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Location of project:	ADAS Arthur Rickwood
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The results and conclusions in this report are based on a series of experiments conducted over one year. 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.

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AUTHENTICATION

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

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GROWER SUMMARY

Headlines

- Glasshouse tests revealed large differences in the relative protectant and curative activity of eight fungicides against celery leaf spot.

- The effects of leaf wetness duration and temperature on disease development were quantified, providing a rational basis for disease risk prediction.

- In an inoculated celery field trial, excellent control of septoria leaf spot was achieved using a fungicide programme of five sprays. Application timing was based on measured leaf wetness duration. Product choice was based on the relative protectant and curative activities of different fungicides combined with recent and forecasted rainfall/irrigation, to estimate disease risk. Spray applications were reduced by one, compared with a prophylactic spray regime.

Background and expected deliverables

Septoria leaf spot (*S. apiicola*) of celery, also known as 'late blight', is the most destructive disease of field-grown crops. Initially seen as small brown spots on leaves, the disease can progress rapidly to cause extensive defoliation and render the whole crop unmarketable if left unchecked. Under optimum conditions, the disease cycle is as short as 10 days. In 1999, the disease was epidemic in East Anglia (major production area in the UK) and in 2001, outbreaks occurred in Sussex and Lancashire. There were no reports of septoria on conventionally produced crops in 2002 but in 2003, disease outbreaks were again observed. Septoria leaf spot can be effectively controlled through frequent fungicide applications but sprays may need to be applied at 10-day intervals for the duration of the growing season to ensure a marketable crop. There are two potential ways to control septoria effectively using fewer spray treatments. Firstly, to use newer, more effective fungicides representative of different chemical groups. Secondly, to target sprays when infection risk is high or predicted to be high. Leaf wetness duration and temperature are strongly influential in the development of celery leaf spot and are obvious parameters to consider to aid spray decisions.

The expected deliverable from this project is an integrated strategy for improved control of leaf spot in field crops of celery developed by:

- Evaluation of newer fungicides representative of different chemical groups for their efficacy against celery leaf spot.
- Development of a spray-timing decision tool
- Highlighting cultural practices that minimise the risk of disease spread.

Summary of the project and main conclusions

Conditions favouring infection

Experiments on celery plants in controlled environment (CE) cabinets were carried out over 3 years to determine the effects of temperature and leaf wetness duration on the development of celery septoria. The main conclusions were as follows:

- There was a trend for disease severity to increase with both temperature (5-25ºC) and leaf wetness duration (1-96 h). Data from this study provided a rational basis for disease risk prediction (Table 1).
- For temperatures of 20ºC or more and leaf wetness durations of 24 hours or more, symptom development was generally rapid, with leaf lesions evident in as few as 10 days after inoculation and present on all plants after 15 days. Although infection occurred at most other combinations tested (in the range 5-30ºC and 1-96 h leaf wetness), first symptoms were rarely seen before 15 days and the disease incidence at 28 days was often less than 100 %.
- At temperatures less than 10ºC, considerable periods of leaf wetness duration (over 72 h) were required before disease severity exceeded 5 %. Slight infection was recorded at low temperatures (5ºC) and short wetness durations (1 h), which has not been reported previously.
- Under fluctuating temperature conditions relevant to a late season celery crop, there is the potential for high levels of disease severity (over 5 %) to develop, following leaf wetness periods of 24 h or more. However, further work is required to determine more clearly the influence, if any, of fluctuating daily temperatures, compared with a constant temperature.

Table 1. Effect of incubation at different leaf wetness durations and temperatures on the severity of septoria leaf spot, 28 days after inoculation

Temperature (ºC)	Leaf wetness duration (hours)					
	Less than 1	1 – 6	6.1 – 24	24.1 – 48	48.1 – 72	72.1 – 96
5	Low*	Moderate	Moderate	Moderate	Moderate	High
10	Low	Low	Low	Moderate	Very high	Very high
15	Low	Low	Low	High	Very high	Very high
20	Low	Moderate	High	Very high	Very high	Very high
25	Low	Low	Very high	Very high	Very high	Very high
30	Low	Low	Low	High	Very high	Very high

*Disease severity (% leaf area affected)
Low: less than 1% High: 5-20%
Moderate: 1-5% Very high: over 20%

Fungicide activity

Fungicides effective when applied prior to infection have a 'protectant' mode of action. 'Curative' fungicides are effective when applied after spore infection but before symptom development, while 'eradicant' fungicides can delay disease development when applied after symptoms are visible.

The relative protectant and curative activity of eight fungicides on celery plants, cv. Celebrity was determined in a glasshouse trial (2001). Fungicides (Bravo 500, Cuprokylt, Croptex Fungex, Amistar, Folicur, Plover, Alto 240EC and experimental product BAS 516F) applied

once, 10 days prior to inoculation, all significantly reduced disease severity. Highly effective protectant activity was shown by BAS 516F and Plover (less than 1 % leaf area affected), and good activity by Amistar, Folicur and Bravo 500 (less than 5 %), compared with the untreated plants (16 %). When applied 4 days prior to inoculation, all fungicides reduced disease severity and three (Bravo 500, Plover and BAS 516F) also reduced disease incidence.

When fungicides were applied 3 days after inoculation with *S. apiicola,* disease severity was reduced by all fungicides except the two copper products. Plover again reduced disease incidence. When fungicides were applied 10 days after inoculation with *S. apiicola*, only Plover and Folicur showed notable curative activity, reducing disease severity from 16 % to less than 5 % (Figure 1).

Twenty-four hours after application of fungicides to leaves with septoria lesions, spore germination was significantly reduced following treatment with Amistar and BAS 516F (eradicant activity), but not with the other fungicides. The triazole fungicides (Alto 240 EC, Folicur and Plover) act on fungal growth after germination and so would not be expected to reduce germination. None of the eight fungicides affected spore release from pycnidia (spore cases) or the appearance of germ tubes developing from germinating spores.

Figure 1. Relative protectant and curative activity of eight fungicides against celery leaf spot (*S. apiicola*)

	No. of days before/after inoculation				
Fungicides	10	4	0	3	7
Bravo 500[a]	**	***		**	
Cuprokylt[a]	*	**			
Croptex Fungex[a]	*	**			
Amistar[a]	***	***			
Folicur	**	***		***	**
Plover[a]	***	***		***	**
Alto 240 EC	*	***		***	*
BAS 516 F	***	***		**	*
	PROTECTANT			CURATIVE	

[a]Permitted on field celery

*** excellent disease control
** good disease control
* some disease reduction

Efficacy of fungicide programmes

In an inoculated field trial on cv. Celebrity, conducted at ADAS Arthur Rickwood from 18 July to 31 October 2001, seven fungicide programmes significantly reduced disease severity (Table 2). Alternating programmes of Amistar/Plover and BAS 516F/Plover, with sprays applied every 14 days (6 in total), reduced disease severity (% leaf area affected) at harvest from 33 % to less than 0.05 %. A programme of Bravo 500/Plover was only slightly less effective (0.4 % leaf area affected). Effectiveness of disease control was reflected in increased marketable yield. None of the treatments adversely affected the appearance of the harvested crop.

Results from the 2001 glasshouse and field trials showed the potential for use of BAS 516F, now available as Signum (boscalid + pyraclostrobin), as a protectant for control of celery septoria. Currently it is not permitted to use this fungicide on celery.

