Project title:	Outdoor lettuce: forecasting and control of Sclerotinia
Project number:	FV 294
Project leader:	Dr Caroline Young, ADAS
Report:	Final report, 30 September 2008
Previous report	30 September 2007
Key staff:	Dr Caroline Young, ADAS, Plant pathologist Dr Laura Fawcett, ADAS, modeller Dr John Clarkson, Warwick-HRI, Sclerotinia expertise and inoculum
Location of project 2008:	Site 1: Merrymac Salads, Mudds Drove, Three Holes, Wisbech, Cambs PE14 9JU, field location GR TL 675 898, nr Feltwell Site 2: G's, G S Shropshire & Sons, Pioneer & Severals, Wissington, Kings Lynn, Norfolk PE33 9SA, field location GR TL 672 956, Severals Farm, nr Wissington
Project coordinator:	John Sedgwick, Kettle Produce, Balmalcolm, Cupar, Fife KY15 7TJ.
Date project commenced:	1 October 2006
Date project completed (or expected completion date):	30 September 2008
Key words:	Field lettuce, Sclerotinia, fungicides

The results and conclusions in this report are based on an investigation conducted over a two-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

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.

Dr Caroline Young
Plant Pathologist
ADAS UK Ltd

Signature .... Date ....

Dr John Clarkson
Plant pathologist
Warwick HRI

Signature .... Date ....

Report authorised by:

Dr W E Parker
Horticulture Research & Consultancy Manager
ADAS UK Ltd

Signature .... Date ....

[Name]
[Position]
Warwick HRI

Signature .... Date ....

GROWER SUMMARY

Headline

- A forecasting model for Sclerotinia in outdoor lettuce was successful in predicting germination of *Sclerotinia sclerotiorum* inoculum in soil and a single spray, timed according to the model, was as effective as a two or three-spray programme.

- In a fungicide experiment, Sclerotinia disease was best controlled by Signum (boscalid + pyraclostrobin), Switch (cyprodinil + fludioxonil), Amistar (azoxystrobin), or two new fungicide products. Rovral 75WG and Octave did not control Sclerotinia. No fungicides prevented downy mildew infection, but Amistar (azoxystrobin) treated lettuce had the lowest percentage leaf area affected by downy mildew.

Background and expected deliverables

Sclerotinia disease is a common problem in outdoor lettuce, sometimes causing very high losses. A large proportion of crops are treated with fungicide routinely. The fungus produces resting bodies (sclerotia) in infected plants. The sclerotia become incorporated into soil and can germinate the following year in spring to produce apothecia, the fungal fruiting bodies which release the spores that can infect lettuce. One problem with control of Sclerotinia in outdoor lettuce is the difficulty of timing fungicide applications or justifying omission of sprays. There is good potential to improve fungicide timing using a forecasting model that predicts when sclerotia will germinate. The background data on which to base a forecasting model have been generated in a previous Defra-funded project (HH3215TFV, 'Forecasting Sclerotinia in field-grown lettuce'), in which the environmental conditions leading to germination of sclerotia were determined. In this HDC project, the aim was to produce and field-test a model with predictive capability for sclerotial germination. The model has been incorporated into MORPH, the software used to operate the decision support models for various pests and diseases, developed at Warwick-HRI. The next MORPH update is planned to be released in April 2009, and the Sclerotinia prediction model will be fully functional in this version.

The number of fungicides for use on lettuce against Sclerotinia, and the number of applications permitted per crop, is limited. Therefore, in addition to field experiments to test the Sclerotinia forecasting model, fungicide experiments were set up to test various products for efficacy against Sclerotinia. Downy mildew and Botrytis infections were also assessed.

The objectives of this project were as follows:

1. To develop a Sclerotinia disease forecasting model and incorporate it into the disease forecasting system MORPH (developed at Warwick-HRI).
2. To evaluate the efficacy of Sclerotinia disease control on lettuce using fungicide spray applications timed according to the forecasting model.
3. To compare the efficacy of different fungicides for Sclerotinia control.

Summary of the project and main conclusions

Development and evaluation of the Sclerotinia forecasting model

In summary, the forecasting model:

- has been developed from a non-predictive model to forecast time to 10% germination of sclerotia (T10) as an indicator of the onset of a flush of apothecia.
- is adapted to operate with in-field data, recorded every half-hour. The minimum data required are soil temperature at 1 cm depth (or air temperature if soil temperature not available) and rainfall. Hourly or daily data can be used if necessary and 30 cm soil depth temperature prior to lettuce planting will be used if available.
- has similar predictive capability to the original simulation model.
- uses historical weather data in the forecast and is updated as new data become available.
- includes an option to simulate fleeced crops.

- has been developed using data from one of the fastest germinating Sclerotinia isolates to indicate the earliest onset of an apothecial flush.
- uses weather data from the last cultivation date in the autumn and/or any cultivation dates thereafter which may bring sclerotia to optimum depths for germination.
- the model is a predicted date for germination of 10% of sclerotia.

The model has now been programmed into MORPH. It will be available in the next update of MORPH, planned for April 2009.

In 2008 the model was tested at two sites with the same growers as in 2007 but using different fields (site locations given in Table 1 below). At both sites, experiment plots were marked out in the farm crops and sclerotia buried on the day of planting. There were 5 treatments for the Sclerotinia forecasting model experiment ('modelling experiment'):

1. Untreated
2. Fungicide sprays applied close to T10 (10% germination of sclerotia) as predicted by the Sclerotinia forecasting model
3. Fungicide applied at spray time 1 (early in crop development)
4. Fungicide applied at spray time 1 & 2 (early and mid crop development)
5. Fungicide applied at spray time 1, 2 & 3 (early, mid and late crop development)

Signum (boscalid + pyraclostrobin) was the selected fungicide used for treatments 2, 3, 4 and 5. The Sclerotinia forecasting model was started when sclerotia were buried at each field site on 19 October 2007. Each week post-planting the weather data logger was downloaded and checked on the same day or next day and the model run to predict T10. The T10 prediction was emailed or telephoned to the ADAS site manager so that preparation for treatment sprays could be made if the predicted time was imminent. For treatments 3, 4 and 5, appropriate plots were sprayed with Signum, at 2, 4 and 6 weeks after planting (dates given in Table 1). At both sites the spray timed according to the Sclerotinia forecasting model was as effective in controlling Sclerotinia disease as any of the other fungicide spray treatments and significantly better than the untreated control. The model tended to predict earlier sclerotial germination than was actually observed in grids between the lettuce plots where sclerotia had been previously buried. At Merrymac's, the spray on 24 April timed according to the prediction model was as effective as the early & mid crop sprays (16 April and 2 May), or the early, mid and late crop spray (late spray was 14 May) (Figure 1). At G's, for logistical reasons, the 'model' spray on 24 April was not applied at the correct time but was surprisingly effective and gave as good control of Sclerotinia as the early- and mid-crop sprays (31 Mar and 16 April) or the mid- and late-crop sprays (last spray was 2 May). At harvest on 5 June Sclerotinia disease was low at G's and there were no differences between the fungicide treatments but the 'model' spray was the most effective (Figure 1). However by 16 June the untreated plots at G's had 11.4% Sclerotinia, but the 'model' spray and the late fungicide spray were still effective, reducing Sclerotinia to 4% or less.

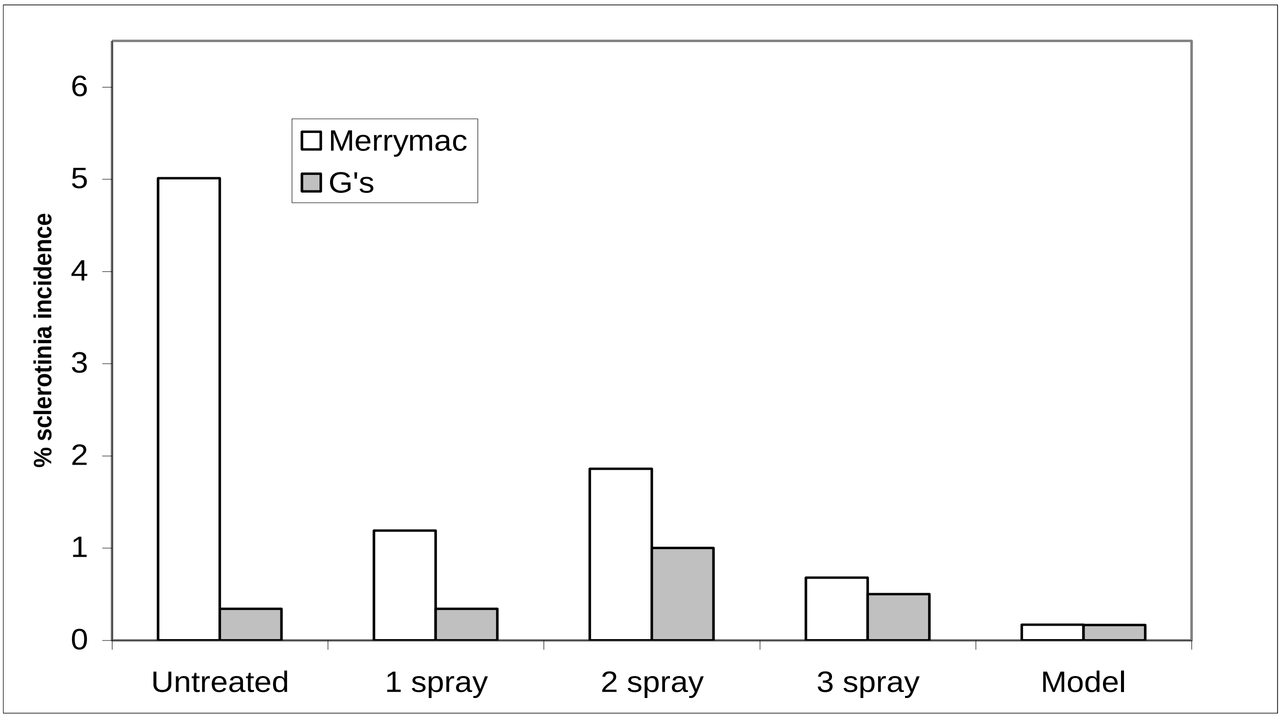


Figure 1. % lettuce with Sclerotinia at harvest, Merrymac (cv Challenge 13 June) and G's (cv Jiminy 5 June) 2008, for different spray timings of Signum (see Table 1 for dates).

Table 1. 2008, site summary for Sclerotinia modelling and fungicide experiments.

2008	Merrymac site	Gs site
Site GR	TL 675 898	TL 672 956
Farm	Nr Feltwell CW66, 8.9 ha	Severals Farm, Wissington
Field comments	peat soil	Field 21, 3 ha, peat soil
Previous crop	Winter wheat	Winter wheat
Date field last cultivated	03-Apr	06-Mar
Sclerotia first buried, 2007	19-Oct	19-Oct
Planting date & sclerotia in grids	03-Apr	07-Mar
Variety	Challenge (Iceberg)	Jiminy (Romaine)
Fleece type	Non-woven ('Tildenet')	Non-woven ('Tildenet')
Fleece on crop	03-Apr	07-Mar
Fleece off crop	02-May	09-May
Modelling & Fungicide experiments, 1st spray	16-Apr	31-Mar
Modelling & Fungicide experiments, 2nd spray	02-May	16-Apr
Modelling & Fungicide experiments, 3rd spray	14-May	02-May
Date of harvest	11-Jun	04-Jun
Date first apothecia seen in grids	02-May	16-Apr
Predicted T10, buried 19 Oct at 1 cm	25-Apr	15-Apr
Predicted T10, buried 19 Oct at 30cm	25-Apr	30-Mar
Apothecia first observed, buried 19 Oct at 1 cm	2 May	2 May
Apothecia first observed, buried 19 Oct at 30cm	29 May	16 Apr
Modelling experiment, 'model' spray	24-Apr	24-Apr
Sclerotinia disease, UT model	5.0 %	11.4 %
Sclerotinia disease, UT fungicide	5.0 %	6.8 %

Field experiments to compare Sclerotinia control using different fungicides

The crop sites and planting dates were the same as for the modeling experiment (see Table 1). A three-spray programme (Table 2) was selected for all fungicides, regardless of label restrictions, to ensure comparability between products, timed to ensure a sufficient minimum harvest interval for an early crop where the duration of the crop could only be estimated.

Table 2. 2008, G's and Merrymac: fungicides, spray timing and rates for field lettuce.

			Weeks post planting*									
No.	**Product**	**Active ingredient**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Rate**	**Water L/ha**
1	Untreated											
2	Amistar	azoxystrobin		x		x		x			1 L/ha	400
3	Signum	boscalid + pyraclostrobin		x		x		x			1.5 Kg/ha	400
4	Switch	cyprodinil + fludioxonil		x		x		x			0.8 Kg/ha	400
5	Rovral 75WG	Iprodione (not approved)		x		x		x			0.33 Kg/ha	400
6	UKA383c	Confidential		x		x		x			0.5 L/ha	400
7	UKA386a	Confidential		x		x		x			0.6 L/ha	400
8	Octave	prochloraz		x		x		x			0.2 Kg/ha	400

*Spray dates given in Table 1.

At Merrymac's, despite low levels of Sclerotinia disease there were significant differences by harvest observed between fungicides, with Amistar, Switch, UKA 383c and UKA386a all reducing Sclerotinia compared to Rovral 75WG and Octave which were similar to the untreated (Figure 2).

At G's there were no significant differences observed for Sclerotinia incidence at harvest, most probably because of low Sclerotinia levels due to the generally dry weather. However, by 16 June, at the last assessment made, there were still some effects of some of the fungicide treatments despite the fact that the last application was 2 May. Signum, Switch, UKA383c and UKA 386a still reduced Sclerotinia compared to the untreated, by 16 June.

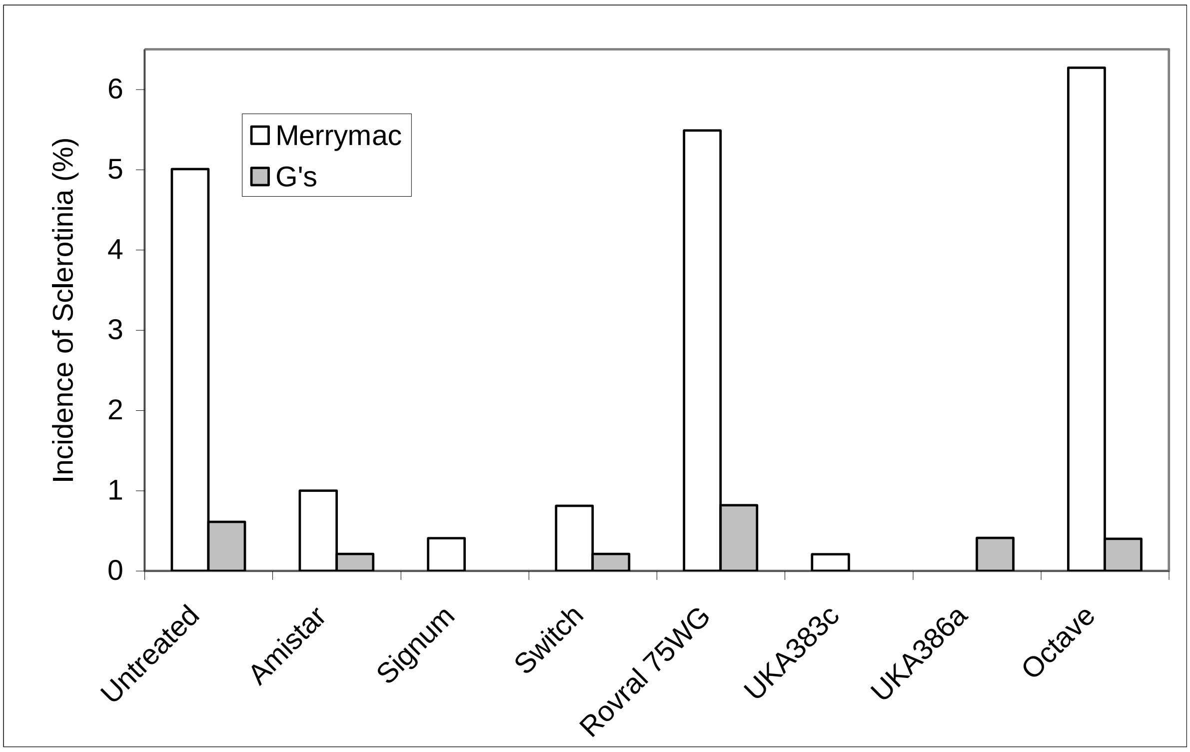


Figure 2. % lettuce with Sclerotinia at harvest, Merrymac (cv Challenge 13 June) and G's (cv Jiminy 5 June) 2008, fungicide experiment, All fungicides were applied three times, see Table 1 for dates.

