21
4. Fortress	0	0	10
5. Nativo 75WG	0	0	13
6. Serenade ASO	0	0	3
7. Signum	0	0	11
8. Switch	0	0	15
9. Systhane 20EW	0	4	0
10. Thiovit + Silwet L-77	0	1	3
Significance (88 df)	-	0.03	-
LSD treated vs untreated[b]	-	6.9	-
LSD between treatments[b]	-	8.5	-

*Assessed 3 weeks after inoculation.

[a] Plants not treated with fungicide at 1, 7 and 14 days before inoculation are the same and results were combined.

[b] The LSD values shown are for product x timing comparisons.

Table 3.3. Overall effects of factors on severity of aster powdery mildew (Experiment 1) - 2011

Factors and comparisons	Replication	Mean % leaf area affected	Significance	LSD
Untreated vs treated				
No fungicide	12	38	<0.001	4.93 (max-min)
Fungicide	108	3		
Untreated vs timing				
Nil	12	38	<0.001	4.01 (min rep)
Day 1	36	<0.1		2.84 (max-min)
Day 7	36	1		
Day 14	36	10		
Untreated vs product				
Nil	12	38	NS (0.210)	-
Cyflamid	12	5		
Flexity	12	7		
Fortress	12	3		
Nativo 75WG	12	4		
Serenade ASO	12	1		
Signum	12	4		
Switch	12	5		
Systhane 20EW	12	1		
Thiovit Jet + Silwet L-77	12	1		

Table 3.4: Persistence of various fungicides and a biofungicide as protectant treatments against aster powdery mildew (Experiment 2) – 2011

Treatment	Mean % leaf area affected* on plants treated at intervals before inoculation:		
	1 day	7 days	14 days
1. Untreated	-	-	36.7
2. Cyflamid	0	0	0.3
3. Flexity	0	0	0.2
4. Fortress	0	0	0.2
5. Nativo 75WG	0	0	0
6. Serenade ASO	0	0	0
7. Signum	0	0.1	0.2
8. Switch	0	0	0.3
9. Systhane 20EW	0	0	0.1
10. Thiovit + Silwet L-77	0	2.8	0
Significance (88 df)	-	NS	-

* Assessed 3 weeks after inoculation.

Table 3.5. Overall effects of factors on severity of aster powdery mildew (Experiment 2) - 2011

Factors and comparisons	Replication	Mean % leaf area affected	Significance	LSD
Untreated vs treated				
No fungicide	12	36.7	<0.001	6.92
Fungicide	108	0.1		
Untreated vs timing				
Nil	12	36.7	NS	-
Day 1	36	0		
Day 7	36	0.3		
Day 14	36	0.1		
Untreated vs product				
Nil	12	36.7	NS	-
Cyflamid	12	0.1		
Flexity	12	0.1		
Fortress	12	0.1		
Nativo 75WG	12	0		
Serenade ASO	12	0		
Signum	12	0.1		
Switch	12	0.1		
Systhane 20EW	12	<0.1		
Thiovit Jet + Silwet L-77	12	1.0		

Evaluation of fungicides for control of established powdery mildew on aster

Introduction

Some fungicides are known to differ in their effectiveness in controlling established powdery mildew. On strawberry for example, potassium bicarbonate plus wetter gives good control of established powdery mildew and has relatively little preventative activity while the reverse is true for Fortress. Information on the relative efficacy of many other fungicides in controlling established powdery mildew is lacking. The aim of this experiment was to determine the relative efficacy of nine fungicides in controlling established powdery mildew on aster. A second aim was to determine if a programme of two sprays in the autumn delays the appearance of powdery mildew in the spring.

Materials and methods

Site and crop details

Work was done at ADAS Boxworth using 2L container-grown aster cv. Purple Dome naturally infected with powdery mildew. Containers were stood on Mypex matting in the open, in an area protected from wind by netting. Plants were cut down to around one third of their original height, ensuring that each plant retained at least five fully green leaves (with visible powdery mildew). Plants untreated with fungicide were located away from the experiment, around 20 m downwind. A crop diary is given in Appendix 6.

Treatments

Details of treatments are given in Table 4.1. Products were each applied twice, on 18 and 25 October, at 1,000 L/ha at a pressure range of 200-300 KPa using flatfan nozzles.