Table 2. Effect of fungicide programmes on septoria leaf spot (2 months after inoculation), and marketable yield (ADAS Arthur Rickwood, 2001)

Treatment	% Disease incidence	% Disease severity	% Marketable sticks
Untreated control	100	33.1	0
Bravo 500/Cuprokylt	100	6.8	8.3
Bravo 500/Amistar	100	3.6	54.2
Bravo 500/Plover	79	0.4	83.3
Bravo 500/Folicur	100	5.8	25.0
Amistar/Plover	15	0.0	83.3
Amistar/Folicur	82	1.3	62.5
BAS 516F/Plover	24	0.0	91.7

Spray timing and product choice

2002

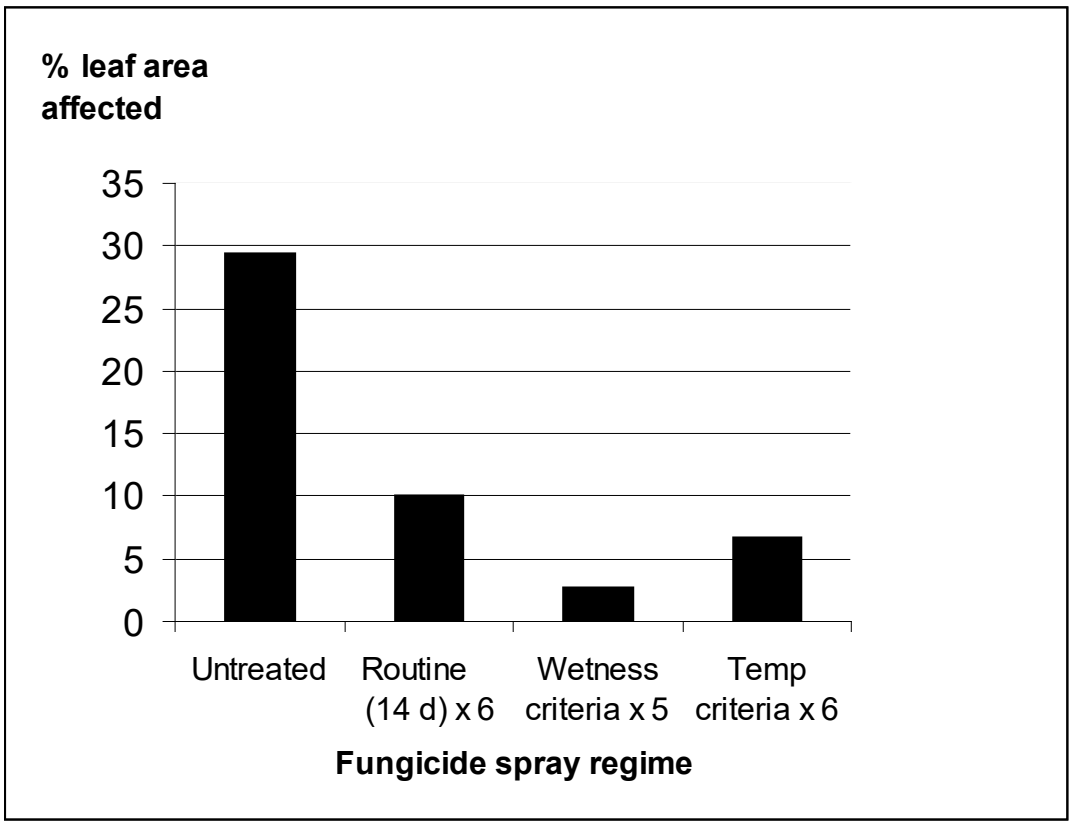
An artificially inoculated field trial was carried out at ADAS Arthur Rickwood in 2002, to compare fungicide spray programmes applied either prophylactically (fortnightly) or according to environmental variables, on the development of celery leaf spot and yield. The timing of sprays applied according to environmental variables (leaf wetness and temperature) was determined according to a set of risk criteria developed using data from experiments carried out in project year 1. For all treatments, the sequence of fungicide applications was Amistar (azoxystrobin), Plover (difenoconazole), then Bravo 500 (chlorothalonil), irrespective of spray timing.

The spray schedule that was timed according to leaf wetness criteria (≥12 h leaf wetness duration was deemed to indicate a disease risk), provided excellent control of celery septoria throughout the trial period (July to October), even though one less spray than the prophylactic schedule was used (5 instead of 6). Mean disease severity did not exceed 2 % even 2 months after inoculation, compared with 5-10 % in treatments sprayed prophylactically or according to temperature criteria, and approximately 30 % in the untreated control (Figure 2). Treatment effects on disease severity were closely reflected by the yield data with marketable yields significantly higher for treatments applied according to leaf wetness criteria compared with all other treatments.

It was concluded that if a forecasting system for celery septoria were to be based on a single environmental criterion, leaf wetness duration is likely to be a more accurate indicator of the risk of disease development than temperature. The low disease levels recorded in plots treated according to leaf wetness criteria, shows that a fungicide programme incorporating Amistar, Bravo 500 and Plover can be highly effective in minimising development of celery septoria, even under conditions of high inoculum pressure. However, the higher disease levels on plots treated with the same fungicide sequence but applied according to a marginally different spray schedule, indicates that effective disease control is dependent on both the choice of product and the timing of application in relation to infection events and environmental conditions.

Figure 2. Effect of fungicide spray programmes on *S. apiicola* (% leaf area affected) – 2002

[Timing of fungicides (Amistar, Plover, Bravo 500) was either every 14 days (routine) or based on leaf wetness duration or mean night temperature]



2003

In an inoculated field trial in 2003, we looked further at possibilities for effective septoria control using spray timing according to leaf wetness periods and product choice according to recent and forecasted rainfall and irrigation (Table 3). The criteria for fungicide product choice was based on the relative protectant and curative action of fungicides approved for use on celery, as identified in year 1. A forecasting system for celery septoria developed by the University of California was also trialled.

Table 3. Criteria for fungicide product choice

Rainfall/irrigation In last 7 days	5-day forecast	Product choice
Dry	Dry	Amistar
Wet*	Dry	Plover
Dry	Wet	Bravo
Wet*	Wet	Plover

*At least one significant rainfall or irrigation event in last seven days

Treatment 2 (prophylactic spray regime with fixed fungicide sequence) provided effective disease control throughout the trial as did Treatment 3 (prophylactic spray regime with product choice) (Table 4). Both programmes would be easy for growers to implement. It is considered that over several seasons, Treatment 3 would provide better control, since the fixed fungicide sequence could result in use of an inappropriate product in relation to environmental conditions, as was observed in the 2002 field trial.

The results for Treatment 4 (fungicides triggered by at least one continuous period of leaf wetness of 12 h or more in the last 7 days) showed effective control of celery leaf spot throughout the season with a reduction of one spray, in agreement with field trial results from 2002. Due to the relative frequency of leaf wetness periods exceeding 12 h, it is likely that this programme would largely be similar to a prophylactic regime but with the scope for reducing spray numbers if conditions are dry and settled. There is good potential for growers to use this system of timing sprays according to in-crop leaf wetness data, and selecting an appropriate product according to recent and forecasted precipitation (including irrigation).

In contrast to results from 2002, medium and high risk leaf wetness regimes (Treatments 5 and 6) were ineffective in controlling disease throughout the trial. Although disease severity was low at the end of the trial, disease incidence had increased to more than 70 % for Treatment 5 and there was a yield reduction. It is likely that leaf wetness periods of between 12-24 h in late September, would have contributed to disease development in these plots, which had not received a fungicide application since July.

Treatment 7 (published model) resulted in a low disease severity but there was a rapid increase in disease incidence in the latter half of the season. The model would need trialling over several seasons, to determine its worth in celery-growing regions in the UK.