At Merrymac's, downy mildew occurred all over the trial at 6% or less incidence, but there were no significant differences observed between fungicide treatments. At G's there was no downy mildew seen in the fungicide experiment, as expected, due to the good resistance of Jiminy to downy mildew. At Merrymac's there was no Botrytis observed and at G's only very low levels, with 0.05% or less incidence with all fungicides except Octave which had 0.35% incidence. Unlike 2007, there were no phytotoxic effects observed from any of the fungicide treatments (Switch caused some stunting in 2007 probably due to stress from lack of water).

At Merrymac's there were small differences between the trimmed weights for the various fungicide treatments, with the weights tending to reflect the level of Sclerotinia control. At G's, as for the untrimmed weights, there was no significant difference between the trimmed weights for the different fungicide treatments.

At Merrymac's there was no Sclerotinia development in the lettuce stored at ambient temperature for 12 days. At G's there was low Sclerotinia incidence after 9 days at ambient temperature. The range was 0 to 0.4% Sclerotinia incidence out of 25 plants, with no significant difference between the fungicide treatments.

Financial benefits

In summary, the cost of one fungicide spray is minimal compared to the production costs and the value of the lettuce crop. Therefore, the most important financial benefit from a Sclerotinia forecasting model is to improve timing of disease control to prevent crop loss, rather than saving the costs of one or more fungicide applications.

Cost of fungicide spray per hectare (Ha):

Approximately £30 per ha for chemicals and £5 per Ha for application costs = £35 per Ha.

Costs of lettuce production:

Fleecing, including layout and disposal - £675 per Ha

Seeds, blocks & planting – up to £2,010 per Ha

Fertiliser (depending on site fertility) - £720 per Ha

Other inputs (seed treatment, fungicides, insecticides, herbicides) - £980 per Ha

Total - £4,385 per Ha

Value of lettuce crop per ha:

For a typical crop of 78,000 heads of lettuce per Ha, worth £2.50 per dozen, which has a 62.5% cut at harvest, the value is £10,156 per Ha. Therefore, a 10% loss from Sclerotinia, not uncommon, is £1,015. Losses of 30% or more, or even the whole crop, have been reported (pers. comm., John Sedgwick, Kettle Produce), which has serious implications for customer supply, in addition to immediate financial losses.

Value of lettuce crop in the UK:

There are approximately 6,000 Ha of salad production in the UK (http://www.britishleafysalads.co.uk/). About 75% of this is estimated to be whole head lettuce, where Sclerotinia is most prevalent. The value of the crop ex-farmgate is estimated at £9,000 per hectare (average income required to cover cost of production/harvest/margin, but not including packaging). Therefore, if:

1% of UK whole head crop is lost to Sclerotinia each year, the loss is 4,500 Ha x £9,000 x 1% =£405,000 per year.

If 5% of UK crop has Sclerotinia, the loss is £2,025,000 per annum.

If 10% of UK crop has Sclerotinia, the loss is £4,050,000 per annum.

(In most years, losses are probably around 5%).

Action points for growers

- The Sclerotinia forecasting model will be available from HDC in the next update of MORPH which is planned for April 2009.
- To run the model in MORPH, growers will need planting date, rainfall and soil temperature (from mid-October the previous year) and dates of previous soil cultivations.
- On-site weather loggers will give better Sclerotinia predictions than regional weather data. MORPH can use yearly average data if necessary for all or some of the data.
- The forecasting model should be run before lettuce planting to determine whether fungicides are needed at, or close to, planting.
- The forecasting model should be run at approximately weekly intervals, and particularly if there has been a rain or irrigation event after a period without rain.
- MORPH does not currently use weather forecasts to run models. Growers may choose to take forecast weather into account when making decisions, e.g., if the weather is dry and the forecast is to remain dry, germination of sclerotia is likely to be delayed.
- Any sclerotia produced in infected plants at the beginning of the season will not present a risk to crops until the following year (they will need to over-winter before

they are able to germinate). When a field infested with sclerotia is re-planted with lettuce, infection will occur via sclerotia brought to the soil surface at the time of cultivation.

- In 2007, Sclerotinia risk was low and the experiment did not provide a good test of the fungicides. In 2008, Amistar, Signum, Switch, UKA 383c and UKA 386a all had good activity against Sclerotinia; Rovral 75WG and Octave were not effective.
- No fungicide tested prevented downy mildew infection. Amistar had the most activity against downy mildew in terms of % leaf area affected per plant, in 2007 and in 2008.
- Use of resistant or partly resistant cultivars for downy mildew if the disease is a known problem is recommended.
- Switch was the only fungicide to prevent Botrytis, but in both years the highest infection was only 4% of plants/plot affected.
- Fungicides from different chemical groups will need to be alternated, according to label instructions. This is to avoid the build-up of resistance to fungal pathogens. For example, Signum and Amistar are QoI (Quinone outside Inhibitor) fungicides and should not be used consecutively.

SCIENCE SECTION

Introduction

Most Sclerotinia disease on field vegetables in the UK is caused by the fungus *Sclerotinia sclerotiorum*, which is the species referred to here as 'Sclerotinia'. Sclerotinia survives in the soil as resistant resting bodies called sclerotia, which can remain viable for years. Under the right soil conditions, usually in spring, the sclerotia near to the soil surface produce small mushroom-like apothecia. These release airborne ascospores which infect plants. The fungus then grows within infected plants, causing rotting and plant death. Sclerotia also develop which subsequently become incorporated into soil to begin the disease cycle again. Sclerotinia disease in field lettuce tends to occur each year at low to moderate incidence, but with occasional severe outbreaks with heavy crop losses. Currently it is difficult to predict when these epidemics will occur, and hence decisions about the timing of treatments can be difficult to make.

The main problems with fungicidal control of Sclerotinia are the timing of fungicide applications to achieve good control, and the selection of an effective fungicide product. There is good potential to improve the timing of fungicide applications by developing a Sclerotinia disease forecasting model for practical use by growers. There are a few published forecasting systems for Sclerotinia on oilseed rape, but there is a need for an effective forecasting model for Sclerotinia disease for use in field lettuce. A major outcome of this project will be the development of a Sclerotinia forecasting model that can be used by growers. The main benefit of this to the industry is the potential to justify fungicide treatments and reduce the number of sprays needed. In addition, a forecasting system could result in improved efficacy of control through better timing of fungicide applications. A further objective of this project is improved control of Sclerotinia through a comparison of fungicide products. This, combined with development of a Sclerotinia forecasting model, would result in fewer losses for the industry. Some results from this project may also be applicable to other horticultural and agricultural crops susceptible to Sclerotinia, such as carrots, celery, parsnips, brassicas and oilseed rape.

The number of fungicides approved for use on lettuce against Sclerotinia is limited, and there is therefore interest in testing the relative efficacy of these against Sclerotinia as well as other common diseases, such as downy mildew and Botrytis. Amistar (azoxystrobin) is currently approved for control of Sclerotinia on lettuce (SOLA nos. 2004/0513 and 2001/1465 respectively). Signum (boscalid + pyraclostrobin) has full label approval for Sclerotinia control on outdoor lettuce. These act by killing the ascospores released by apothecia. New fungicides and others targeted at different diseases which may have some efficacy against Sclerotinia are also of interest in the present study. These include Amistar, Signum, Switch (cyprodinil + fludioxonil), Rovral 75WG, and Octave (prochloraz) and two formulations of a new product.

The objectives of this project were as follows:

1. To develop a Sclerotinia disease forecasting model and incorporate it into the disease forecasting system MORPH (developed at Warwick-HRI).
2. To evaluate the efficacy of Sclerotinia disease control on lettuce using fungicide spray applications timed according to the forecasting model.
3. To compare the efficacy of different fungicides for Sclerotinia control.

Materials and methods

The Sclerotinia germination model

The existing published model for carpogenic germination of *S. sclerotiorum* sclerotia (Clarkson *et al.*, 2007) was modified to run in a forecasting mode and tested with data from the 2007 and 2008 lettuce crop season. The derivation and development of the prediction model is presented in the 2007 report for this project. Briefly the model predicts two phases involved in the production of apothecia by *S. sclerotiorum* sclerotia: a conditioning phase (where the sclerotia require cold temperatures to break dormancy) and a subsequent germination phase where apothecia are produced. Firstly, the model uses soil temperature and rainfall data to calculate the rate of conditioning every half-hour. These values are then accumulated and the end of the conditioning phase is predicted when this cumulative value reaches 1. The germination part of the model then begins, again using soil temperature and rainfall data, this time accumulating germination rates such that 10% of sclerotia (T10) are predicted to have produced apothecia when the cumulation reaches 1. T10 is used as a prediction of when germination of sclerotia is first occurring in the field and hence when the first apothecia should appear. A new feature of the model developed this year is that it takes into account the depth that *S. sclerotiorum* sclerotia are buried at. Previous work and model simulations have suggested that unless sclerotia are very near the soil surface, they do not germinate but can still fully condition and achieve up to 80% of their subsequent germination progress (a cumulative germination model value of 0.8, where 1 = germination). Hence, sclerotia that are deeply buried because of tillage operations will not be able to fully germinate until they are brought to the surface by subsequent tillage.

Field site details

There were two field sites in 2008, located with the same growers as in 2007, but in different fields.

Site 1: Merrymac Salads (referred to in this report as 'Merrymac's', Mudds Drove, Three Holes, Wisbech, Cambs PE14 9JU, OS GR TL 675 898, in field CW66 (7.5 ha planted area), nr Feltwell.

The previous crop was winter wheat, with no cultivations after harvest until ploughing the week before fertilising on 27 March 2008 and power harrowed immediately prior to lettuce planting on 2 April 2007. Previous crops were potatoes, lettuce, winter wheat and dwarf beans, 2, 3, 4 and 5 years ago, respectively. Lettuce cv. Challenge (Iceberg) were planted as blocks on 3 April (4-5 true leaves) and harvested 11 June. The soil type was peat/organic, 67.2% organic matter, pH 7.3 with 28, 126 and 67 mg/l P, K and Mg mg/l respectively. The crop was grown under non-woven fleece (Tildenet 18g/m^2) from planting until 2 May. Irrigation (20mm) was applied using hose reels and booms between 15 and 19 May. Field application records are given in Appendix 1.

Site 2: G S Shropshire & Sons (referred to in this report as 'G's'), Pioneer & Severals, Wissington, Kings Lynn, Norfolk PE33 9SA, OS GR TL 672 956, in Field 21 (3 ha) at Severals Farm, nr Wissington.

The previous crop was winter wheat, with no cultivations after harvest until ploughing immediately prior to lettuce planting in March 2007. Lettuce cv. Jiminy (Romaine) (4-5 true leaves) were planted as blocks on 7 March 2007 and harvested 4 June. The soil type was peat/organic, 83.9% organic matter, pH 6.0 with 69.6, 145 and 77 mg/l P, K and Mg mg/l respectively. The crop was grown under non-woven fleece (Tildenet 18g/m^2) from planting until 9 May. Field application records are given in Appendix 1.

At both sites, experiment plots were marked out in the farm crops and sclerotia were buried on the day of planting.

Sclerotinia sclerotiorum isolates and production of sclerotia

The isolates used in this project were all derived from Sclerotinia infected lettuce plants. Details of the sources of the isolates and methodology used to produce sclerotia are given in the 2007 report for this project. Briefly, isolates 13 and TM were used to derive the original germination model (Clarkson *et al.,* 2004). Isolates HDC1_1 and 2_6 were 'local' isolates collected from fields near the experiment sites. Sclerotia were produced on sterile wheat grain.

Burials of sclerotia and inoculation of field experiments

Sclerotia from all *S. sclerotiorum* isolates were buried at a depth of 1cm or 30cm on 19 October 2007. This was done to simulate natural sclerotia produced on infected plants from the previous season being incorporated into different levels of the soil by tillage operations and hence test the importance of burial depth on subsequent germination. The burial time was chosen as results from year 1 where sclerotia were buried in December indicated the need to bury earlier as these sclerotia germinated later than disease appeared in the crop at Merrymac's, suggesting that the natural population of sclerotia had germinated earlier. In addition, preliminary results from testing the model using different burial dates also suggested that mid-October was an appropriate time to start the model. Other experiments where sclerotia were buried in October also supported this (BASF Sclerotinia monitoring bulletins, *http://www.totaloilseedcare.co.uk/downloads/disease.html*).

After the initial burials at 1cm and 30cm, sclerotia from all isolates were subsequently retrieved the following year and re-buried at 1 cm in grids (50 sclerotia x 3 reps per isolate) within the experimental plots, on the day of planting at each field site. This therefore simulated sclerotia either being at the surface all year or being brought to the surface by tillage operations associated with planting; both scenarios being possible under natural conditions. Grids were monitored weekly for appearance of apothecia so that germination times could be compared between isolates and also with the time predicted by the Sclerotinia germination model. In addition, a mixture of sclerotia from isolates HDC1-1 and HDC 2-6 ('local' isolates') were also used to inoculate all the experimental plots (100 sclerotia per plot) at each site on the day of planting).

Weather data loggers for field experiments

A Delta-T weather data logger was located as close as possible to each of the proposed 2008 experiment sites on 9 November 2007 to monitor the overwintering conditions after burial of the test sclerotia. On the day of planting of the 2 experiments, each logger was moved within the experiment area, with probes located within or between plots as appropriate. Half of probes were positioned in the crop under the fleece and a similar set of probes were positioned in the open to monitor any differences between the two situations. Each logger recorded the following data at hourly intervals: rain (mm), soil temperature (°C) at 30 cm and 1 cm depth before planting and 1 cm after planting (5 probes), soil moisture (mV), air temperature (°C), relative humidity (% RH), leaf wetness as % of time wet. Data was downloaded and checked weekly. Probes and logger batteries were checked weekly and replaced if necessary.