Table 4.1: Details of fungicides evaluated for control of established powdery mildew on aster

Product	Active ingredients	Rate of use	Approval status	
			Outdoor	Protected
1. Untreated	-	-	-	-
2. Cyflamid	50 g/L cyflufenamid	0.5 L/ha	SOLA 0512/07	-
3. Flexity	300 g/L metrafenone	0.5 L/ha	SOLA 2850/08	-
4. Fortress	500 g/L quinoxyfen	0.25 L/ha	SOLA 2852/08	SOLA 2852/08
5. Nativo 75 WG	50:25% tebuconazole + trifloxystrobin	0.4 kg/ha	LTAEU	-
6. potassium bicarbonate + Silwet L-77	$KHCO_3$ + wetter	10 g/L + 0.025%	Commodity substance	Commodity substance
7. Systhane 20EW	200 g/L myclobutanil	225 ml/ 750 L	Label	-
8. Signum	26.7:6.7% boscalid + 500 g/L pyraclostrobin	1.35 kg/ha	SOLA 1842/09	-
9. Swift SC	500 g/L trifloxystrobin	0.5 L/ha	SOLA 2882/08	-
10. Switch	37.5:5.25% cyprodinil + fludioxonil	1 kg/L	Label	-

Experiment design and statistical analysis

Treatments 2-10 were arranged in a randomised block design with four replicates. Each plot contained five plants arranged pot tight in a square around a central plant. Plots were arranged 2 m apart to reduce interplot interference. The design could not be fully randomised since the untreated controls (eight replicates) were located 20 m downwind to reduce risk of spores from these plants infecting new growth in the spring. Plants were blocked according to severity of powdery mildew. Results were examined by ANOVA and generalised linear modelling as appropriate for the data.

Disease assessments

Individual plants were assessed for percentage leaf area affected by powdery mildew on 1 November at one week after the second spray application. New growth was assessed for powdery mildew every one to two weeks between 26 April and 6 July 2011.

Results and discussion

All treatments reduced disease severity compared with the untreated control (37% leaf area affected) when assessed at 1 week after the second spray (Table 4.2). Treatment with

potassium bicarbonate + Silwet L-77 resulted in the least disease (11% leaf area affected). This result is consistent with the known eradicant activity of this treatment.

There was no significant difference between the individual fungicide products.

In 2011, powdery mildew was confirmed on new growth of two of the untreated plants on 19 May. The disease remained at a low level and was not found on other plants. No powdery mildew was found on any of the fungicide treated plants. One possible conclusion is that a combination of cutting back and application of two fungicide sprays in the autumn is an effective treatment for reduction of overwintering powdery mildew on aster. However, given the low level of powdery mildew that occurred on untreated plants in spring 2011, its relatively late occurrence, and the failure to find mildew on any of the numerous plants in other treatments, results should be interpreted with caution. The occurrence of powdery mildew on untreated plants in spring 2011, and failure of the disease to develop on plants treated with fungicide the previous autumn, may be a chance occurrence.

Table 4.2: Efficacy of fungicides in controlling established powdery mildew on container-grown aster – Cambs, 2010

Treatment	Mean % leaf area affected (1 Nov)
1. Untreated	37.2
2. Cyflamid	19.4
3. Flexity	21.1
4. Fortress	22.9
5. Nativo 75WG	20.2
6. Potassium bicarbonate + Silwet L-77	11.0
7. Systhane 20EW	14.4
8. Signum	15.8
9. Swift SC	17.1
10. Switch	11.6
Significance (30 df)	<0.001
LSD between treatments	13.21
vs untreated	11.44

Project conclusions

Rose powdery mildew

1. High volume sprays of six fungicides, three coded products, a biofungicide (Serenade ASO) and a commodity substance (potassium bicarbonate) + wetter (Silwet L-77) applied at 14 day intervals all significantly reduced powdery mildew on rose under natural infection conditions.
2. Control of powdery mildew incidence on rose leaves and flowers was less effective with Serenade ASO than other treatments
3. Potassium bicarbonate plus Silwet L-77 was as effective as the fungicide treatments.
4. Potassium bicarbonate plus Serenade ASO was less effective than potassium bicarbonate + Silwet L-77; it gave control similar to Serenade ASO alone.
5. There was no significant difference between any of the fungicide treatments. At 2 weeks after the fourth spray application, disease reduction by fungicides ranged from 68% (Kindred) to 99% (Nativo 75WG).
6. None of nine fungicide programmes used on rose cv. Ruby Wedding in 2011 caused any obvious crop damage.