Table 4. Effect of selected fungicide programmes on septoria leaf spot (3 months after inoculation), ADAS Arthur Rickwood, 2003

Fungicide regime	No. of sprays applied	% plants affected	% leaf area affected
1. Untreated control	0	97	22.4
2. Prophylactic (14 d interval); fixed product sequence*	6	0	0.0
3. Prophylactic (14 d interval); product choice**	6	1	0.0
4. Timing according to ≥12 h leaf wetness: product choice	5	1	0.0
5. Timing according to ≥ 24 h leaf wetness: product choice	1	72	1.4
6. Timing according to ≥48 h leaf wetness: product choice	1	29	0.9
7. University of California model	2	17	0.1

*Fixed sequence of Amistar, Plover, Bravo 500
**Fungicide product chosen on basis of recent and forecasted rainfall

Integrated management practices

Fungicide sprays are likely to form a major component of integrated management strategies for celery septoria but should not be used in isolation. Cultural and hygiene practices as described in HDC Factsheet 06/01 (Management of celery leaf spot), should also be used. The key components are:

- Volunteer celery plants or wild celery (*Apium graveolens*) in or bordering the field should be controlled since they could harbour the disease
- Check transplants on arrival. Do not use seedlings with any disease symptoms. If possible isolate new plantings to avoid splash dispersal from currently or recently affected crops.
- To minimise the risk of disease spread, bury crop debris rather than leaving it on the surface, and leave one clear year before re-planting with celery.
- Regular crop monitoring is important to detect the early symptoms of disease. Small foci of infected plants should be promptly removed and destroyed, to prevent epidemic development through the crop.
- Where it is possible to raise the water table as an alternative to overhead irrigation, this will reduce disease risk. Wider plant spacing may also help to improve air circulation in the canopy, thus reducing leaf wetness duration and associated disease risk.

The following sanitation measures should be implemented to minimise spread of the disease by people, equipment and machinery:

- Restrict entry into the crop
- Clean boots and waterproofs
- Clean planting and harvesting equipment
- Do not re-use fleece from an infected crop
- Avoid disposal of celery debris in or near to reservoirs
- Remove any surplus or reject plants from the cropping field.

Other diseases

Due to negligible incidence of other diseases (e.g. rhizoctonia and sclerotinia) during field trials, recommendations on the efficacy of fungicide programmes to manage these diseases cannot be made based on project results. Some growers now find sclerotinia more problematic to control than celery leaf spot but find that an early spray of Amistar can provide useful protection against the disease.

Financial benefits

An estimate of £100 k crop loss in East Anglia in 1999 due to celery septoria, clearly shows the necessity for effective management of celery leaf spot. Moreover, severe annual outbreaks of the disease on crops produced to organic standards emphasises the difficulty of managing celery septoria without effective fungicide programmes.

Field trials in year 1 showed that crop loss can be minimised using a prophylactic spray regime (six sprays, 14 day intervals) of currently approved fungicides, even under heavy disease pressure. Field trials in years 2 and 3 showed that there is the potential to maintain disease control while reducing spray applications to five (with corresponding financial benefit) by appropriate product selection and application timing according to in-crop leaf wetness data.

Action points for growers

Assessing disease risk

- Results from this project indicate that at average late summer day and night temperatures, infection of celery by *S. apiicola* can occur after only 6 h leaf wetness. This suggests that if the fungus is present in the crop, then disease development could be rapid. *Growers should be vigilant to ensure healthy seed is used and other cultural measure to minimise the development of celery septoria are practised (see HDC Factsheet 06/01: Management of celery leaf spot).*

- A simple disease risk assessment scheme based on leaf wetness durations and temperatures, is shown in the Table 1. *It may prove helpful as a decision tool to help you determine whether or not to spray during a particular weather period.*

Fungicide activity

- Amistar, Bravo 500 and Plover all show good protectant activity against leaf spot when applied 4 days before an infection event. Bravo 500 was outstanding, significantly reducing disease incidence as well as severity. Amistar and Plover showed excellent protectant ability when applied as much as 10 days before an infection event. *In a high disease risk situation (based on forecasted weather), and with no disease established in the crop, it is recommended that either Amistar or Bravo 500 are used as a protectant. It is advisable to use Plover only when good curative activity is also required.*

- The good curative activity of Plover was demonstrated in glasshouse and field trials. *It is recommended that Plover is used immediately after a prolonged wet period, when it has not been possible to spray at the planned time (subject to remaining within the SOLA conditions of use).*

Fungicide programme

- An alternating sequence of Amistar, Plover and Bravo 500 (14 day interval, six sprays in total), provided effective control of celery septoria. Bravo 500 has full approval for use against celery septoria while Amistar and Plover have off-label approvals. *It is recommended that growers use the range of fungicide products that are available against celery septoria. Alternating between products with different modes of action can help to reduce the risk of pathogen resistance to an individual product. Consider following this programme if you are not using leaf wetness duration to assess infection risk. Note that disease control may be reduced if septoria leaf spot is evident in the crop before the first spray is applied.*

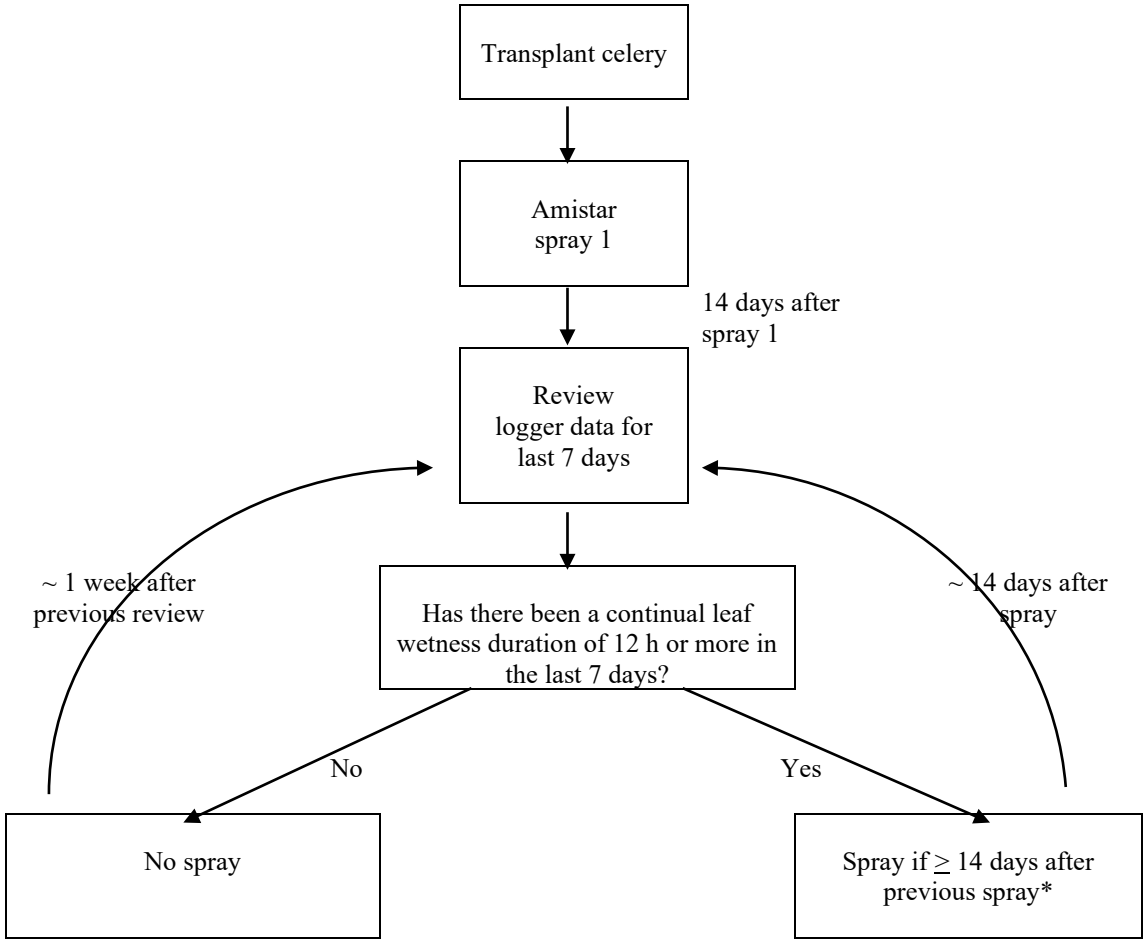
Selecting the best fungicide according to rainfall