Field experiments to evaluate the Sclerotinia forecasting model

There were 5 treatments for the Sclerotinia forecasting model experiment ('modelling experiment'):

1. Untreated
2. Fungicide sprays applied close to T10 as predicted by the Sclerotinia forecasting model ('model' spray)
3. Fungicide applied at spray time 1 (early in crop development)
4. Fungicide applied at spray time 1 & 2 (early and mid crop)
5. Fungicide applied at spray time 1, 2 & 3 (early, mid and late crop)

Plots were marked out in the growers' crops at both sites (site descriptions in above section 'field sites') on the day of planting at each site. The crop planting dates were Merrymac 3 April and G's 7 March. Signum (boscalid + pyraclostrobin) was the selected fungicide used for treatments 2, 3, 4 and 5, applied according to EPPO guidelines. The experiment design was a randomised complete block, with 5 treatments and 6 replicate plots per treatment (= 30 plots). Plot size was selected to ensure that there were at least 100 lettuce for assessment, with an un-assessed buffer area allowed around each plot. Plots were inoculated by scattering sclerotia over the plots and raking them in to a depth of about 1cm around the lettuce plants. A summary of field operation dates is given in Table 6.

The Sclerotinia forecasting model was started when the sclerotia were buried at each field site on 19 October 2007, at first using Met Office data which was interpolated from the weather stations to the farm locations using Irriguide (Bailey and Spackman, 1996), and then using on-site logger data from 9 November. For predictions of sclerotial germination (T10), yearly average weather data from Irriguide was used for days going forward from the latest time of downloading the on-site loggers. Each week post-planting the weather data logger was downloaded and checked on the same day if possible, otherwise the next day, and the model run to predict T10. The prediction of the time of T10 was communicated by email or telephone to the ADAS site manager so that preparation for treatment sprays could be made if the predicted time was imminent. An alert for germination in the 2 weeks or so prior to the expected date of harvest would not have resulted in a spray treatment because of minimum harvest interval requirements. For treatments 3, 4 and 5, the appropriate plots were sprayed with Signum 2, 4 and 6 weeks after planting.

As in the previous year, lettuce total diameter and heart diameter were measured on a subset of 5 randomly selected lettuce in one untreated plot each week (same plot each week), to monitor lettuce growth. Disease was assessed and recorded after 2 weeks, 4 weeks and then weekly, on all assessed plants per plot. Sclerotinia incidence was recorded as 1 (diseased) or 0 (no disease), similarly for Botrytis. Downy mildew was recorded both as incidence and as % area affected. To enable spraying and assessing, the crop fleeces were removed beforehand by ADAS staff, and replaced afterwards. Sclerotial germination was assessed weekly in all grids, recorded as the presence or absence of stipes or apothecia.

Field experiments to compare Sclerotinia control using different fungicides

Plots were marked out in the growers crops at the Merrymac and G's sites (site descriptions in above section 'field sites') on the day of planting at each site, adjacent to the modelling experiment. The experiment design was a randomised complete block, with 8 treatments and 5 replicate plots per treatment (= 40 plots). Plot size was selected to ensure that there were at least 100 lettuce for assessment, with an un-assessed buffer area allowed around each plot. Plots were inoculated by scattering sclerotia over the plots and raking them in to a depth of about 1cm around the lettuce plants. The crop planting dates were the same as for the modeling experiment, i.e., Merrymac 3 April and G's 7 March (Table 6). The following fungicides were selected for inclusion in the fungicide experiment after consultation, in particular with Cheryl Brewster and Vivian Powell (HDC). There were 8 treatments in total, including an untreated control (Tables 3 and 4).

Table 3. 2008, fungicides, active ingredients and approval status

Treatment number	**Trade name**	**Active ingredient**	**Approval status for outdoor lettuce**
1	Untreated		
2	Amistar	azoxystrobin	SOLA 1465/01
3	Signum	boscalid + pyraclostrobin	Approved for sprays 1 April to 31 Oct
4	Switch	cyprodinil + fludioxonil	SOLA 2079/07, max. 2 trts/crop
5	Rovral 75WG	iprodione	Not approved
6	UKA383c	N/A	Not approved
7	UKA386a	N/A	Not approved
8	Octave	prochloraz	SOLA 0650/01

A three-spray programme (Table 4) was selected for all fungicides, regardless of label restrictions, to ensure comparability between products, timed to ensure a sufficient minimum harvest interval for an early crop where the duration of the crop could only be estimated.

Table 4. 2008, G's and Merrymac: fungicides, spray timing and rates for field lettuce.

			Weeks post planting*									
No.	**Product**	**Active ingredient**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Rate**	**Water L/ha**
1	Untreated											
2	Amistar	azoxystrobin		x		x		x			1 L/ha	400
3	Signum	boscalid + pyraclostrobin		x		x		x			1.5 Kg/ha	400
4	Switch	cyprodinil + fludioxonil		x		x		x			0.8 Kg/ha	400
5	Rovral 75WG	iprodione		x		x		x			0.33 Kg/ha	400
6	UKA383c	Confidential		x		x		x			0.5 L/ha	400
7	UKA386a	Confidential		x		x		x			0.6 L/ha	400
8	Octave	Prochloraz		x		x		x			0.2 Kg/ha	400

*Spray dates for Merrymac were 16 April, 2 May and 14 May 2008, and spray dates for G's were 31 March, 16 April and 2 May 2008.

Disease (Sclerotinia, Botrytis and downy mildew), phytotoxicity and weights were assessed as described in the 2007 project report. Shelf life was assessed in 2008, on the 25 lettuce from each plot harvested for weight. The lettuce were stored at ambient temperature in plastic bags and assessed for disease every 3-5 days until a final assessment on day 10-12 when the lettuce were cut in half to check for internal rotting.

Results

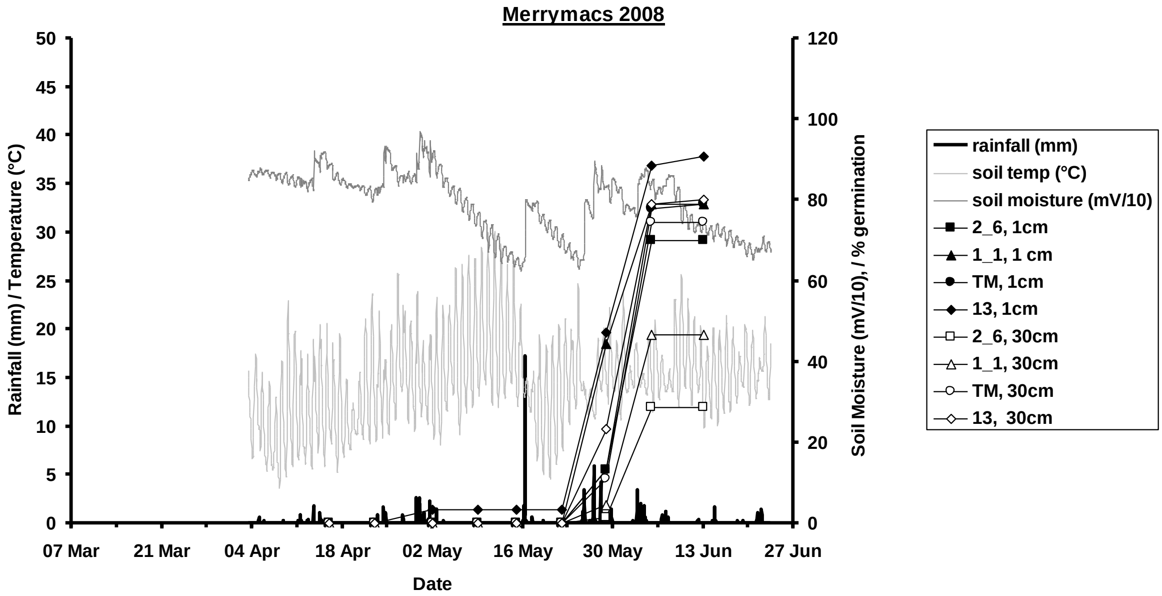
All treatments and assessments were made as planned at both sites. In summary, both sites had Sclerotinia, but Merrymac's had downy mildew and no Botrytis, while G's had no downy mildew and very low levels of Botrytis.

Field experiments to evaluate the Sclerotinia forecasting model

Observed germination of sclerotia

At Merrymac's, sclerotia were buried on 19 Oct 2007 (at 1 cm or 30 cm) and moved into the monitoring grids (at 1cm) the day after planting on 4 April 2008. The first apothecia were observed on 2 May (isolate 13, 1cm) but most of the significant germination for all isolates occurred from 29 May (Figure 3). This delay in the majority of the sclerotia germinating corresponded with a period where there were long periods of low soil moisture and high soil temperature (>20°C) known to inhibit germination. The different isolates of *S. sclerotiorum* had very similar germination times and patterns irrespective of whether they were buried initially at 30cm or 1cm but differed in total % germination, e.g., by 16 June isolate 13 reached over 90% germination but isolate 2_6 only 30%.

At G's, sclerotia were again initially buried on 19 Oct 2007 (at 1 cm or 30cm) but moved into the monitoring grids (at 1cm) earlier than at Merrymac's as planting was on 7 March 2008. The first apothecia were seen on 16 April 2008 (isolate 2_6, 30 cm; Figure 3) but, as at Merrymac's, the major sclerotial germination was delayed until 29 May. Low moisture levels and high temperatures were recorded during this period and again there were some differences between isolates in the proportion that germinated.



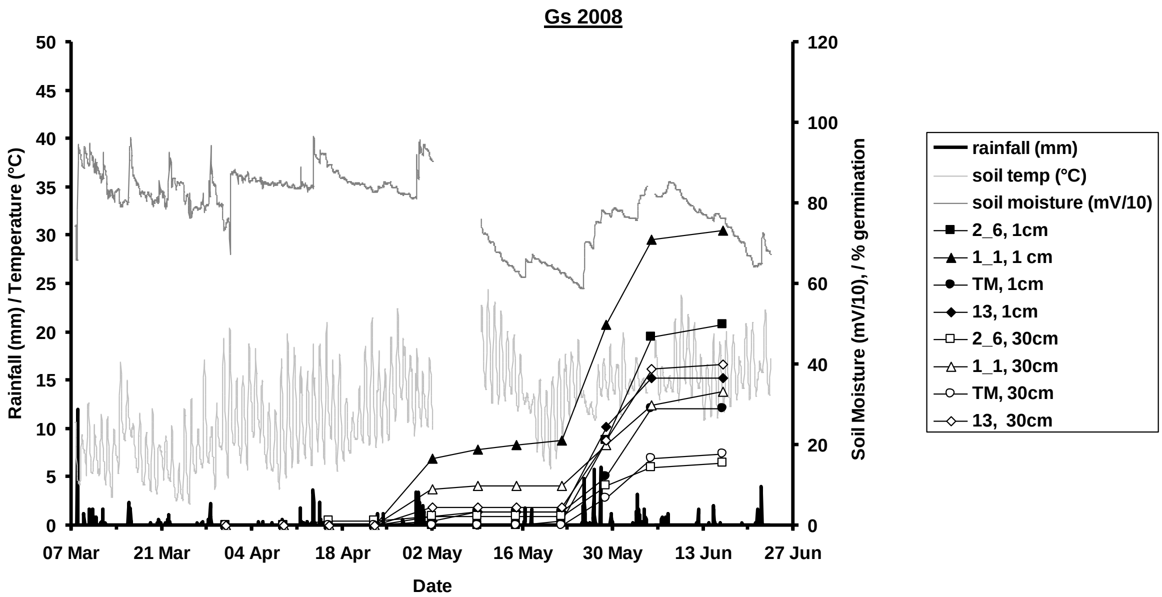


Figure 3. Weather data and cumulative germination of sclerotia at Merrymac and Gs, 2008

In the previous project report (Year 1), there are no equivalent graphs for sclerotial germination and weather because there was little or no germination by the end of each lettuce crop.

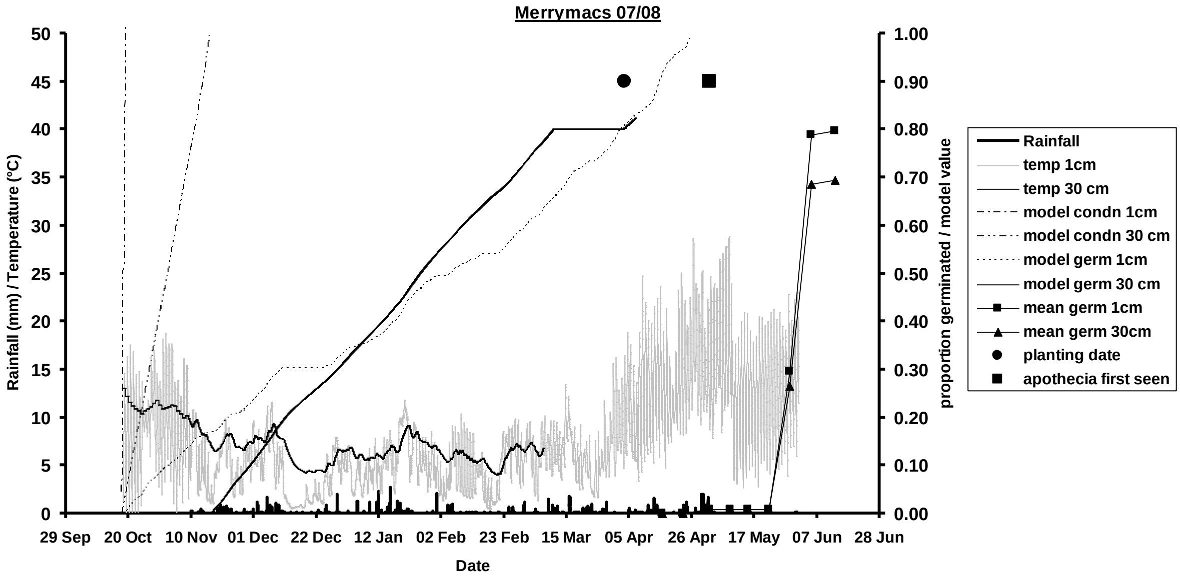
Predictions of sclerotial germination

At Merrymac's, the model predicted that sclerotia buried initially at 1 cm in October 2007 conditioned in a couple of days compared to the sclerotia buried at 30 cm where conditioning time was 29 days (Figure 4). Subsequently, germination of sclerotia buried initially at 1cm was predicted for 25 April with the same date predicted for those at 30 cm. Actual germination of sclerotia in the grids was first observed 7 days later (isolate 13, 1 cm on 2 May).

At Gs, the model again predicted that sclerotia buried initially at 1 cm in October 2007 conditioned in a couple of days whereas those at 30 cm took 30 days (Figure 4). Subsequent germination for the 1 cm sclerotia was predicted for 15 April and for 30 cm sclerotia was 30 March. Actual germination of sclerotia in the grids was first observed on 16th April (isolate 2_6, 30cm). This was 17 days after the 30 cm prediction and 1 day after the 1 cm prediction.

Overall therefore, the model predictions were closest to the time of observations of the first apothecia seen in the grids. However, although the first apothecia observed at Gs was from isolate 2_6 at 30 cm, the earlier germination predicted for 30 cm sclerotia was not observed for the majority of sclerotia which produced apothecia at a similar time irrespective of initial burial depth, as observed at Merrymac's.