Aquilegia and Phlox powdery mildews

1. High volume sprays of eight fungicides, a biofungicide (Serenade ASO) and a commodity substance (potassium bicarbonate + Silwet L-77) applied at 14 day intervals significantly reduced powdery mildews on Aquilegia and Phlox.
2. At the final disease assessment on phlox, 18 days after spray 5, Nativo 75WG and Signum had less than 1% leaf area infected compared with 70% on untreated plants; most other treatments were not significantly inferior, with disease levels ranging from 3.5% (Cyflamid) to 16.3% (Systhane 20EW).
3. Although Serenade ASO significantly reduced powdery mildew, on phlox it was less effective than the fungicide treatments. It was noticeably less effective against mildew on the lower leaf surface than the upper leaf surface.
4. Potassium bicarbonate + Silwet L-77 applied every 2 weeks was as effective as the conventional fungicide treatments in controlling powdery mildew on phlox.

5. Cyflamid, Nativo 75WG and Signum appeared to have a greater persistence of control than other treatments with very little increase in powdery mildew between 2 September (8 days after spray 3) and 7 November (17 days after spray 5).
6. After 5 sprays, Fortress at 0.25 L/ha, Nativo 75WG at 0.4 kg/ha and potassium bicarbonate at 10 g/L had a growth regulating effect, reducing the mean height of phlox stems by 2-4 cm.
7. Seven simple fungicide programmes, each based on two or three products, gave good control of powdery mildew on aquilegia and phlox.

Aster powdery mildew

1. Nine fungicides, each applied as two high volume sprays 7 days apart, all significantly reduced established powdery mildew on aster.

Aster: persistence of fungicide protection

1. A single spray of various fungicides to container grown aster gave almost complete control for 1 day, excellent control for 7 days and some control for 14 days.
2. Serenade ASO, Systhane 20EW and Thiovit Jet + wetter appeared to give slightly more persistent protection than the other fungicides tested.

Technology transfer

Presentations

Fungicide treatments for control of powdery mildew (Tim O'Neill). HTA tree and hedging group seminar, Wellesbourne, 22 September 2010.

Evaluation of fungicides for control of powdery mildew on aquilegia and phlox (Tim O'Neill). IPPS Conference, Ipswich, 7 October 2010.

Fungicide treatments for powdery mildews on herbaceous crops (Jason Pole and Tim O'Neill). Herbaceous Perennial Technical Discussion group seminar, London, 22 February 2011.

Fungicide treatments for powdery mildew (Tim O'Neill). East Grow Show, Norfolk, 3 August 2011.

Powdery mildew update (Tim O'Neill). Bransford Nurseries, Hereford, 24 October 2011.

Articles

O'Neill TM & Xu X (2010). Combined effort against mildew. *HDC News* **167**, 28-30.

O'Neill TM (2011). New treatments for herbaceous mildews. *HDC News* **170**, 24-25.

O'Neill TM (2012). Fungicide programmes for powdery mildew. *HDC News* (in press).

References

Cook RTA & Brown U (2009). Conidial germination patterns in powdery mildews. *Mycological Research* **113**, 616-636.

Tiffin D & Green KR (2005). Use of potassium hydrogen carbonate for powdery mildew control. HDC project CP 48, Final report.

Xu X (2010). Prediction and sustainable management of rose powdery mildew. HDC project HNS 165, Final Report.