- The efficacy of a prophylactic spray regime (e.g. 14 day spray interval) may be enhanced by selecting the appropriate fungicide product in relation to recent and forecasted rainfall and irrigation. A simple scheme for product selection, based on the relative protectant and curative ability of approved fungicides for celery, was found to be effective in the 2003 field trial. *The information in Table 3 may provide a useful scheme for selecting the most appropriate fungicide to use when a spray application is due.*

Using leaf wetness data to aid spray timing

- Effective control of celery septoria was achieved over two growing seasons when fungicide sprays were only applied when at least one leaf wetness duration exceeding 12 h had been recorded on an in-crop logger in the previous 7 days. Spray timing based on longer leaf wetness durations (more than 24 h, more than 48 h) was not so effective. In 2003, product choice was made according to the criteria in Table 3. *Leaf wetness duration recorded on in-crop loggers provides a useful indication of risk of septoria development. A possible scheme on how to use logger data to aid spray timing is shown in Figure 3.*

Figure 3. Flow chart used to make spray decisions for treatment of septoria leaf spot in a celery crop



Once a spray is due, select the appropriate fungicide to use based on the criteria in Table 2

SCIENCE SECTION

1. Introduction

Prior to this project, there had been no work on control of septoria on celery in the UK for over 20 years. Work in the 1960s and 1970s clearly demonstrated that septoria can survive in celery debris in soil over one winter but not two; and led to the development of the now standard warm thiram soak seed treatment.

In the USA and Canada, three models have been developed for septoria on celery which predict disease severity as a function of leaf wetness and temperature. For example, Lacy (1994) identified 12 hour leaf wetness as a useful threshold above which there is a significantly increased likelihood of septoria spore germination and leaf infection. Prolonged leaf wetness (24 and 36 hours) was highly conducive to infection. In three successive seasons, spray timing based on a 12 hour wetness threshold reduced by two (from seven to five) the number of sprays required to maintain control in an inoculated crop in the USA. These models represent a useful starting point for identifying weather periods associated with high risk of disease development, although it cannot be assumed that a model validated for a region of the USA will be directly applicable to the UK. In year 1 of this project, experiments on celery plants in controlled environment (CE) cabinets were successfully used to quantify the relationship between infection by *S. apiicola* and leaf wetness duration at different constant temperatures (Green & O'Neill, 2002; HDC 2002). In agreement with previous work (Mathieu & Kushalappa, 1993), for temperatures ≥20ºC and leaf wetness durations ≥24 h, symptom development was generally rapid, with leaf lesions evident in as few as 10 days after inoculation and present on all plants after 15 days. Slight infection was also recorded at low temperatures (5ºC) and short wetness durations (1 h), which has not been reported previously.

Work on celery leaf spot in Australia showed that chlorothalonil has good protectant activity and also revealed that some triazole fungicides (e.g. propiconazole and tebuconazole) have curative activity (of 3-5 days), while chlorothalonil has none (Wicks, 1990). Recent work on winter wheat in the UK has investigated the relative protectant and curative activities of new fungicides against *Septoria tritici*, and identified marked differences. In ADAS consultancy work, resistance of *S. apiicola* to carbendazim has been identified in isolates from some celery crops. In crops where resistant isolates are present, Bavistin DF and related fungicides will no longer control leaf spot.

In the year that this project commenced (2000-2001), the protectant fungicides Bravo 500 (chlorothalonil), Croptex Fungex (copper ammonium carbonate) and Cuprokylt (copper oxychloride) had full approval for use on field celery and Amistar had recently gained a specific off-label approval for use on the crop. The triazole fungicides Plover (difenoconazole), Folicur (tebuconazole) and Alto 240 EC (cyproconazole) had approval for use on other minor vegetable crops and were evaluated together with BAS 516 F (experimental product) under Administrative Experimental Approvals. In 2002, Plover also gained a specific off-label approval for use on celery. In project year 1, glasshouse experiments provided detailed information regarding the relative protectant and curative activity of the above-listed fungicides. The results were closely supported by disease assessments in the field. The results highlighted the superior performance of Plover, which showed long term control when applied both pre- and post-infection but also demonstrated the

efficacy of Amistar and Bravo 500, and the potential for BAS 516F to be used as a protectant fungicide for celery production, should use on the crop be permitted.

There are two recently completed HDC-funded projects on other diseases of celery. Project PC/FV 173 investigated crater spot caused by *Rhizoctonia solani*; Amistar applied to the soil surface resulted in a significant disease reduction. Project PC 131 investigated fungicides for control of *Sclerotinia* (pink rot) in protected crops; Amistar and Bavistin DF applied as sprays gave significant control. This current project focuses on the control of celery leaf spot caused by *S. apiicola*, but incorporates field trial monitoring of other important celery diseases such as *Sclerotinia* and *Rhizoctonia* to determine treatment effects on these diseases.

This final report describes trials conducted from October 2002 – October 2003 (project year 3). The objective of Experiment 1 was to determine the effect of temperature and leaf wetness duration on disease development. The experiment was a continuation of controlled environment experiments carried out in year 2, to study the effect of different leaf wetness combinations under fluctuating temperature conditions, which were selected to reflect diurnal variations in a field situation. In Experiment 2, an inoculated field trial was carried out at ADAS Arthur Rickwood. The aim of the experiment was to compare fungicide spray programmes applied either prophylactically or according to environmental variables on disease development and yield.

2. Experiment 1: Controlled environment experiment to determine the effect of temperature and leaf wetness duration on infection of celery by *Septoria apiicola*

Introduction

Results from controlled environment experiments in Year 1 showed that there was a consistent trend for a combination of temperatures >20ºC and leaf wetness durations >24 h to result in rapid and severe development of celery leaf spot on inoculated plants (Annual Report, 2002). In Year 2, the effects of a narrower range of critical temperatures/leaf wetness durations (selected from Year 1 results) on disease development were evaluated. In addition, the effects of fluctuating temperature regimes on disease development were evaluated but results were inconclusive. In year 3, controlled environment experiments were carried out to investigate further the effect of diurnal temperature variation over different leaf wetness durations, on the development of celery septoria.

Materials and methods

Celery plants artificially inoculated with *S. apiicola* were incubated at two temperature regimes (18ºC continuously and 12h 18ºC / 12h 13ºC). The latter treatment represented the day-time mean (09:00 – 21:00 h) and night time mean (21:00 – 09:00 h) from July 1st – September 30th based on 2 years meteorological data at ADAS Arthur Rickwood. At each incubation temperature, three leaf wetness periods were tested (6, 24 and 48 h).

The experiment was run using two controlled environment cabinets simultaneously:

Week	Cabinet 1	Cabinet 2
1	18ºC	18/13ºC
2	18/13ºC	18ºC

As temperatures were tested over time, their effect could have been confounded with that of inoculum. To minimise confounding, percentage spore germination was determined to ensure that spore viability remained uniform for both temperatures (>95 % germination).

Plant material

For each temperature tested, young celery plants cv. Celebrity, unsprayed with fungicide were obtained from Delflands Nurseries, Cambs. The plants had 2-3 true leaves when the trial commenced.