This is the first year the Sclerotinia forecasting model has been run using 30 cm depth data, and further validation of the depth effects prior to planting is needed. The model was modified using 2008 data to take into account the effect of burial depth prior to planting on the germination process. Burial depth over the winter period and the date of tillage operations at planting both potentially play an important role in the time of germination. Although the model showed that conditioning occurred more slowly for sclerotia at 30cm, the warmer temperatures compared to those at 1 cm in December 2007 and early in 2008 allowed them to 'catch up' and 'overtake' those sclerotia at the soil surface in terms of their progress towards germination. During this period, sclerotia at 1 cm made no progress towards germination at either field site as shown by a flat period in the germination progress curve (12-28 December, Figure 4). At Merrymac's, the late planting date (3 April, compared to Gs, 7 March) where sclerotia were therefore brought to the surface later meant that there was a period of 25 days (9 March – 3 April) where sclerotia at 30 cm were 'held' at 80% of their germination progress (Figure 4). This then allowed the 1 cm sclerotia to 'catch up' and resulted in a predicted synchronisation of germination of sclerotia from both depths on 25 April. This was not the case at Gs where the earlier planting date when the sclerotia were raised from 30 cm (7 March) meant that the sclerotia only spent 2 days 'delayed' at 80% of their germination progress (5-7 March) before they could continue. Hence, in this case, germination was predicted earlier for the sclerotia at 30 cm than for those at 1 cm.



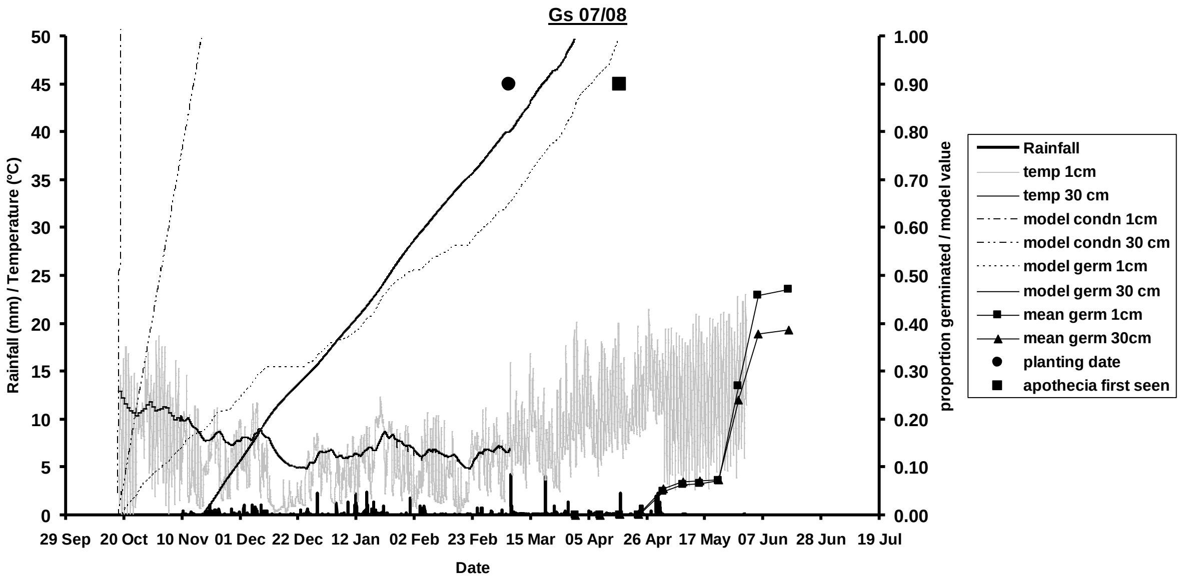


Figure 4. Weather data from October sclerotial burials to lettuce harvest, progress towards conditioning and predicted germination and observed germination of sclerotia at Merrymac and Gs, 2007-2008. Note: sclerotia are predicted to germinate when the germination model value =1.

Modelling experiments

The last disease assessment for the modelling experiment was on 13 June at Merrymac (harvest date for the modeling experiment was 11 June) and 16 June at G's (harvest date was 4 June). Dates of the field operations, appearance of apothecia and predictions of T10 are given in Table 6.

At Merrymac's, the 'model' spray (Trt 2) was applied on 24 April. Sclerotinia disease was first observed just prior to harvest, with a maximum of 5% of plants infected in the untreated plots by 13 June (Figure 5). Although the early, mid and late fungicide sprays (Trts 3, 4, 5) were applied much earlier than the 'model' spray (Trt 2), all fungicide programmes reduced Sclerotinia incidence compared to the untreated, and were comparable in their effects (Figure 5). Disease was observed 6 weeks after the very first apothecia were seen in the grids.

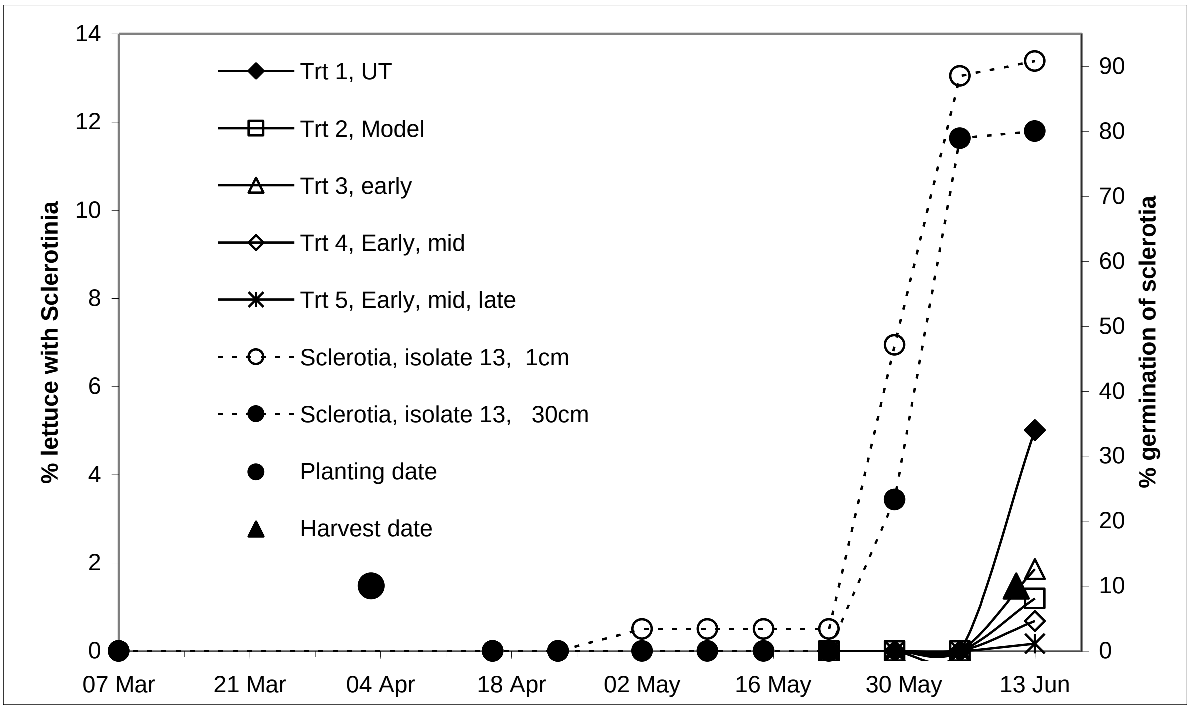


Figure 5. Merrymac 2008, modelling experiment, % lettuce with Sclerotinia disease, cv. Challenge (for 13 June assessment F = 0.002, s.e.d. = 1.1), and % sclerotial germination. Treatment 2, ('model' spray), was applied on 24 April. Dates of early, mid and late sprays were 16 April, 2 May and 14 May.

At G's, the 'model' spray for T10 (Trt 2) was also done on 24 April. Sclerotinia disease was first observed just prior to harvest, with 11.4% of plants infected in the untreated plots on 16 June (Figure 6). As at Merrymac's, the early, mid and late fungicide sprays (Trts 3, 4, 5) were applied earlier than the spray treatment according to predicted germination (Trt 2), but by harvest, 4 June, there was low Sclerotinia overall with no difference between any fungicide treated plots and the untreated plots (Figure 6). At the last assessment (16 June, beyond harvest) the untreated plots had 11.4% Sclerotinia, similar to the early-spray only treatment which had 12.5% Sclerotinia. The later fungicide treatments (Trt 5, early + mid + late, and Treatment 2, 'model' – 24 April) still had some effect by 13 June, reducing Sclerotinia to 4% or less (Figure 6). Disease was observed 4 weeks after the very first apothecia were seen,

Overall therefore, the spray at each field site timed according to the Sclerotinia forecasting model ('model' spray) was as effective in controlling Sclerotinia disease as any of the other fungicide spray treatments and was significantly better than the untreated control.

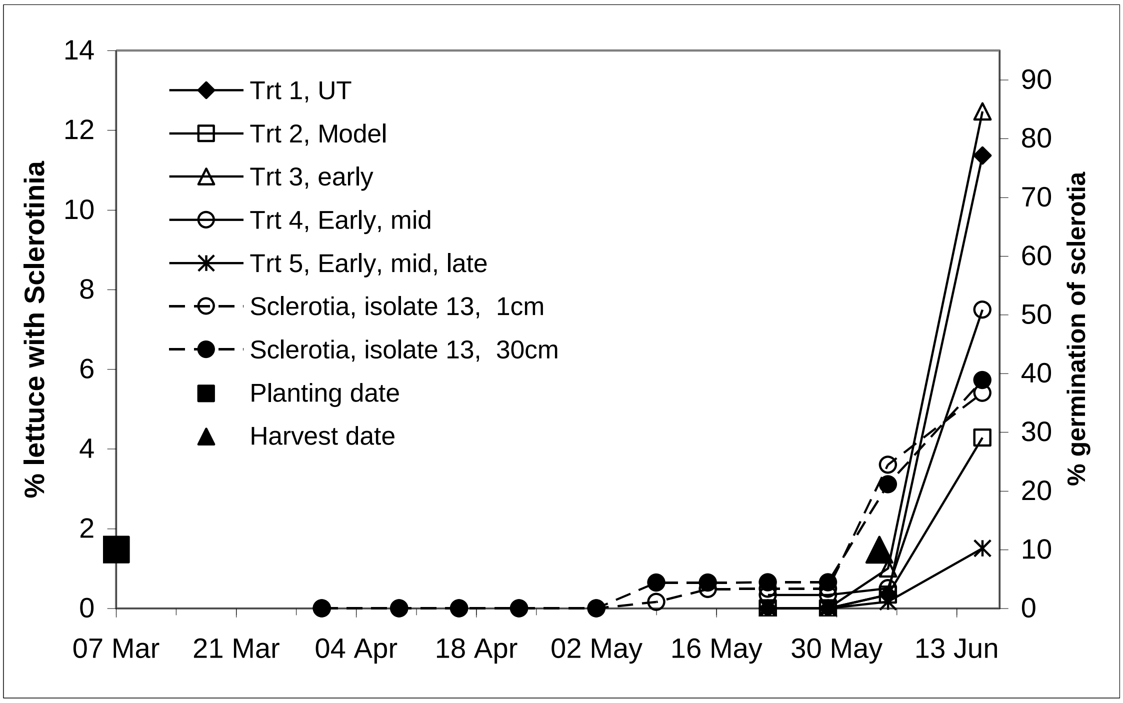


Figure 6. G's 2008, modelling experiment, % lettuce with Sclerotinia disease, cv Jiminy. (16 June assessment, F = 0.001, s.e.d. = 2.53), and % sclerotial germination. Treatment 2, (spray timing according to model predictions) was applied on 24 April. Dates of early, mid and late sprays were 31 March, 16 April and 2 May.

Downy mildew was only seen at low severity at Merrymac's, at the last assessment (13 June, two days after harvesting 25 plants for weights). The average % leaf area affected was 3 – 5% with no significant differences between the spray treatments.

Table 5. 2008, site summary for Sclerotinia modelling and fungicide experiments.

2008	**Merrymac site**	**Gs site**
Site GR	TL 675 898	TL 672 956
Farm	Nr Feltwell CW66, 8.9 ha	Severals Farm, Wissington
Field comments	peat soil	Field 21, 3 ha, peat soil
Previous crop	Winter wheat	Winter wheat
Date field last cultivated	03-Apr	06-Mar
Sclerotia first buried, 2007	19-Oct	19-Oct
Planting date & sclerotia in grids	03-Apr	07-Mar
Variety	Challenge (Iceberg)	Jiminy (Romaine)
Fleece type	Non-woven ('Tildenet')	Non-woven ('Tildenet')
Fleece on crop	03-Apr	07-Mar
Fleece off crop	02-May	09-May
Modelling & Fungicide experiments, 1st spray	16-Apr	31-Mar
Modelling & Fungicide experiments, 2nd spray	02-May	16-Apr
Modelling & Fungicide experiments, 3rd spray	14-May	02-May
Date of harvest	11-Jun	04-Jun
Date first apothecia seen in grids	02-May	16-Apr
Predicted T10, buried 19 Oct at 1 cm	25-Apr	15-Apr
Predicted T10, buried 19 Oct at 30cm	25-Apr	30-Mar
Apothecia first observed, buried 19 Oct at 1 cm	2 May	2 May
Apothecia first observed, buried 19 Oct at 30cm	29 May	16 Apr
Modelling experiment, 'model' spray	24-Apr	24-Apr
Sclerotinia disease, UT model	5.0 %	11.4 %
Sclerotinia disease, UT fungicide	5.0 %	6.8 %

Validation of Sclerotinia forecasting model with additional data sets

The Sclerotinia model was also applied to data from a Defra project where sclerotia from several different *S. sclerotiorum* isolates were buried in grids at a depth of 1 cm on 3 December 2007 at a field site at HRI Wellesbourne. The model predicted T10 to occur on 8 May 2008 and apothecia were actually observed on 27 May, 19 days later (Figure 7). However, again there was a dry and hot period from when the model predicted germination to occur and the observed germination.

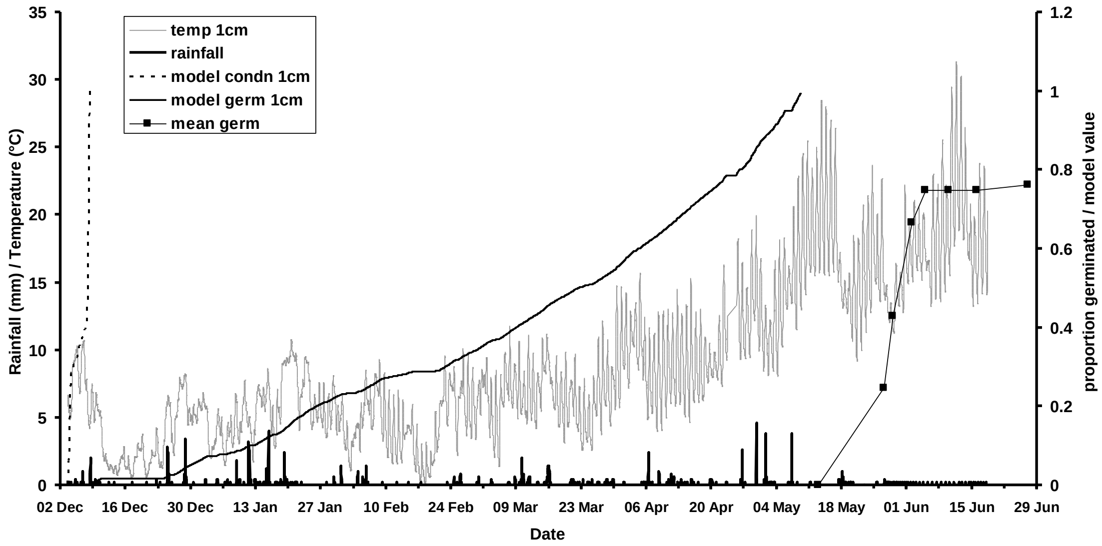


Figure 7. Weather data from December sclerotial burials, progress towards conditioning and predicted germination and observed germination of sclerotia at Wellesbourne, 2007-2008. Note: sclerotia are predicted to germinate when the germination model value =1.