Appendix *1. Rose crop diary*

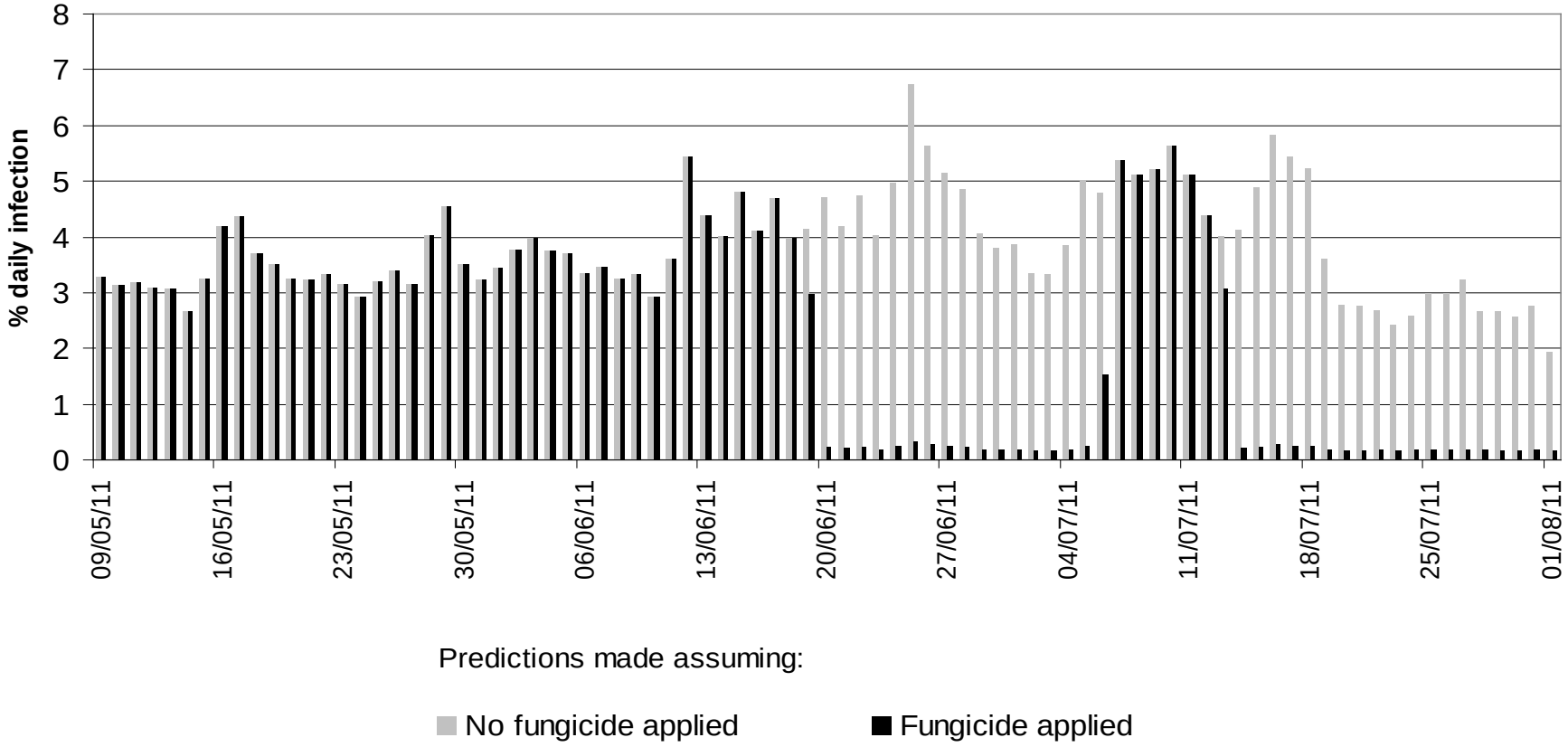
Rose: evaluation of fungicide programmes for control of powdery mildew

Trial Task	Date completed
Experiment laid out	27/04/2011
Spray 1 applied except Treatments 8 and 10	25/05/2011
Spray 2 applied except Treatments 8 and 10	07/06/2011
Spray 3 applied except Treatment 8	21/06/2011
Spray 4 applied. Assessment 1	05/07/2011
Spray 5 applied. Leaf samples brought back, PM confirmed	13/07/2011
Spray 6 applied.	22/07/2011
Assessment 2	26/07/2011
Final Spray and untreated assessment (Assessment 3)	05/08/2011
Assessment 3 and flower assessment	12/08/2011
Quality assessment and trial cleared up	19/08/2011
Data tabulated and analysed	24/08/2011

Temperature and humidity records for Rose

	Overall mean Temp °C		Overall mean % Humidity	
	Day	night	Day	night
Logger data **6th May to 2nd August**	16.70	14.37	66.27	75.97