Preparation of inoculum

10-30 g dried celery leaves naturally infected with *S. apiicola* were immersed into 150-400 ml distilled water, left for 30 min and agitated. The suspension was strained through four layers of cheesecloth and adjusted to 1 x 10^6 conidia/ml using a haemocytometer.

A sample of spore suspension (20 µl) prepared for each temperature treatment was pipetted and spread on to each of three plates of PDA+S. Percentage spore germination was determined after incubation for 24 h at 20ºC.

Plant inoculation

The plants to be inoculated were sprayed to run-off using a spray bottle with atomiser. The plants were placed within a misting chamber in a controlled environment cabinet. For each run, six un-inoculated control plants were also placed in the misting chamber but separated from the inoculated plants. In order to maintain leaf wetness, intermittent mist was provided by a timer-operated cold mister. For all temperature regimes, misting for 2 min every 2 h was sufficient to maintain continual leaf wetness. The plants received a 12 h day/12 h night light regime.

At the end of each wetness period, ten plants were removed and gently dried for approximately 30 min with an electrical fan until water droplets were no longer visible on the leaves. The 2nd and 3rd true leaves were marked to allow subsequent disease assessments on these leaves. After drying, plants were potted on using 9 cm diameter pots and placed on capillary matting. The temperature in the polytunnel was monitored with a data logger. The plants were grown on for 4 weeks to allow symptom development. The plants were watered around the base, avoiding leaf wetting and were spaced so that there was no contact between plants.

Assessments

Twice weekly from the time of inoculation, the incidence of septoria lesions was scored on each plant. At 28 days after inoculation, percentage leaflet area affected by septoria lesions was estimated for each of the three leaflets of the two previously marked leaves.

Results and discussion

Spore germination exceeded 90 % for each set of inoculum used in the experiment. There was no disease development on the untreated control plants.

Symptom development occurred on all treatments irrespective of leaf wetness duration or temperature regime. However, the time until first symptom development was noticeably more rapid for plants exposed to 24 h or more leaf wetness, with first symptoms developing after 12 days, compared with 15 days for plants incubated with only 6 h leaf wetness (Table 1).

Disease incidence was high (>80 %) following incubation at leaf wetness durations of 24 h, while 100 % incidence was consistently recorded following leaf wetness durations of 48 h, irrespective of temperature regime (Table 2). Disease incidence after 6 h leaf wetness duration was highly variable, but was not apparently related to differences in temperature regime or cabinet environment.

Disease severity after 6 h leaf wetness duration was consistently low (<2 %) irrespective of temperature regime (Table 3). Disease severity after longer wetness durations (24 h or more) was variable. However for individual runs of the experiment, disease severity following 48 h leaf wetness was always more than double the disease severity recorded following 24 h leaf wetness. Following 24 h or more leaf wetness, there was a trend for disease severity to be higher after incubation at a uniform rather than fluctuating temperature regime (when comparing runs set up in the same week).

Table 1. Effect of temperature and leaf wetness duration on the number of days between inoculation with *Septoria apiicola* and appearance of the first lesions on celery

		Wetness duration (h)[a]					
Temp (°C)	Week	6		24		48	
		Cabinet 1	2	1	2	1	2
18	1	15-	-	12-	-	12-19	-
18	2	-	15-28	-	12-15	-	12-26
18/13	1	-	15-	-	12-	-	12-19
18/13	2	15-28	-	12-21	-	12	-

[a]The range represents the period during which first lesions appeared on the 10 plants sampled.

Table 2. Effect of temperature and leaf wetness duration on the incidence of septoria lesions, 28 days after inoculation of celery plants with *Septoria apiicola.*

		% disease incidence[a] for different leaf wetness durations					
Temp (°C)	Week	6		24		48	
		Cabinet 1	2	1	2	1	2
18	1	50	-	90	-	100	-
18	2	-	100	-	100	-	100
18/13	1	-	10	-	80	-	100
18/13	2	100	-	100	-	100	-

[a]Mean % disease incidence for ten plants per treatment.

Table 3. Effect of temperature and leaf wetness duration on % leaf spot severity 28 days after inoculation of celery plants with *Septoria apiicola*

		% disease severity[a] for different leaf wetness durations					
Temp (°C)	Week	6		24		48	
		Cabinet 1	2	1	2	1	2
18	1	1.8	-	4.2	-	34.4	-
18	2	-	0.8	-	39.7	-	81.6
18/13	1	-	0.0	-	2.6	-	13.6
18/13	2	1.3	-	9.3	-	34.1	-

[a]Mean % disease severity for six leaflets per plant, ten plants per treatment.

For individual temperature/leaf wetness combinations evaluated, there were substantial differences in disease development between the two different runs (weeks) of the experiment. Possible sources of variation include inoculum pathogenicity, cabinet conditions, seedling age, or polytunnel conditions, although efforts were made to reduce variability from all these sources. Because of the variation between runs, it is difficult to draw firm conclusions about the effects of fluctuating temperature conditions on disease development.

Clear findings from the experiment were as follows:

- The number of days to first symptom development tends to be less following incubation at 24 h or more leaf wetness, compared with 6 h leaf wetness

- Disease incidence can reach 100 % after incubation with only 6 h leaf wetness duration, but disease severity tends to remain low (<2 %).
- For an individual temperature regime, there is a strong trend for disease severity to increase, with increasing leaf wetness durations.
- Under fluctuating temperature conditions relevant to a late season celery crop, there is the potential for high levels of disease severity (>5 %) to develop, following leaf wetness periods of 24 h or more.
- Following 24 h or more leaf wetness, there was a trend for disease severity to be higher after incubation at a uniform rather than fluctuating temperature regime (when comparing runs set up in the same week). These results contrast with year 2, where a 18.5/13.5ºC temperature regime resulted in a markedly greater disease severity, after 28 days, than a constant 16.6ºC or 10ºC, at a wide range or wetness durations (6-48 h). Further work is required to determine more clearly the influence, if any, of fluctuating daily temperatures, compared with a constant temperature.

3. Experiment 2: Field trial to evaluate fungicide programmes for the control of celery leaf spot (*Septoria apiicola*)

Introduction

Results from inoculated field trials in Project years 1 and 2 showed that effective control of celery septoria could be obtained even under high inoculum pressure, using a fortnightly spray regime commencing at the beginning of the season (six sprays in total), alternating the products Amistar, Bravo 500 and Plover. In Year 2, it was found that effective disease control could be achieved and spray numbers reduced, when sprays were timed according to leaf wetness criteria (≥12 h leaf wetness duration). The objective in year 3 was to compare fungicide spray programmes applied either prophylactically or according to environmental variables on i) the incidence and severity of celery leaf spot, ii) the incidence of other celery diseases, and iii) the total and marketable yield of celery. Spray timing and product choice for different treatments were selected according to a set of risk criteria developed using data from project years 1 and 2. The efficacy of a model published by the University of California for spray timing to control celery septoria was also evaluated (Phillips, 1997). This model was based on the "Tom-Cast" model originally developed for Alternaria blight on tomato (Madden *et al.*, 1978).

As in previous years, the trial was artificially inoculated with *S. apiicola*, however, inoculum pressure was reduced to reflect more closely a commercial situation. Uninoculated treatments were also included in the trial.

Materials and methods (Crop diary in Appendix 2)

Site and crop details
Crop: Celery plants cv. Victoria were raised in modules from thiram-treated seed at Delflands Nursery, Cambs. Fungicides were not applied during the propagation stage. The plants were transplanted to the field by vegetable planter and by hand.