Scenario testing using the Sclerotinia forecasting model

The Sclerotinia model was used to examine the effect of different tillage dates (equivalent to different planting dates) in the growing season, March – September, when sclerotia initially at depth in the winter would be raised to the soil surface and could then germinate. As stated earlier, the model was modified to allow for depth of sclerotia, i.e., sclerotia at depth can only achieve 80% of their germination progress with the final 20% achieved once they are raised to the surface. Hence, the later the planting/tillage date in the year, the longer the sclerotia are 'held' at 80% of the germination process. The model was run using weather data from Gs from 19 October 2007 until 1 March 2008 which covered the period where sclerotia were predicted to have conditioned and reached 80% of their germination progress. Weather data from 2003-2005 from a previous Defra project (HH3215TFV) was then used from 1 March to examine the effect of different tillage (planting) dates on subsequent germination at four week intervals throughout the growing season. Predicted germination times of the sclerotia followed the same chronological order as the tillage dates but the time taken for this to occur varied considerably with tillage date (Figure 8). The overall result from this scenario testing using the three years of weather data revealed that sclerotial germination times varied between 9 and 67 days post-tillage (Table 6). The wide variation in germination times was due to differences in temperature and rainfall at different times of the year and between years. It was clear that long periods above 20°C or low rainfall were the cause of longer germination times as illustrated in Figure 8 for 2003 data. In some years therefore particularly in the summer, the Sclerotinia model would predict fairly long periods of time (e.g., 5 August – 25 September 2003, Figure 8) when the risk of apothecia being present in the field is low.

However, further work is needed to establish a precise value in the model where germination progress is halted at depth. Soil temperature data sets for 30 cm depth are required in order to run scenarios where the effect of the autumn burial date is tested so that a default model start date can be more accurately derived. Currently, the default start date is 14 October as supported by results from developing the model using 2007 data.

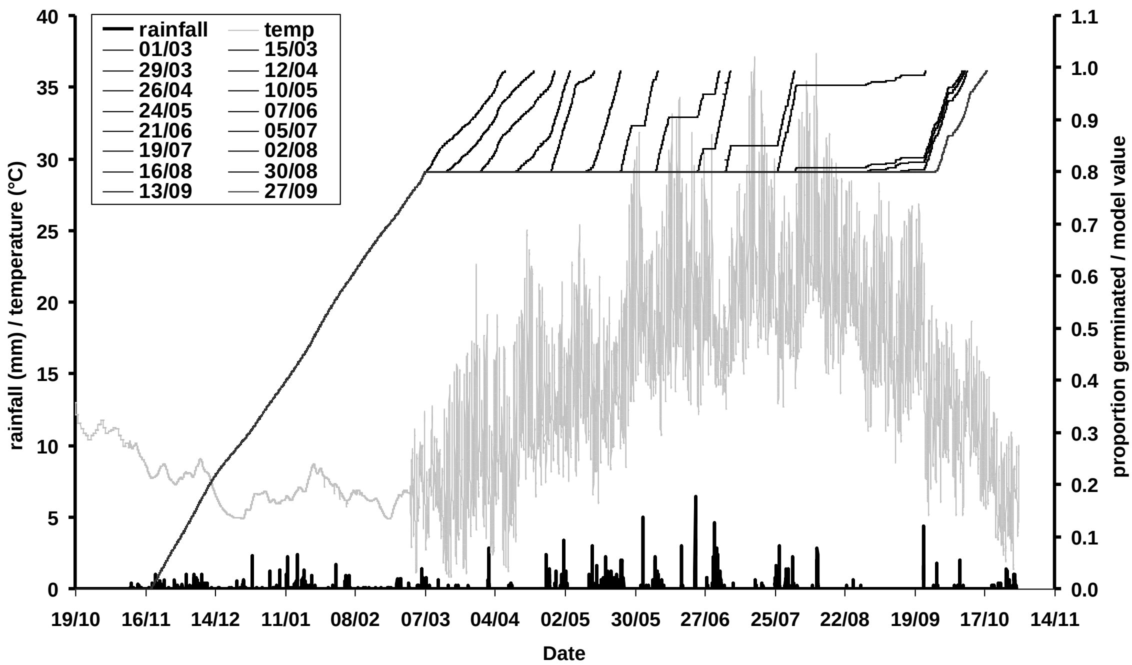


Figure 8. Effect of tillage date (see figure legend) on germination of sclerotia according to the Sclerotinia model, for 2003 weather data. Sclerotia are predicted to germinate when the germination model value = 1. The order of germination follows the chronological order of tillage date. Note: this scenario uses the assumption that sclerotia are conditioned, and reach 80% of the germination process on 1 March. Weather data from 19 Oct 2007 to 29 Feb 2008 was used prior to 1 March 2003 (data for 30 cm soil temperature not recorded in 2003).

Table 6. Predicted germination times for sclerotia according to the Sclerotinia model for weather data from 1st March 2003, 2004 and 2005.

Tillage (planting) date	predicted germination date	Days to germinate 2003 data	days to germinate 2004 data	days to germinate 2005 data
01 March	07 April	37.9	36.6	37.6
15 March	19 April	35.4	24.4	23.6
29 March	27 April	29.7	23.4	22.7
12 April	03 May	21.7	19.5	18.7
26 April	13 May	17.5	15.8	11.6
10 May	24 May	14.1	25.9	22.8
24 May	07 June	14.9	28.1	20.7
07 June	02 July	25.6	23.8	23.9
21 June	06 July	16.0	12.3	16.0
05 July	01 August	27.5	9.4	22.7
19 July	23 September	66.2	30.8	20.5
02 August	07 October	66.9	20.8	19.1
16 August	08 October	53.7	8.7	11.7
30 August	08 October	39.7	20.0	-
13 September	09 October	26.6	11.8	-
27 September	17 October	20.8	19.2	-
	Mean germination time	32.1	20.6	20.9
	Max germination time	66.9	36.6	37.6
	Min germination time	14.1	8.7	11.6

Sclerotinia forecasting model in MORPH

The Sclerotinia model is now programmed into MORPH. The inputs required are hourly logger data for soil temperature at 1 cm and 30cm and rainfall. The user inputs a start date (default 1 October equivalent to autumn tillage) and also a planting date (equivalent to spring tillage). The output is a predicted date for T10 (time for 10% of the sclerotia to germinate and produce apothecia) for sclerotia present at the soil surface for the entire period, or brought to the surface by the spring tillage operation. It is important that logger data is inputted regularly to ensure an accurate prediction, because in the absence of current weather data the model will use an historic data set to calculate T10. As the T10 date approaches, the user should then make a decision when a fungicide spray should be applied. The next MORPH release will be April 2009 and the Sclerotinia model is planned to be fully functional in this version.

Field experiments to compare Sclerotinia control using different fungicides

Progress of lettuce growth

The rate of increase in lettuce total plant diameter was similar at Merrymac (cv. Challenge, Iceberg) and G's (cv. Jiminy, Romaine), at first (Figure 9), but total diameter by harvest was larger at Merrymac as expected because of the difference between types: Iceberg vs Romaine.

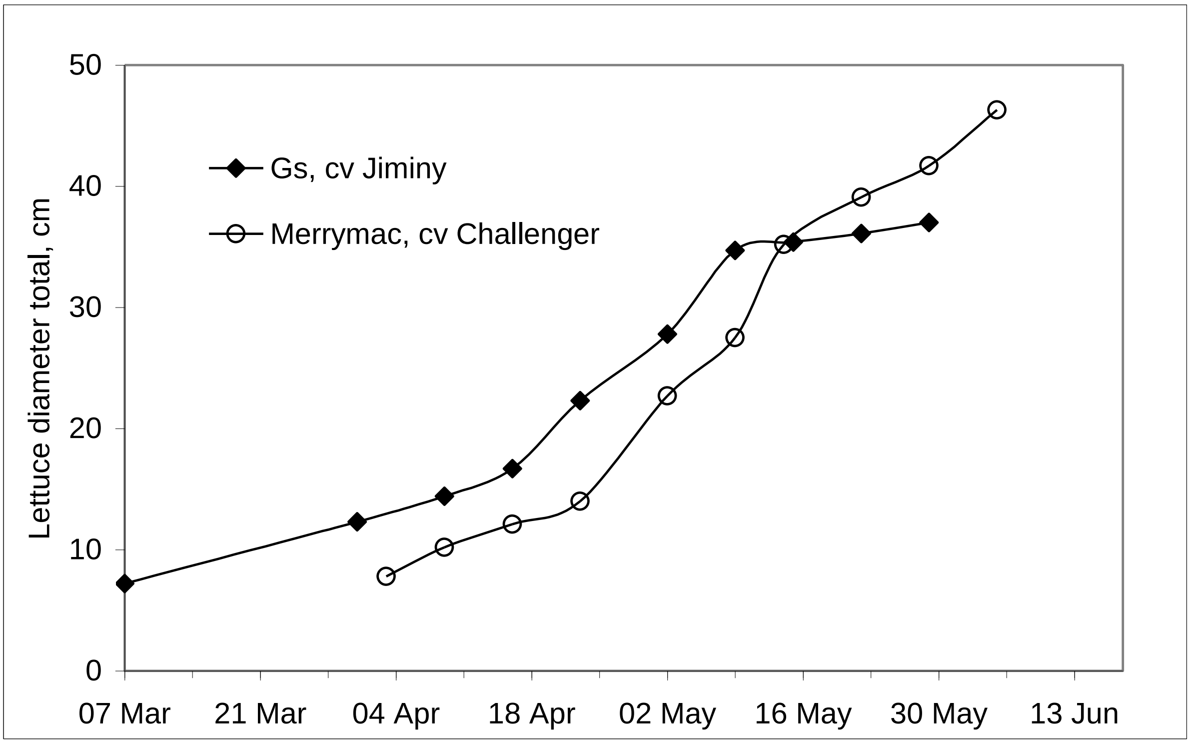


Figure 9. Merrymac and G's, 2008, total lettuce diameter.

Sclerotinia disease

At Merrymac's, Sclerotinia disease was first observed at low levels a few days before harvest, with less than 1% of plants infected in the untreated plots (Figure 10). Sclerotinia incidence increased rapidly such that by harvest on 11 June the untreated plots had an average of 5% plants infected. Disease followed 5 weeks after the first appearance of apothecia and followed 2 weeks after the predicted time to 10% germination, (T10). (Figure 10).

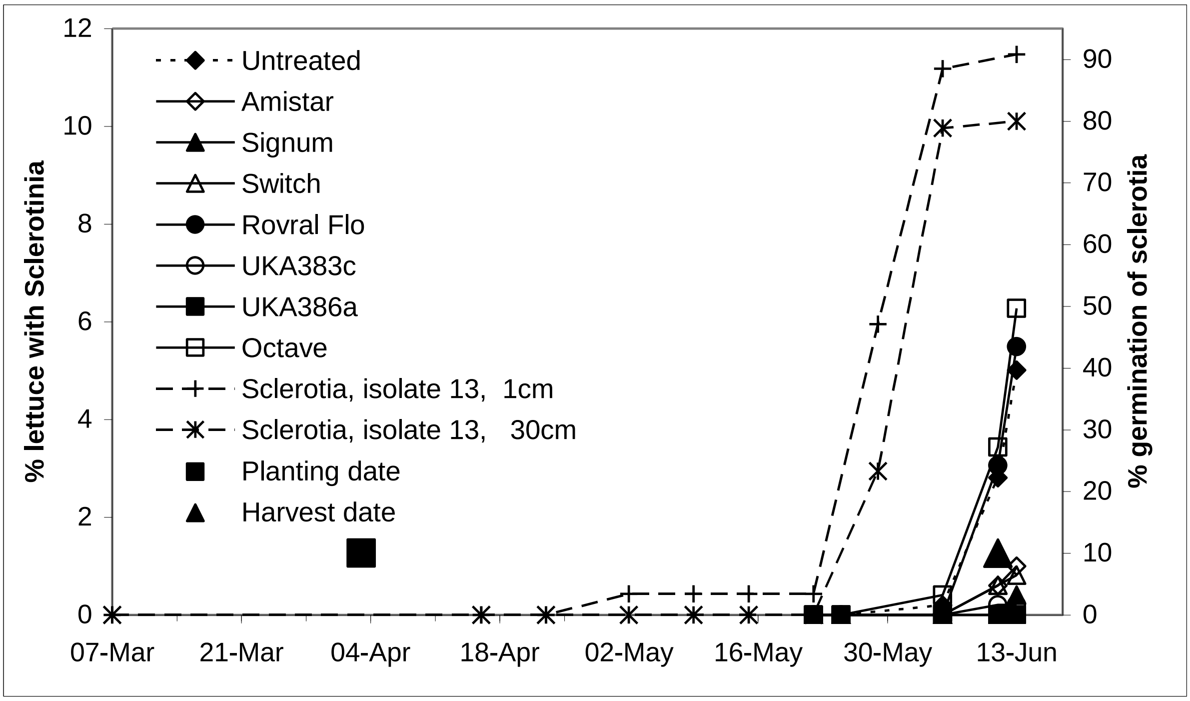


Figure 10. Merrymac 2008, fungicide experiment, cv Challenge, % lettuce with Sclerotinia and % germination of Sclerotinia isolate 13. All fungicides were applied three times, 16 April, 2 May and 14 May.

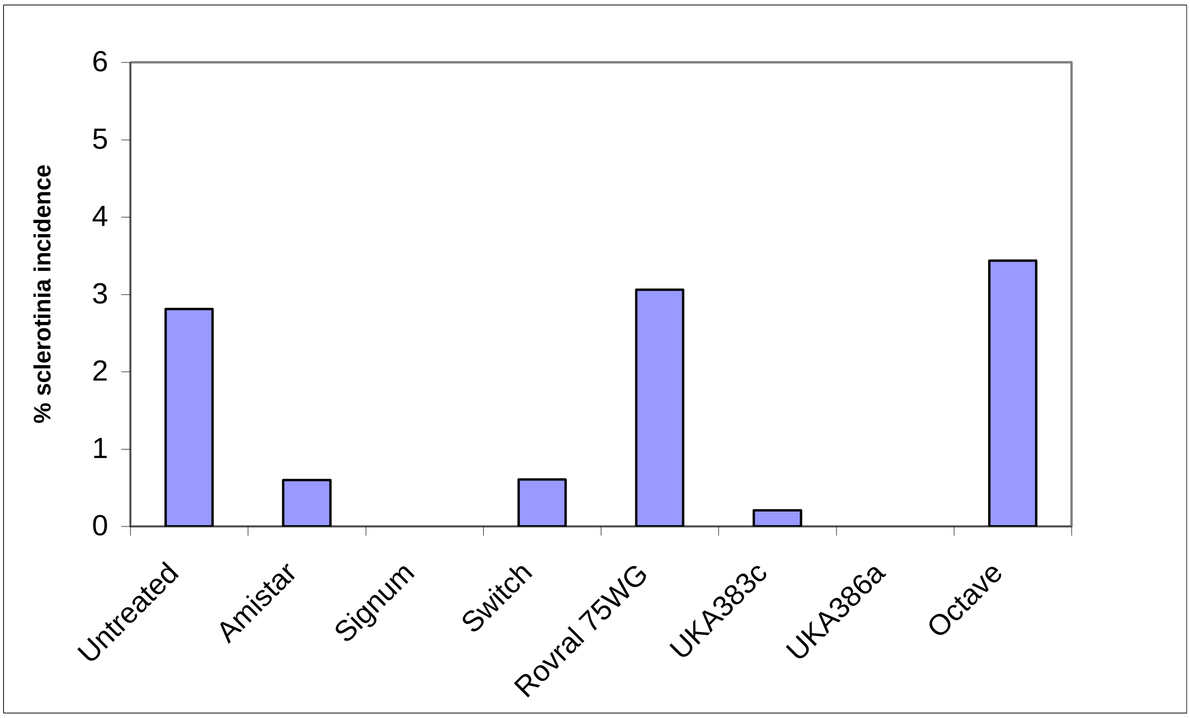


Figure 11. Merrymac 2008, fungicide experiment, cv Challenge, % lettuce with Sclerotinia at harvest, 11 June (F <0.001, s.e.d. = 0.9). All fungicides were applied three times, 16 April, 2 May and 14 May.