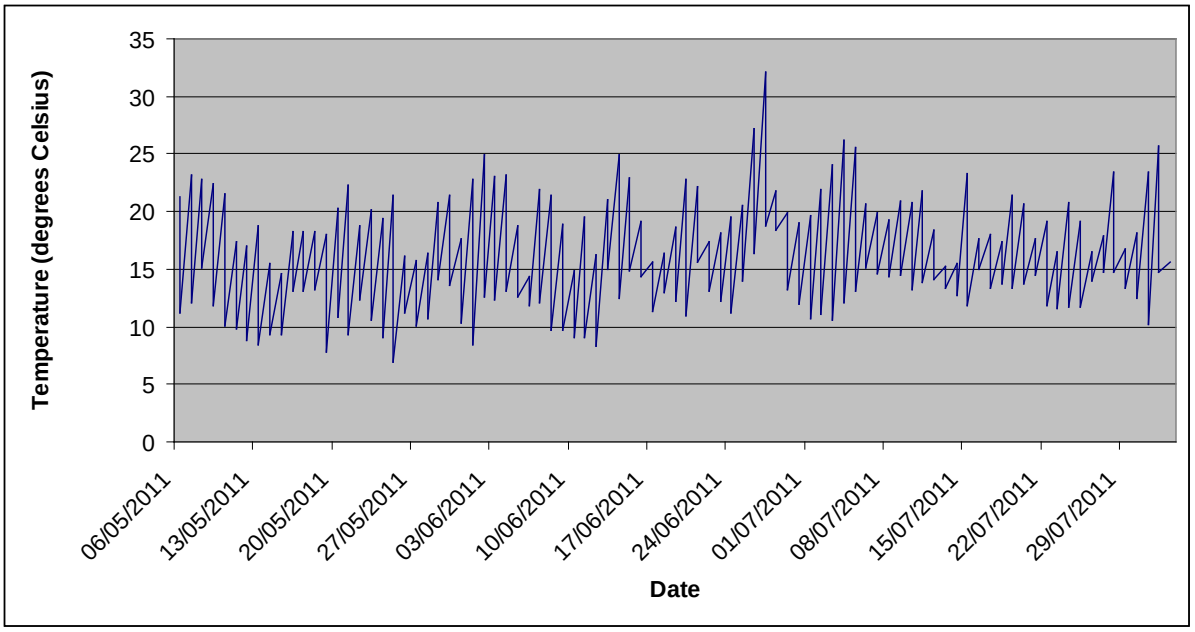
Appendix 2. Predicted mildew infection risk on rose



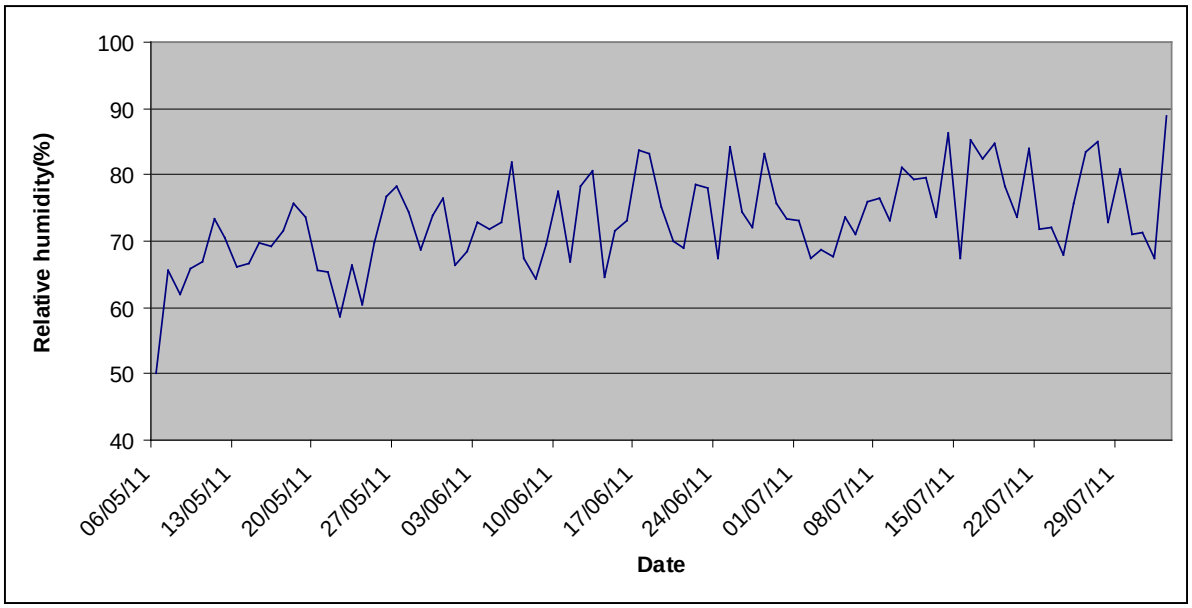
Daily powdery mildew infection predictions for rose, based on EMR prediction model, Norfolk trial, 2011