Site: Little Rough Lots, ADAS Arthur Rickwood.
Soil: Previously cropped with potatoes
pH 5.8
P 22 mg/l (index = 2)
K 202 mg/l (index = 2+)
Mg 90 mg/l (index =2)
Bo 2.32 mg/l

Fertilisers applied prior to transplanting:
N 75 kg/ha
P 125 kg/ha
K 300 kg/ha
Bo 0.5kg Solubor / 10 litres water

Fertilisers applied four weeks after planting:
N 75kg/ha

In addition, manganese sulphate was applied at fortnightly intervals during crop production at a rate of 4 kg/ha in 200 l water/ha.

Land preparation: The area was power harrowed before and after the pre-planting fertiliser application, followed by bed formation.

Weed control: The experimental plot was weeded by hand as required.

Pest management: A prophylactic spray of Hallmark (Lambda-cyhalothrin) (SOLA 0289/00) was applied 12 days after transplanting (0.05 l in 300 l/ha water). Regular monitoring of sticky fly traps set up in the trial area at the time of planting, indicated that further insecticide sprays were not necessary.

Irrigation: Misting equipment (Rightrain 3" irrigation standpipes) was set up at the beginning of the trial. The irrigation schedule was as follows (D. Norman and P. Hooker pers. comm.):

- 12 mm irrigation at planting (week 1)
- 12 mm irrigation 3 days after planting (week 1)
- 25 mm irrigation after crop inoculation to ensure 12 h leaf wetness
- No irrigation for weeks 3-5
- 12-20 mm per week for weeks 6-8, depending on rainfall
- 25 mm per week for weeks 9-13
- 25 mm in final week before harvest

Logger: A DeltaT data logger (DL2e) was installed in the experimental plot at the beginning of the trial to monitor the following variables: rainfall, canopy temperature and leaf wetness (type SWS). The logger was set to record at hourly intervals and data was collected in the crop from 11/07/03 until 23/10/03. The leaf wetness sensor was placed at canopy level, the temperature probe just under the top of the canopy and the rain gauge at ground level. The position of the leaf wetness sensor and temperature probe was adjusted as plants grew, to ensure they were near the top of the canopy.

Experiment design

The experiment was laid out as a randomised block design with four replicate blocks. There were eight fungicide programmes, an untreated control and an untreated uninoculated control, giving a total of 40 plots. Each plot comprised a bed measuring 1.8 m (width) x 4.32 m (length) with five rows of celery per bed at a spacing of 30 cm between and 27 cm along rows. Plots were separated by a bed width of 1.8 m to avoid spray drift between plots; these beds were not planted with celery.

Treatments

The following alternating fungicide programmes commenced 12 days after transplanting:

1. Untreated inoculated control.
2. Amistar/Plover/Bravo 500 alternated at fortnightly intervals (inoculated).
3. Amistar applied before inoculation, then fortnightly spray application with product choice determined according to recent precipitation and weather forecast.
4. Amistar applied before inoculation, then spray timing according to leaf wetness criteria (low risk) and product choice according to recent precipitation and weather forecast.
5. Amistar applied before inoculation, then spray timing according to leaf wetness criteria (medium risk) and product choice according to recent precipitation and weather forecast.

6. Amistar applied before inoculation, then spray timing according to leaf wetness criteria (high risk) and product choice according to recent precipitation and weather forecast.
7. Amistar applied before inoculation, then spray timing according to University of California model and product choice according to recent precipitation and weather forecast.
8. No inoculation; Amistar then spray timing according to leaf wetness criteria (low risk) and product choice according to recent precipitation and weather forecast.
9. No inoculation; no spray until disease observed, then Plover, then Bravo (after 7 days), then Amistar (after 7 days).
10. Untreated uninoculated control.

Fungicides

Fungicides were applied in a water volume of 400 l/ha using an Oxford precision sprayer with a 1.5 m or a 2 m boom and medium flat fan nozzle (02F110) at 2 Bar pressure. The following rates were used:

Product	**Active ingredient**	**Product application rate**
Amistar	Azoxystrobin	1.0 l/ha
Plover	Difenoconazole	0.5 l/ha
Bravo 500	Chlorothalonil	3.0 l/ha

For treatments 2-8, the first Amistar spray was applied 11 days after transplanting and 2 days prior to inoculation of celery plants with *S. apiicola*. Amistar was selected to start the fungicide programme in order to reflect grower practice whereby an early application of Amistar is used to protect the crop from sclerotinia.

Treatment 2 was a prophylactic spray regime applied at fortnightly intervals with products alternated in a fixed sequence of Amistar, Plover, Bravo 500 (maximum of six sprays).

Treatment 3 was a prophylactic spray regime applied at fortnightly intervals but with product choice according to recent rainfall/irrigation and weather forecast (maximum of six sprays). The criteria for fungicide product choice is shown in Table 4. This system was devised based on year 1 data on the relative protectant and curative action of fungicides approved for use on celery (Annual Report, 2002).

Table 4. Criteria for fungicide product choice

Rainfall/irrigation in last 7 days	5-day forecast	Product choice
Dry	Dry	Amistar
Wet*	Dry	Plover
Dry	Wet	Bravo
Wet*	Wet	Plover

*At least one significant rain or irrigation event in last seven days

For **Treatments 4, 5 and 6**, after the first Amistar application, spray timing was based on leaf wetness durations (h) calculated from in-crop logger data for the previous 7 days. The thresholds for individual treatments are shown below in Table 5 and the process used to make spray decisions is outlined in Figure 1.

Table 5. Risk criteria used as the basis for spray-timing decisions for Treatments 4-6 in 2003 field trial

Treatment	Leaf wetness criteria:
4	Spray if at least one leaf wetness duration ≥12 h ('low risk')
5	Spray if at least one leaf wetness duration ≥24 h ('medium risk')
6	Spray if at least one leaf wetness duration ≥48 h ('high risk')

For **Treatment 7**, spray timing after the first Amistar application was based on the University of California model (Phillips, 1997). This involves spray timing based on the accumulation of disease severity values (DSVs), which depend on mean temperatures during leaf wetness periods (Table 6). A threshold of 20 DSVs is required to trigger a spray.

Table 6. Disease severity values (DSVs) as a function of leaf wetness period and average air temperature during the wetness period (Phillips, 1997)

	Leaf-wetting time (h) required to produce daily disease severity values of :					
	DSVs					
Mean temp °C	0	1	2	3	4	
13-17	0-6	7-15	16-20	21+		Wet hours
18-20	0-3	4-8	9-15	16-22	23+	
21-25	0-2	3-5	6-12	13-20	21+	
26-29	0-3	4-8	9-15	16-22	23+	

Treatment 8 was the same as Treatment 4 but without septoria inoculation, to be more representative of a commercial situation. After an initial Amistar application, subsequent sprays were timed according to the low risk leaf wetness threshold (Table 5) with products selected according to Table 4.

Treatment 9 was a reactive programme based on three sprays at 7 day intervals following symptom development. Once symptoms had been confirmed within the field trial, Plover was applied followed by Bravo 500 and Amistar, after 7 and 14 days respectively.

Inoculation

The experiment was inoculated with *S. apiicola* 2 days after the first fungicide application. A spore suspension was prepared by soaking dried celery leaves infected with *S. apiicola* in distilled water. After 1 h, the leaf material was squeezed out and put aside and the spore suspension was decanted through a piece of muslin and a funnel into a 10 l water container. The final volume of the spore suspension was 2.5 l at a concentration of 1 x 10^5 spores/ml. The spore suspension was applied to six plants (the central two plants in each of three middle rows) in 28 plots (90 ml/plot), using a pump action hand-held mister. Leaf debris used for spore suspension preparation was distributed evenly around the inoculated plants. There was no need to irrigate the trial on the day it was inoculated because of continuous rainfall.