At Merrymac's, despite low Sclerotinia there were significant differences observed between fungicides by the time of harvest. Amistar, Switch, UKA 383c and UKA386a all reduced Sclerotinia compared to Rovral 75WG and Octave which were similar to the untreated (Figure 11).

At G's, as at Merrymac's, Sclerotinia disease was first observed close to harvest at low levels, and had only reached a maximum of 0.5% in the untreated plots. However, following a prolonged period of damp weather, at the last assessment on 16 June there were 9% of plants infected in the untreated plots (Figure 12). The large increase in Sclerotinia disease incidence was observed about 5 weeks after the first appearance of apothecia, and two weeks after time to 10% germination, or T10 (Figure 12).

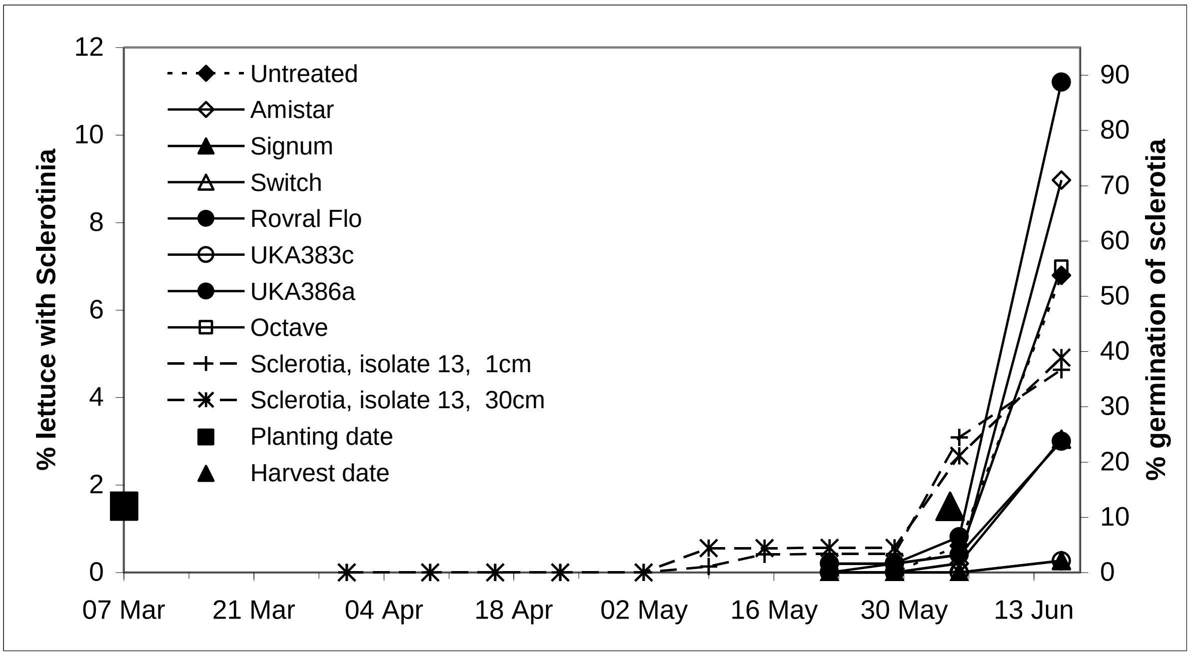


Figure 12. G's 2008, fungicide experiment, cv Jiminy, % lettuce with Sclerotinia and % germination of Sclerotinia isolate 13. All fungicides were applied three times, 31 March, 16 April and 2 May.

At G's there were no significant differences observed for Sclerotinia incidence at harvest (Figure 13), most probably because of low Sclerotinia levels.

However, when the last assessment was made on 16 June, there were still some effects of some of the fungicide treatments, despite the fact that the last application was 2 May. Signum, Switch, UKA383c and UKA 386a still reduced Sclerotinia compared to the untreated, by 16 June (Figure 14).

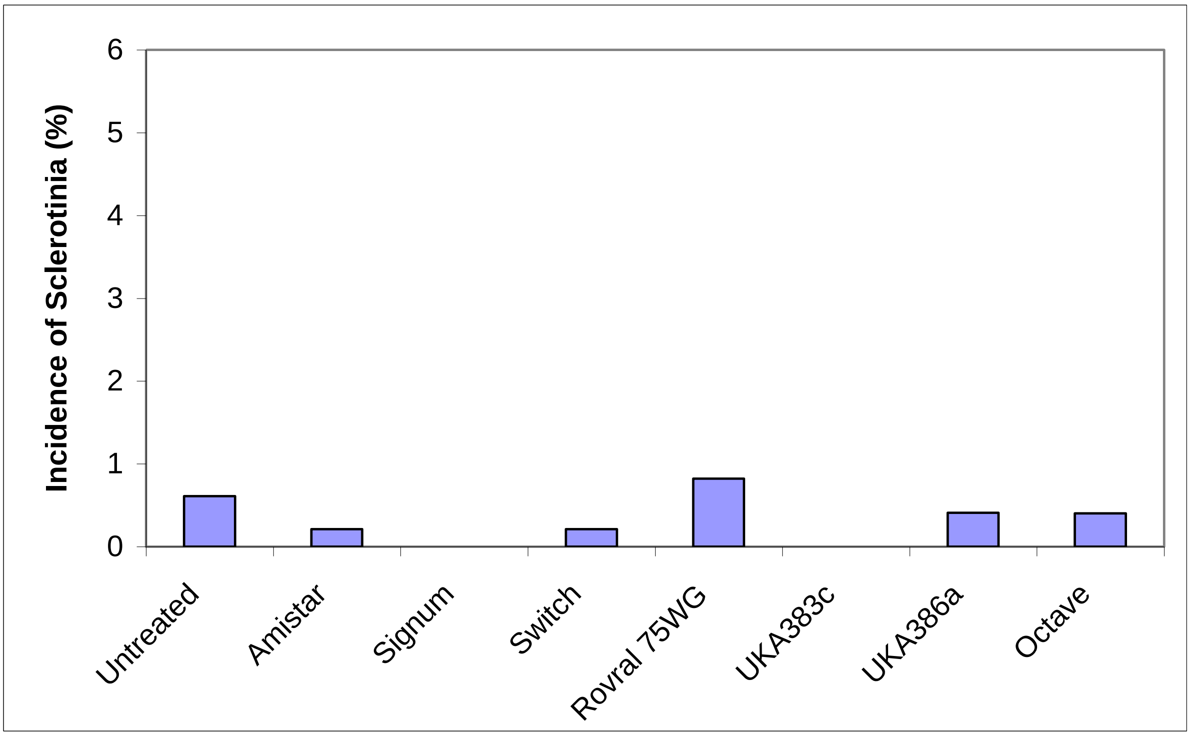


Figure 13. G's 2008, fungicide experiment, cv Jiminy, % lettuce with Sclerotinia at harvest, 4 June (F = 0.6, s.e.d. = 0.5). All fungicides were applied three times, 31 March, 16 April and 2 May.

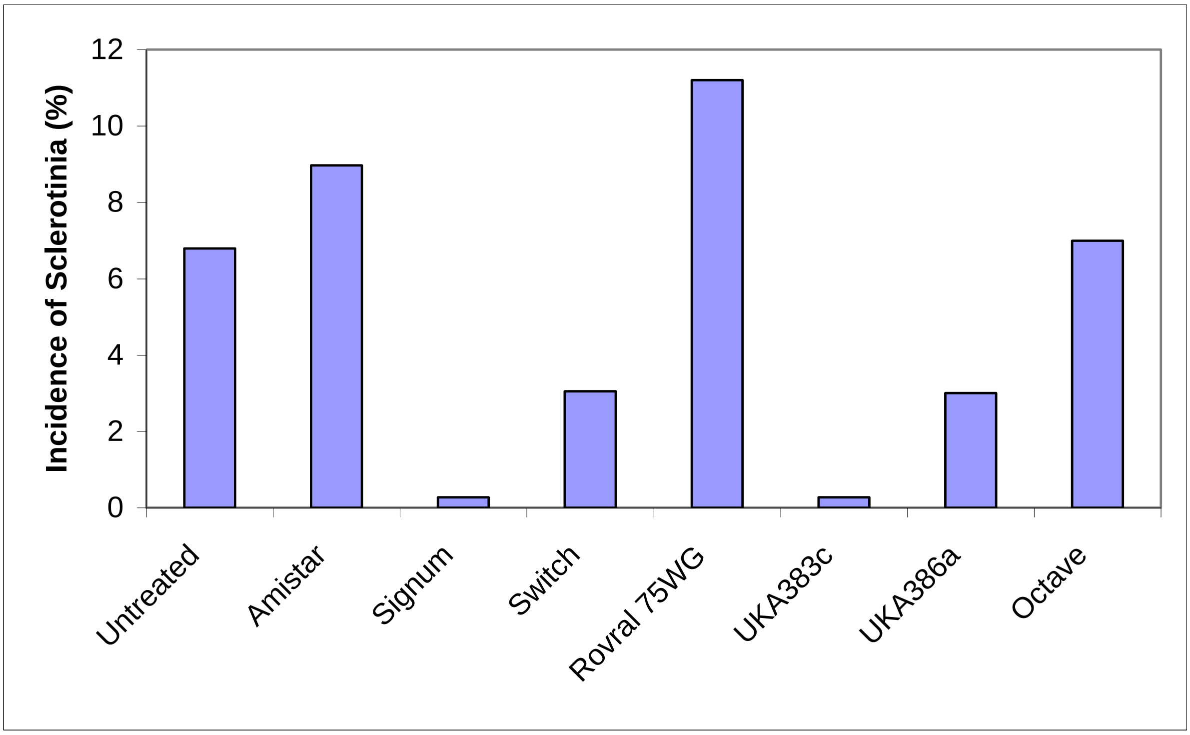


Figure 14. G's 2008, fungicide experiment, cv Jiminy, % lettuce with Sclerotinia post-harvest, 16 June (F = 0.0, s.e.d. = 3.0). All fungicides were applied three times, 31 March, 16 April and 2 May.

Downy mildew

At Merrymac's, downy mildew occurred all over the trial, with no significant differences observed in severity between fungicide treatments (Figure 15).

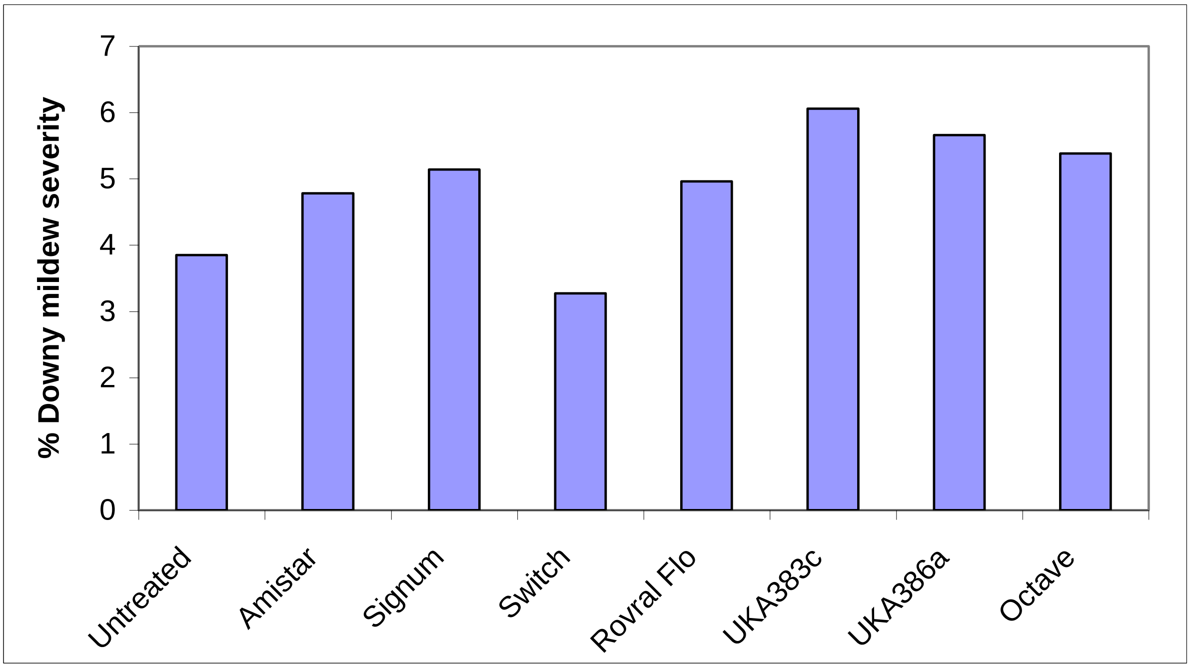


Figure 15. Merrymac 2008, fungicide experiment, cv Challenge, % lettuce with downy Mildew on 11 June (F = 0.12, s.e.d. = 0.96). All fungicides were applied three times, 16 April, 2 May and 14 May, harvest date was 11 June.

At G's there was no downy mildew seen in the fungicide experiment.

Botrytis

At Merrymac's there was no Botrytis observed. At G's only low levels of Botrytis were recorded, with Octave allowing the most Botrytis to develop (Figure 16)

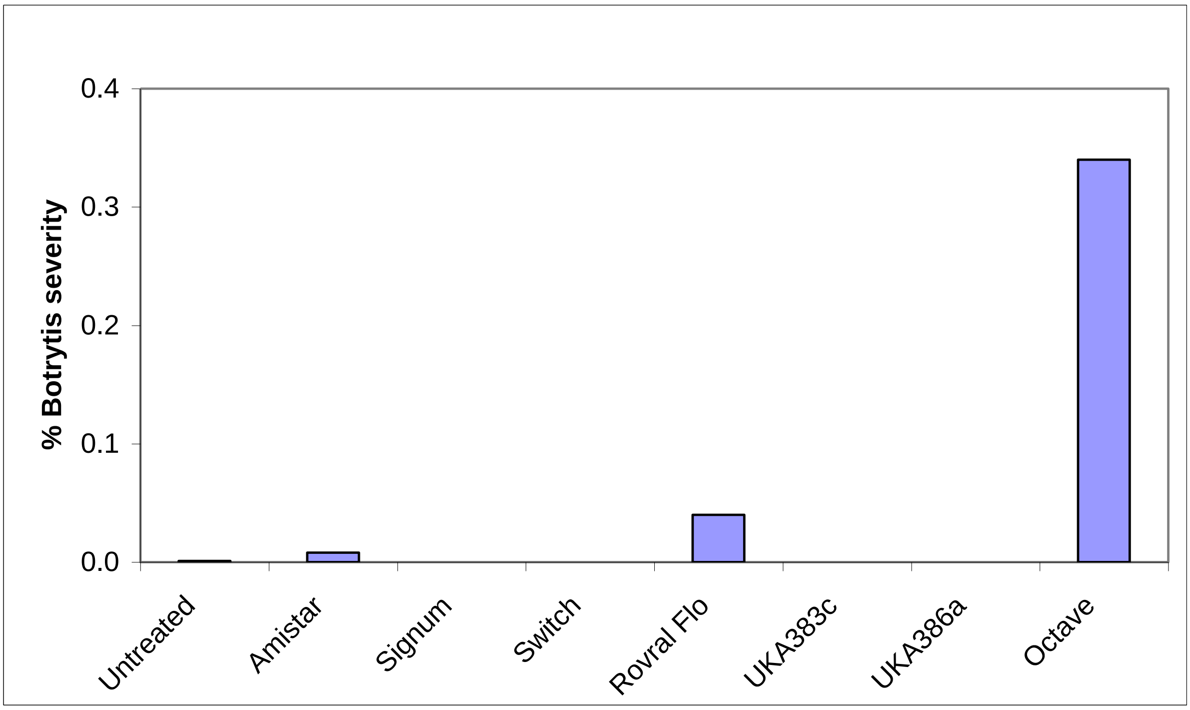


Figure 16. G's 2008, fungicide experiment, cv Jiminy, % lettuce with Botrytis on 16 June (F <0.001, s.e.d. = 0.052). All fungicides were applied three times, 31 March, 16 April and 2 May, harvest date was 4 June.