Appendix 3. Temperature and humidity records - rose

Temperature graph for Rose



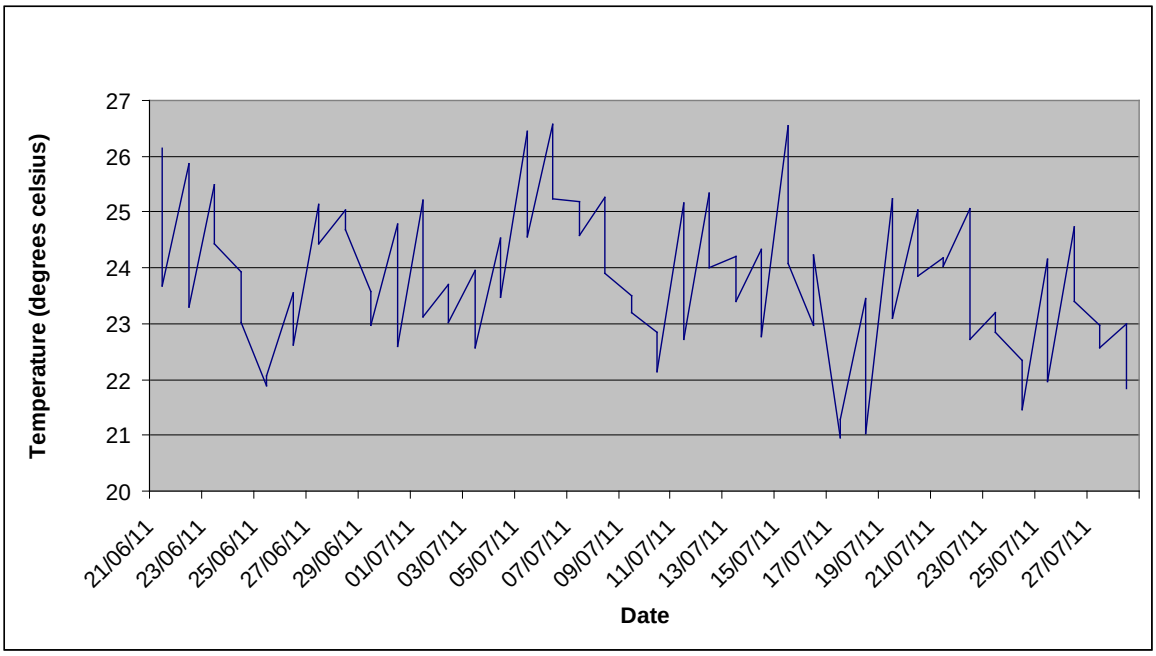
Relative humidity graph for Rose



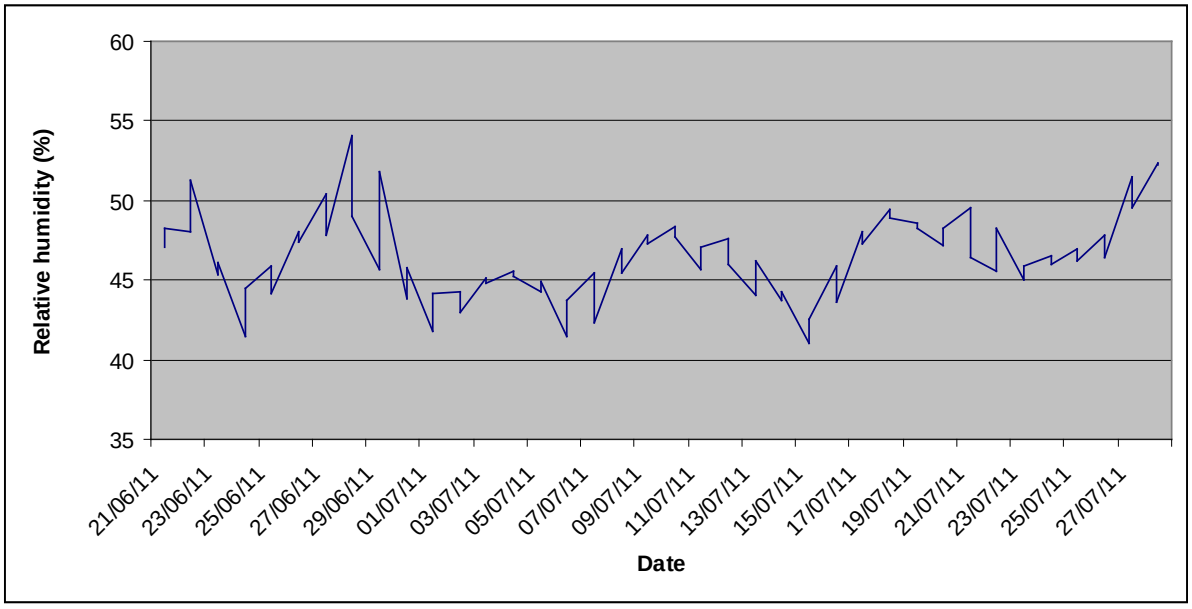
Appendix 4. Aquilegia and phlox crop diary and records