Disease assessments

Approximately 4, 9, 11 and 13 weeks after crop inoculation, the percentage leaf area affected by leaf spot was recorded for the central 12 plants per row in the middle three rows of each plot (i.e. including the six inoculated plants). The incidence of disease symptoms due to other pathogens (e.g. *Rhizoctonia* and *Sclerotinia*) on these plants was also recorded.

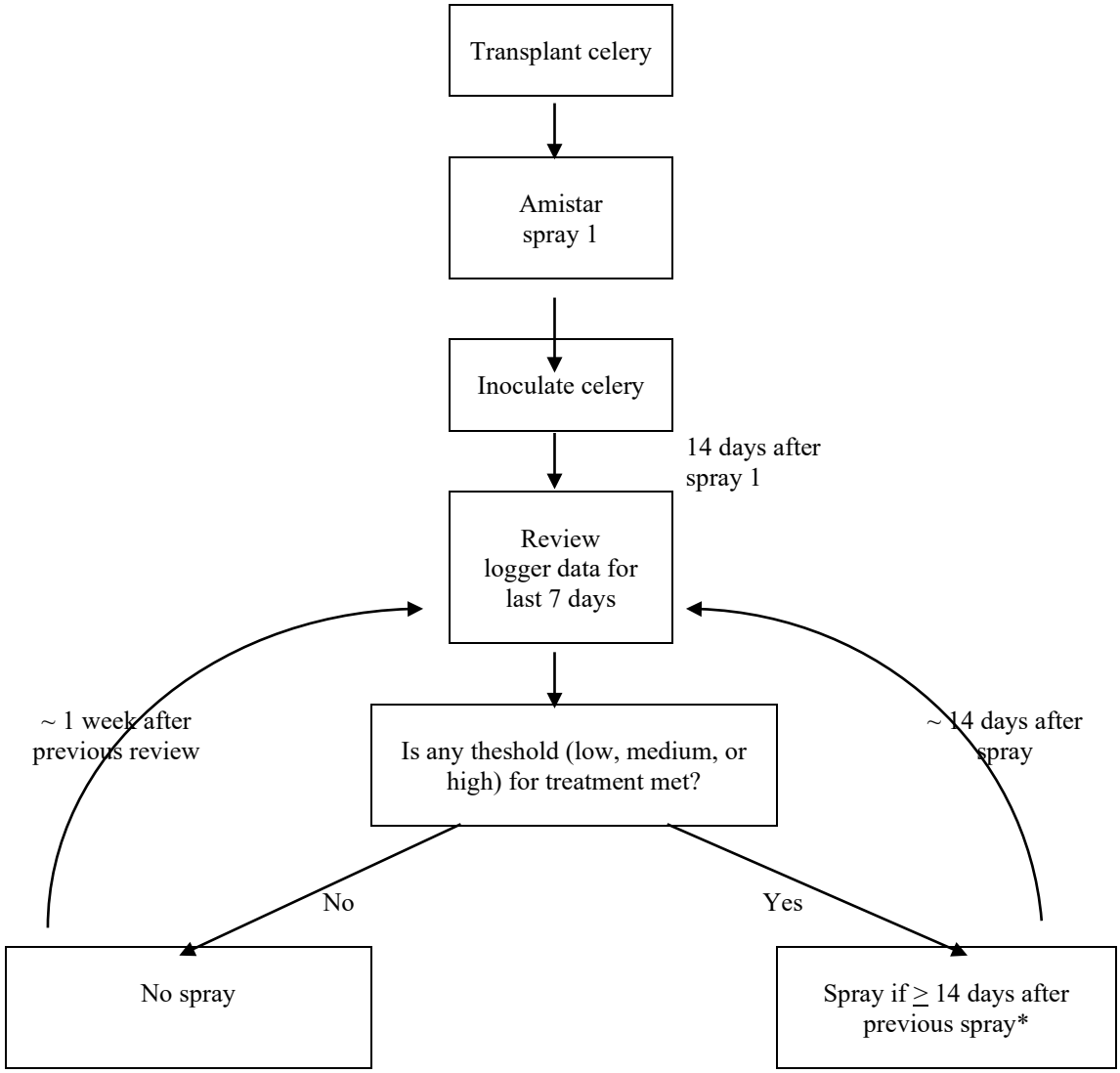
Harvest and yields

The trial was harvested 15 weeks after transplanting. From each plot, 24 plants were cut from the centre of the middle three rows (eight plants per row) excluding the inoculated plants and the row of plants either side, using celery cutting knives. The individual weight for each of the 24 harvested plants was recorded before and after trimming. Plants were trimmed to market specifications (30 cm petiole, no blemishes). Plants weighing >450 g were recorded as marketable. The incidence of plants affected with sclerotinia or rhizoctonia was recorded.

Statistical analyses

Yield data were subjected to analysis of variance. Disease incidence and severity data was analysed using Friedmans Test, since the data did not conform to the assumptions of ANOVA.

Figure 1. Flow chart used to make spray decisions for Treatments 4-6 and 8 in Experiment 2 (2003 field trial)



Product choice based on Table 4

If low risk	Spray only low risk plots
If medium risk	Spray medium and low risk plots
If high risk	Spray high, medium and low risk plots

Results

General observations

- Septoria leaf spot was first observed on 12 August, 18 days after inoculation (on 25.07.04) in all Treatment 1 plots (inoculated control).
- Plots for Treatment 8, 9 and 10 in block 1 were inoculated in error. Disease and yield data from these plots was collected but are not presented or included in statistical analyses.
- Incidence of other celery diseases was negligible in this field trial. Sclerotinia and rhizoctonia were not observed during the growing season or at harvest.

Environmental variables

In-crop logger data for the duration of the trial is summarised in Appendix 2. For rainfall measurements, data from the Arthur Rickwood meteorological Station were used rather than in-crop rain gauge data, as they were considered more accurate. Timing and quantity of irrigation water applied, is also presented in Appendix 2. Following heavy rain in late July, August was mainly dry with high temperatures. Rain was fairly infrequent in September and October, although there was heavy rainfall (19.5 mm) on 22nd September. The relatively dry weather is reflected in Figure 2, which shows the frequency of different leaf wetness durations that occurred during the trial period. There were no leaf wetness durations that exceeded 24 h during the 2003 trial, compared with a similar period in 2002 when there were seven leaf wetness durations of >24 h, including one that was >48 h.

Fungicide timing and product choice (Table 7)

Treatments 1 and 10 remained untreated

Treatment 2: Fungicide applications were made as specified in the Methods section

Treatment 3: Plover was selected for the 2nd spray on 6 August because of rainfall in the previous 7 days (3 days when rainfall was recorded, >10 mm in total). This was followed by two Amistar sprays during a spell of dry and settled weather. Irrigation was applied during this period but did not result in extended periods of leaf wetness because of high temperatures. A second Plover was applied (18th September) following rain and 25 mm irrigation in the previous 7 days, and forecast rain. The last spray was Bravo 500, following a dry week but with rain forecasted.

Treatment 4: The sequence of product choice followed that described for Treatment 3. However there was a gap of 3 weeks between the third and fourth spray applications, since leaf wetness duration of 12 h was not exceeded, due to hot and dry weather. The total number of spray applications was five.

Treatments 5 and 6: Leaf wetness durations did not reach 24 h during the trial period, therefore Treatments 5 and 6 (medium and high risk leaf wetness criteria) only received one fungicide application (Amistar prior to inoculation).

Treatment 7: This treatment (UC model) only received one spray (Plover) in addition to the early season Amistar. Plover was applied late in the season once 20 ‘Disease Severity Values’ (DSVs) had accumulated.