Unlike 2007, there were no phytotoxic effects observed from any of the fungicide treatments (Switch caused some stunting in 2007 probably due to stress from lack of water).

Lettuce yields

At Merrymac's there were significant differences between fungicide treatments for the untrimmed lettuce (Figure 17).

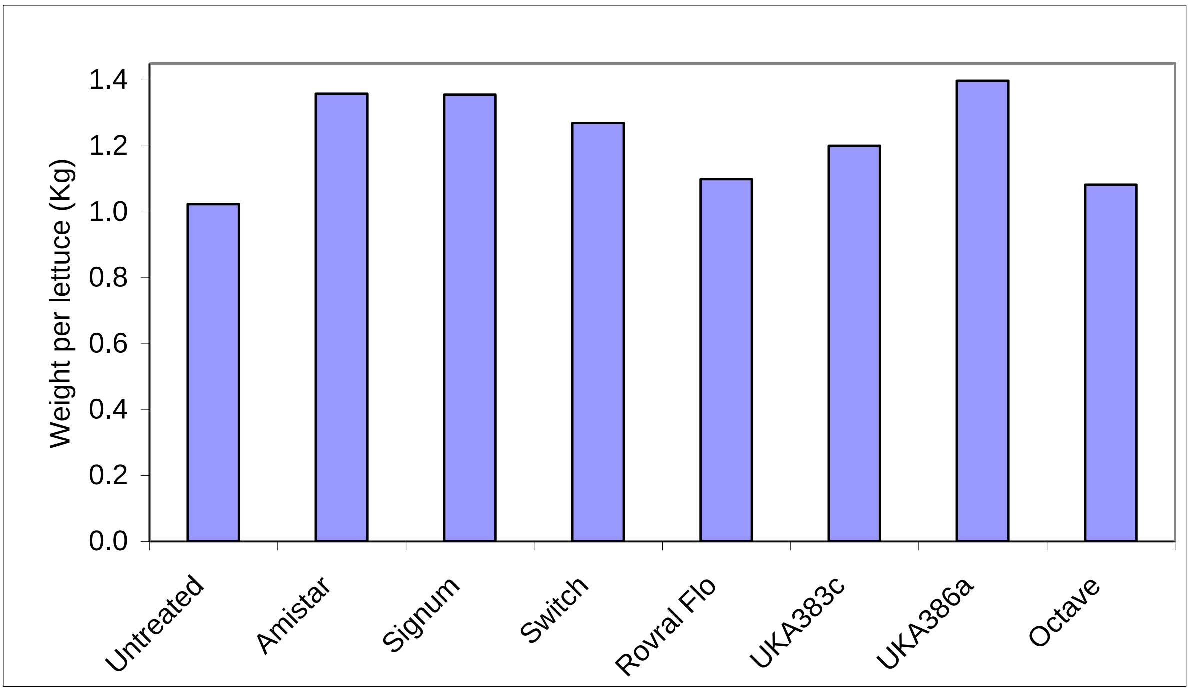


Figure 17. Merrymac 2008 fungicide experiment, untrimmed weight per lettuce, cv Challenge, 11 June ($F < 0.001$, SED trt = 0.07, LSD trt = 0.13).

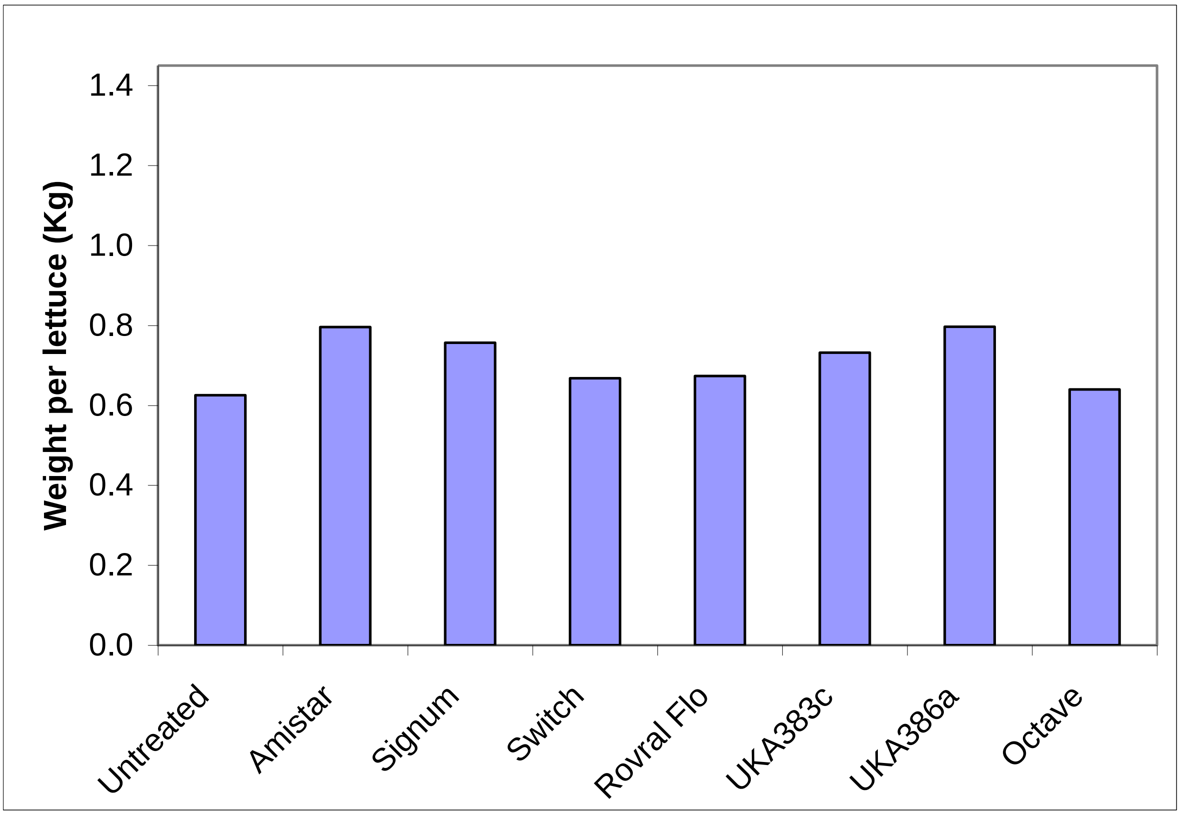


Figure 18. Merrymac 2008 fungicide experiment, trimmed weight per lettuce, cv Challenge, 11 June ($F < 0.001$, SED trt = 0.07, LSD trt = 0.13).

At Merrymac's there were small differences between the trimmed weights for the various fungicide treatments and the weights tended to reflect the level of Sclerotinia control (Figure 18). At G's there was no significant difference in untrimmed weights for the various fungicide treatments (Figure 19).

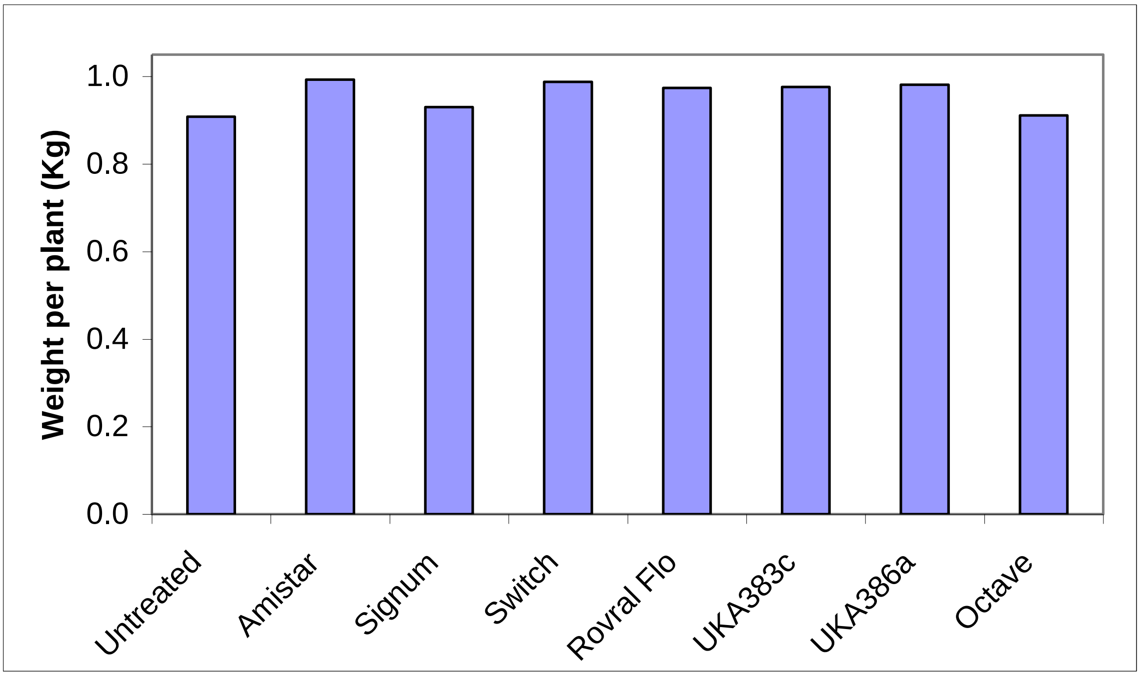


Figure 19. G's 2008 fungicide experiment, untrimmed weight per lettuce, cv Jiminy, 4 June (F = 0.60, s.e.d. = 0.056).

At G's, as for the untrimmed weights, there was no significant difference between the trimmed weights for the different fungicide treatments (Figure 20).

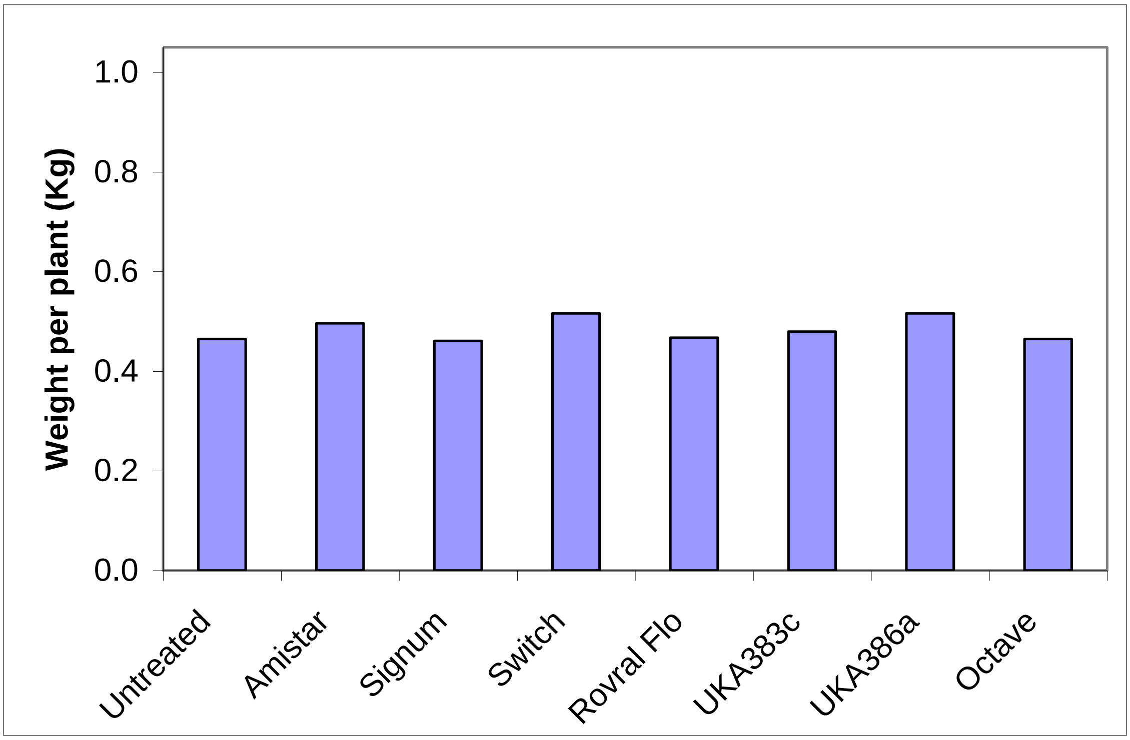


Figure 20. G's 2008 fungicide experiment, trimmed weight per lettuce, cv Jiminy, 4 June (F = 0.22, s.e.d. = 0.027).

There were no obvious phytotoxicity symptoms (e.g., leaf scorch or browning) in any of the fungicide treated plots in 2008.

Shelf life assessments

At Merrymac's there was no Sclerotinia development in the harvested lettuce from all treatments stored at room temperature for 12 days.

At G's there was low Sclerotinia incidence after 9 days at room temperature. The range was 0 to 0.4% Sclerotinia incidence out of 25 plants, with no significant difference between the fungicide treatments (F = 0.66).

Discussion

Sclerotinia forecasting model

Data from two years of lettuce field work have now been used to field-test a practical predictive model for germination of sclerotia from *S. sclerotiorum*, developed from previous data from field experiments and controlled environment experiments (Clarkson *et al.*, 2004 & 2007). Predictions of the germination times by the forecasting model for buried sclerotial inoculum were good in 2006/7 and average in 2007-8. In 2006/7 the predictions were within the range of expected variability when considering the data on which the model was based. In 2007/8, the predictions of germination ranged from coinciding with observed time to 10% germination (T10), to up to one month earlier than observed T10. However, in 2007/08 sclerotia started to produce apothecia just as a dry period occurred and hence germination was halted for a while which may have been one reason why predictions were not as good. In general, the model predictions were early rather than late and hence spray decisions may need to take account of this fact.

The times of germination predicted by the model were generally late in the crop life and suggested a single late fungicide timing. This was effective and compared well with the three-spray programmes. The main benefit of a Sclerotinia forecasting model for field lettuce may be in the justification for omitting sprays, which would be an environmental advantage. There is unlikely to be an economic justification for omitting sprays because the value of the crop is high compared to fungicide costs. In this project, Sclerotinia disease was monitored on early season crops and it is possible that subsequent crops may require more than one spray because germination of sclerotia is likely to continue at intervals throughout the growing season, depending on temperature and soil moisture, as soil is cultivated for each crop.