Trial Task	Date completed
Experiment laid out and spray 1 applied	21/06/2011
Spray 2 applied	05/07/2011
Spray 3 applied.	22/07/2011
Assessment 1	03/08/2011
Spray 4 applied	05/08/2011
Spray 5 applied	19/08/2011
Assessment 2	19/08/2011
Data tabulated and analysed	25/08/2011

Temperature graph for aquilegia and phlox



Humidity graph for aquilegia and phlox



Temperature and humidity records for aquilegia and phlox

	Overall mean Temp °C		Overall mean % Humidity	
	Day	night	day	night
Logger data **21st June to 6th July**	23.51	13.84	56.41	84.57

Appendix 5. Aster powdery mildew experiment diaries and records

Aster powdery mildew dry spore experiment: Run 1

Trial Task	**Date completed**
Powdery mildew infected aster plants collected	07/07/2011
Untreated shoots set up in propagator	11/07/2011
Spray applied to treatments 21-30 (14 day pre-inoculation spray)	12/07/2011
Spray applied to treatments 11-20 (7 day pre-inoculation spray)	19/07/2011
Spray applied to treatments 1-10 (1 day pre-inoculation spray)	25/07/2011
Shake infector plants to remove old conidia	25/07/2011
Set up experiment and inoculate treatments 1-30	26/07/2011
31-33 remain Uninoculated	26/07/2011
No powdery mildew observed on untreated shoots	02/08/2011
Full assessment completed. Run 1 cleared up	09/08/2011

Temperature and humidity records for Aster Run 1

	Overall mean Temp °C		Overall mean % Humidity	
	Day	night	day	night
Logger data **28th July to 9th August**	24.76	22.79	45.45	47.38

Aster powdery mildew dry spore experiment: Run 2

Trial Task	Date completed
Spray applied to treatments 21-30 (14 day pre-inoculation spray)	13/09/2011
Spray applied to treatments 11-20 (7 day pre-inoculation spray)	20/09/2011
Spray applied to treatments 1-10 (1 day pre-inoculation spray)	26/09/2011
Shake infector plants to remove old conidia	26/09/2011
Set up experiment and inoculate treatments 1-30	27/09/2011
31-33 remain Uninoculated	27/09/2011
7 day disease assessment. PM found on some untreated shoots	04/10/2011
14 day disease assessment. PM found on untreated shoots	11/10/2011
21 day disease assessment. Trial cleared up	18/10/2011

Appendix 6. Aster powdery mildew overwintering experiment

Trial Task	**Date completed**
Infected plants cut to 1/3 height and potted into 3L pots. Trial laid out and spray 1 applied	14/10/2010
Spray 2 applied	21/10/2010
Assessment of powdery mildew appearance	28/10/2010
Wind damage to 3 plots	07/02/2011
New shoots starting to grow up from base	18/02/2011
Previous year's growth cut back to soil level and left to re-grow	24/02/2011
Applied Nemasys L at a rate of 62ml per pot	11/03/2011
Applied Nemasys L at a rate of 62ml per pot	15/03/2011
Powdery mildew inspection - none present on any plots	26/04/2011
Powdery mildew inspection - none present on any plots	11/05/2011
Powdery mildew inspection - present on two UT plants only	19/05/2011
Powdery mildew inspection- still only on untreated plots	24/06/2011
Powdery mildew inspection- still only on untreated plots	06/07/2011
Trial cleared up	11/07/2011