The forecasting model for Sclerotinia in lettuce was designed to run on the simplest weather data inputs possible, temperature and rainfall. This data can be obtained from regional weather loggers, but rainfall in particular can be localised and an on-site rain gauge is advised. In-field temperature probes are also desirable, because not only are they more accurate for the field in question, but they can be placed to record temperatures under fleece. This would be important because sclerotia tend to germinate earlier under fleece due to warmer temperatures. However, if only regional data is available, the forecasting model can adjust for the increased temperatures that occur under fleece. Given the variability associated with prediction times for sclerotial germination, the chances of success with the forecasting model would be increased by using on-site weather loggers. Data inputs required for MORPH are hourly records of rainfall and soil temperature at 1 cm, and ideally also at 30 cm depth. On-site loggers will likely be required to fulfill the requirement for the 30 cm depth measurement of temperature. MORPH does not currently use weather forecasts to run models. Growers may choose to take forecast weather into account when making decisions, e.g., if the weather is dry and the forecast to remain dry, germination of sclerotia will likely be delayed and a Sclerotinia spray could be postponed.

The predictions for germination resulted in one 'model' spray timing for Sclerotinia for both sites, but this timing was as effective in controlling Sclerotinia disease as any of the other fungicide spray treatments and was significantly better than the untreated control. With hindsight, other sprays for Sclerotinia could have been omitted. At Merrymac's, the spray on 24 April timed according to the prediction model was as effective as the early & mid crop sprays (16 April and 2 May), or the early, mid and late crop spray (late spray was 14 May). At G's, for logistical reasons, the 'model' spray on 24 April was not applied at the correct time but was surprisingly effective and gave as good control of Sclerotinia as the early- and mid-crop sprays (31 Mar and 16 April) or the mid- and late-crop sprays (last spray was 2 May).

In 2007 the inoculum source that caused lettuce infection was most likely due to natural sclerotia in the fields, as few apothecia developed from the buried sclerotia in grids. However, in 2007/8 the disease appeared to follow on from germination of sclerotia buried in grids and scattered in the plots, and therefore the inoculum source was probably the introduced sclerotia. Apothecia were not seen outside the grids in 2008 until harvest, when they were observed at low density.

The start date for the model is mid-October and is an important factor in predicting germination of sclerotia the following year. Based on weather data in the first project year, 14 October was an appropriate start date but this needs further validation. Sclerotia in year 1 of the project buried in December 2006 germinated later in the following year than those year 2 which were buried in October 2007. It will be important that logger data is available all year round for input into the model.

Planting date is the other key factor in the prediction model because tillage operations at this time bring conditioned sclerotia (which will have also progressed towards germination) to the surface and allow them to complete the germination process. The conditioning phase for sclerotia can be completed within one day if temperatures are cold enough and this rapid conditioning is therefore more likely to occur in sclerotia near the soil surface where temperature fluctuations are greatest. However, sclerotia buried at 30 cm will also undergo enough days at sufficiently low temperatures to condition fully over the winter. Although they then start to germinate, the model predicts that they can only complete about 80% of the germination process until they are brought close to the soil surface. Despite this, scenario testing has shown that generally they will germinate before any sclerotia at the surface because the germination process for the surface sclerotia is usually very slow or halted by exposure to much colder temperatures compared to those buried at depth. However, further work is needed to confirm the effect of depth for overwintering sclerotia on the time to germination the following year after they are brought to the surface by tillage.

The results of scenario testing using the different tillage/planting dates for the model throughout the growing season suggest that in some years there will be warm and dry periods when apothecial production is halted. Therefore lettuce growing during those times will be at low risk of infection, and it may be possible to omit one or more fungicide sprays for Sclerotinia. Further work will be needed to confirm the validity of the model for mid and late-season lettuce crops.

The Sclerotinia model predicts the timing of apothecial development and therefore only indicates the timing of the first Sclerotinia spray needed for lettuce. Follow up fungicide sprays may be needed depending on the time expected to harvest. After the first flush of apothecia, subsequent infection by Sclerotinia spores may not be dependent on further apothecial development, because once airborne spores have been released by apothecia, ungerminated ascospores can survive for long periods (Clarkson *et al*, 2003). Previous work has also shown that ascospores can infect plants over a wide range of environmental conditions so there are very few times during the lettuce season when conditions are not suitable for spore germination and infection.

The results from this project suggest that the Sclerotinia forecasting model has good potential to help with timing of fungicide applications to field lettuce, and possibly to justify omitting sprays. However, it must be stressed that the field testing of this model, i.e., using it to time sprays, has been conducted over only two years and only on early season lettuce. Further work will be needed to validate the forecasting model in future years, and for mid and late-season crops. The model is very likely to be relevant for use with other susceptible field crops, both horticultural and arable, e.g., carrots, peas, potatoes, oilseed rape but will need some adaptation for each crop and subsequent field-testing.

Sclerotinia, downy mildew and Botrytis control with different fungicides

Whereas in 2007 Sclerotinia disease did not develop enough to provide data for fungicide comparisons, in 2008 there was more Sclerotinia and some comparisons were possible. At both sites Sclerotinia was seen at low levels immediately before harvest, but with large increases in incidence shortly after harvest following a period of wet weather. In general the assessment of efficacy of the various fungicides against Sclerotinia was similar in 2007 and 2008. Amistar, Signum, Switch, UKA383c and UKA386a were all effective against Sclerotinia in 2008. However, Rovral 75 WG tested in 2008 did not give control of Sclerotinia whereas Rovral WG used in 2007 was effective.

At Merrymac's, although Sclerotinia disease at harvest on 11 June was less than 5% in untreated plots, there were significant differences between the fungicides, with Rovral 75 WG and Octave having no effect. Amistar, Signum, Switch, UKA383c and UKA386a all reduced Sclerotinia to 0.5% or less compared to the 5% in untreated plots. At G's, by harvest on 4 June there was not enough Sclerotinia disease to show significant difference between fungicides. However, two weeks later when the untreated plots had 6% Sclerotinia, there were still fungicide effects even though the last spray had been applied on 2 May, with Signum, Switch, UKA383c and UKA386a significantly reducing Sclerotinia compared with the untreated plots, or with Amistar, Rovral 75 WG or Octave. This suggests that even when fungicide treatments have to go on early because of weather constraints or early germination predictions, most fungicides may still be effective at? harvest. However, in the current project, when the forecasting model suggested delaying a spray according to sclerotial germination predictions, the single late spray was as effective as a two- or three-spray programme. This suggests that fewer fungicide treatments could be justified on early season lettuce crops.

Downy mildew was only observed at Merrymac's, with no differences between fungicides or the untreated plots. Botrytis was only recorded at G's, at low levels, and as in 2007, only Octave gave no control.

Lettuce weights at harvest, untrimmed and trimmed, were significantly different between treatments at Merrymac (although by relatively small amounts), but not at G's. The weights at Merrymac tended to reflect the % of Sclerotinia at harvest, which was higher at Merrymac's than G's. Unlike 2007, Switch did not cause lower weights in 2008, possibly because of lack of water stress in 2008. It must be noted however that Switch is not approved for three sprays on lettuce, and this and other fungicides such as Amistar (strobilurin) would normally only be applied as part of a spray programme with other active ingredients.

Technology transfer

HDC News article, October 2008.

References

Bailey RJ, Spackman E, 1996. IRRIGUIDE: A model for estimating soil moisture changes as an aid to irrigation scheduling, and crop water use studies: I Operational details and description. *Soil Use and Management* **12**, 122-128.

Clarkson JP, Staveley J, Phelps K, Young CS, Whipps JM, 2003. Ascospore release and survival in *Sclerotinia sclerotiorum. Mycological research.***107**, 213-222.

Clarkson JP, Young CS, 2005. 'Forecasting Sclerotinia in field-grown lettuce' Defra project HH3215TFV, Jan 2003 – Dec 2005, ADAS and Warwick HRI.

Clarkson JP, Phelps K, Whipps, JM, Young CS, Smith JA, Watling M, 2007. Forecasting Sclerotinia disease on lettuce: a predictive model for carpogenic germination of *Sclerotinia sclerotiorum* sclerotia. *Phytopathology* **97**, 621-631.

Collier, R, 2007. New MORPH takes shape. HDC News, no. 135, July/Aug 2007.

Rickard PC, 1978. Perforated polythene for forwarding vegetable crops. ADAS Horticulture, Cambridge.

Schafer MR, Kohn LM, 2006. An optimized method for mycelial compatibility testing in *Sclerotinia sclerotiorum*. *Mycologia* ***98***, 593-597.

Twengstrom E, Sigwald R, Svensson C, Yuen J. 1998. Forecasting Sclerotinia stem rot in spring sown oilseed rape. *Crop Protection* **17**, 405-411.

Young CS, Clarkson JP, Smith JA, Watling M, Phelps K, Whipps JM, 2004. Environmental conditions influencing *Sclerotinia sclerotiorum* infection and disease development in lettuce. *Plant Pathology* **53**, 307-397.

Appendix 1

Site 1: Merrymac Salads, applications made to field CW 66, lettuce crop April 2008

Start: 27/03/2008 04:55 AM, Finish 27/03/2008 06:00 AM
Lettuce base 08 (5.5-8.5-22.5), 8.92 ha, 895.000 kg/ha

Start: 03:00 PM, 31/03/2008 Finish 31/03/2008 03:25 PM
Ammonium Nitrate 8.94 ha 225.000 kg/ha

Start: 06:08 PM, 01/04/2008 Finish 06:08 PM 01/04/2008
T flow startern 11-38-3 7.50 ha 210.000 L/ha

Start: 09/04/2008 12:10 PM, Finish 09/04/2008 01:30 PM
Rovral WP (11694) 7.50 ha 0.200 kg/ha
Harvest interval:07 Days 00 Hours, Active Ingredients:Iprodione, Manufacturer:BASF plc., Official Reference (MAPP):11694, Product
Justification:Botrytis / Bottom rots
Nortrace Manganese Sulphate 7.50 ha 2.000 kg/ha

Start: 02:30 PM 11/04/2008, Finish 03:15 PM 11/04/2008
Comrade (10181) 7.50 ha 2.000 L/ha
Active Ingredients:Chlorpropham, Manufacturer:United Phosphorus, Official Reference (MAPP):10181
Alpha Propachlor 50 SC (04873) 7.50 ha 3.000 L/ha
Harvest interval:42 Days 00 Hours, Active Ingredients: Propachlor, Manufacturer: Makhteshim-Agan (UK) Ltd., Official Reference
(MAPP):04873, SOLA:2540/07, Product Comment: BLW

Start: 01:00 PM 17/04/2008 Finish 02:01 PM 17/04/2008
Alpha Propachlor 50 SC (04873) 7.50 ha 2.000 L/ha
Harvest interval: 42 Days 00 Hours, Active Ingredients: Propachlor, Manufacturer: Makhteshim-Agan (UK) Ltd., Official Reference
(MAPP): 04873, SOLA: 2540/07, Product Comment: BLW

Start: 01:00 PM 25/04/2008, Finish 02:10 PM 25/04/2008
Signum 7.50 ha 1.500 kg/ha
Harvest interval:14 Days 00 Hours, Active Ingredients:Boscalid, Pyraclostrobin, Manufacturer:BASF plc., Official Reference (MAPP):11450,
Product Justification:Botrytis

Nortrace Manganese Sulphate 7.50 ha 2.000 kg/ha

Product Justification:managanese deficiency

Bittersalts 7.50 ha 2.000 kg/ha

Product Justification:magnesium deficiency

Start: 08:30 AM 02/05/2008, Finish 09:30 AM 02/05/2008

Manganese Sulphate 7.50 ha 2.000 kg/ha

Start: 10:30 AM 04/05/2008, Finish 12:01 PM 04/05/2008

Amistar 7.50 ha 1.000 L/ha

Harvest interval:14 Days 00 Hours, Active Ingredients:Azoxystrobin, Manufacturer:Syngenta Crop Protection UK Ltd., Official Reference
(MAPP):10443, SOLA:1465/01

Nortrace Manganese Sulphate 7.50 ha 2.000 kg/ha

Bittersalts 7.50 ha 2.000 kg/ha

Plenum WG 7.50 ha 0.400 kg/ha

Harvest interval:07 Days 00 Hours, Active Ingredients:Pymetrozine, Manufacturer:Syngenta Crop Protection UK Ltd., Official Reference
(MAPP):10652, SOLA:0060/07

Paramount 7.50 ha 100.000 mL/ha

Karamate Dry Flo Newtec 7.50 ha 2.000 kg/ha

Harvest interval:14 Days 00 Hours, Active Ingredients:Mancozeb, Manufacturer:Landseer Ltd, Official Reference (MAPP):12691
completed

Start: 04:40 PM 13/05/2008, Finish 06:00 PM 13/05/2008

Aphox 7.50 ha 0.300 kg/ha

Harvest interval:03 Days 00 Hours, Active Ingredients: Pirimicarb, Manufacturer: Syngenta Crop Protection UK Ltd., Official Reference
(MAPP):10515

Start: 04:47 PM 20/05/2008, Finish 06:04 PM 20/05/2008

Farmphos 7.50 ha 2.000 L/ha

Product Comment: Foliar feed

Aphox 7.50 ha 0.300 kg/ha

Harvest interval:03 Days 00 Hours, Active Ingredients:Pirimicarb, Manufacturer:Syngenta Crop Protection UK Ltd., Official Reference
(MAPP):10515

Bittersalts 7.50 ha 2.000 kg/ha

Product Comment: Foliar feed (Magnesium)

Manganese Sulphate 7.50 ha 2.000 kg/ha

Start: 01:45 PM 29/05/2008, Finish 02:47 PM 29/05/2008

Farmphos 7.50 ha 2.000 L/ha

Product Comment: Downy mildew/foliar feed

Aphox 7.50 ha 0.300 kg/ha

Harvest interval: 03 Days 00 Hours, Active Ingredients: Pirimicarb, Manufacturer: Syngenta Crop Protection UK Ltd., Official Reference
(MAPP):10515

Manganese Sulph 7.50 ha 2.000 kg/ha

Bittersalts 7.50 ha 2.000 kg/ha

Product Comment: Foliar feed (Magnesium)

Earliest safe harvest date: 01/06/2008

Site 2: G's, applications made to field 21, lettuce crop April 2008

	Var Jiminy (Romaine)	Pesticide	Fertiliser	Harvest interval	Harvest after date
6 Mar	Planting date				
		✓	✓		
4 Mar	18.9.9. 300 kg/ha				
	Comrade 2 litres/ha	✓			
	Ramrod Flowable 2 l/ha	✓			
14 Mar	Rovral WG 165 gms/ha	✓			
	Manganese 3 kg/ha		✓		
	Magnesium 3 kg/ha		✓		
2 Apr	Rovral WG 165 gms/ha	✓			
	Manganese 3 kg/ha		✓		
	Magnesium 3 kg/ha		✓		
16 Apr	Signum 1 kg/ha	✓		14	30 Apr
	Manganese 3 kg/ha		✓		
	Magnesium 3 kg/ha		✓		
24 Apr	Farm-Fos-44 2 litres/ha		✓	1	25 Apr
	Decis 0.25 kg/ha	✓			
	Manganese 3 kg/ha		✓		
	FF19 3 kg/ha		✓		