Treatment 8: Fungicide timing and product choice for this uninoculated treatment was the same as for Treatment 4 (inoculated).

Treatment 9: A fixed fungicide sequence commenced on 14th August, following observation of septoria symptoms two days earlier. The third spray (Amistar) had to be deferred for a week due to lack of spray opportunities in the previous week.

Table 7. Timing of fungicide sprays applied to 2003 field trial, ADAS Arthur Rickwood

	Treatment	23/07	W/c 28/07	06/08	14/08	20/08	W/c 25/08	02/09	10/09	18/09	24/09	03/10
1	Inoculated control	-	-	-	-	-	-	-	-	-	-	-
2	Prophylactic	A1	-	P1	-	B1	-	A2	-	P2	-	B2
3	Prophylactic / product choice	A1	-	P1	-	A2	-	A3	-	P2	-	B1
4	LW low risk / product choice	A1	-	P1	-	A2	-	-	A3	-	P2	-
5	LW medium risk / product choice	A1	-	-	-	-	-	-	-	-	-	-
6	LW high risk / product choice	A1	-	-	-	-	-	-	-	-	-	-
7	UC model / product choice	A1	-	-	-	-	-	-	-	-	P1	-
8	LW low risk / product choice	A1	-	P1	-	A2	-	-	A3	-	P2	-
9	Reactive programme	-	-	-	P1	B1	-	A1	-	-	-	-
10	Uninoculated control	-	-	-	-	-	-	-	-	-	-	-

Key:
LW Leaf wetness
A Amistar
P Plover
B Bravo 500

Disease development

There was a significant effect of treatments on disease incidence and severity, assessed in the two weeks prior to harvest (Tables 8 and 9). Approximately one month after inoculation, disease incidence had reached 42 % in the inoculated control plots but severity remained less than 1 %. One month later (25th September), disease incidence had almost doubled in the inoculated control treatment but disease severity was still less than 2 %. A trace of disease (mean severity <0.05 %) was observed for Treatments 2, 7 and also for Treatment 10 which was not inoculated. By early October, disease incidence had rapidly increased in Treatments 5 and 6 (medium and high risk leaf wetness criteria) and Treatment 7 (UC model), following heavy rainfall in late September. By the end of the trial, most of the plants in the inoculated control were infected, with a mean disease severity of 22 %. Disease incidence exceeded 10 % for several other treatments (5, 6, 7 and 10) but disease severity remained less than 2 %.

Yield

Marketable yields were generally low due to long periods of hot dry weather during the trial. Despite apparent treatment differences (Table 10) there were no significant effects, due

perhaps to a high level of variability between individual plants. However, the trends in marketable yield clearly reflected disease incidence and severity with a markedly lower percentage of marketable sticks in the inoculated control treatment. There was also an apparent reduction in yield for Treatment 5 (medium risk leaf wetness criteria) which had the highest disease incidence and severity after Treatment 1.

Table 8. Effect of fungicide programmes on the incidence of celery leaf spot (*Septoria apiicola*), assessed four times during the growing season

Treatment	Total no. sprays	% disease incidence[a]			
		21 Aug	25 Sep	10 Oct	22 Oct
1. Inoculated control	0	42.4	79.9	90.3	96.5
2. Prophylactic	6	0.0	0.7	0.0	0.0
3. Prophylactic/Product choice	6	0.0	0.0	0.0	0.7
4. LW low risk/Product choice	5	0.0	0.0	0.0	0.7
5. LW med risk/Product choice	1	0.0	0.0	42.4	71.5
6. LW high risk/Product choice	1	0.0	0.0	14.6	28.5
7. UC model/Product choice	2	0.0	2.1	8.3	17.4
8. LW low risk/Product choice*	5	0.0	0.0	0.0	0.0
9. Reactive programme*	3	0.9	0.0	0.0	3.7
10. Uninoculated control*	0	0.0	4.6	10.2	22.2
Significance (P-value)		-	-	0.007	0.003
S value (9 d.f.)		-	-	22.78	25.08

Analysed by Friedman's non-parametric test
[a]Mean % of plants (out of 36) with leaf spot symptoms
*not inoculated with *S. apiicola*

Table 9. Effect of fungicide programmes on the severity of celery leaf spot (*Septoria apiicola*), assessed four times during the growing season

Treatment	Total no. of sprays	Mean disease severity (% leaf area affected)			
		21 Aug	25 Sep	10 Oct	22 Oct
1. Inoculated control	0	0.8	1.5	4.4	22.4
2. Prophylactic	6	0.0	0.0	0.0	0.0
3. Prophylactic/Product choice	6	0.0	0.0	0.0	0.0
4. LW low risk/Product choice	5	0.0	0.0	0.0	0.0
5. LW med risk/Product choice	1	0.0	0.0	0.6	1.4
6. LW high risk/Product choice	1	0.0	0.0	0.1	0.9
7. UC model/Product choice	2	0.0	0.0	0.0	0.1
8. LW low risk/Product choice*	5	0.0	0.0	0.0	0.0
9. Reactive programme*	3	0.0	0.0	0.0	0.0
10. Uninoculated control*	0	0.0	0.0	0.1	0.5
Significance (P-value)		-	-	0.010	0.004
S value (9 d.f.)		-	-	21.89	24.42

Analysed by Friedman's non-parametric test
*not inoculated with *S. apiicola*

Table 10. Effect of fungicide programmes on yield and marketability of celery, ADAS Arthur Rickwood, 2003

Treatment	Yield at harvest (kg per plot)	Marketable yield (kg per plot)	Mean weight of marketable sticks (g)	% Marketable sticks[a]
1. Inoculated control	17.57	1.08	390	8.3
2. Prophylactic	19.12	7.30	579	52.1
3. Prophylactic/Product choice	18.81	4.20	556	30.2
4. LW low risk/Product choice	19.05	5.05	540	38.5
5.LW med risk/Product choice	17.85	2.32	427	16.7
6. LW high risk/Product choice	20.10	4.99	541	37.5
7. UC model/Product choice	18.52	4.38	527	34.4
8. LW low risk/Product choice*	18.30	5.26	535	39.6
9. Reactive programme*	18.09	3.92	549	28.1
10. Uninoculated control*	18.90	3.92	500	30.2
SED (27 d.f.)	1.192	1.358	0.093	14.76
Significance (P<0.05)	Ns	Ns	Ns	Ns

[a]Above minimum weight of 450 g and minimum height of 28-30 cm, with no *Septoria* present.
* not inoculated with *S. apiicola*

Discussion and conclusions

The rapid spread of infection in inoculated control plots, from the central six plants to >40 % plants in one month, emphasises the potential for rapid spread of celery leaf spot from primary foci of infection.

Similarly, the increase from 4 to 22 % disease severity in 12 days in the inoculated control plots shows how rapidly the disease can develop under conducive environmental conditions. Despite lower inoculum pressure at the beginning of the trial and a long period of dry weather, the disease severity in the control plots was comparable to that recorded in the 2002 trial.

It was interesting to note that by the end of the trial, even with a hot dry summer, disease had spread into the uninoculated plots. This shows the potential for disease transmission, for example, in a commercial situation from diseased plantings, to neighbouring younger plantings.

Treatment 2 (prophylactic spray regime with fixed fungicide sequence) provided effective disease control throughout the trial as did Treatment 3 (prophylactic spray regime with product choice). Both programmes would be easy for growers to implement. It is considered that over several seasons, Treatment 3 would provide better control, since the fixed fungicide sequence could result in use of an inappropriate product in relation to environmental conditions, as was observed in the 2002 field trial (Annual Report, 2003).

The results for Treatment 4 (fungicides triggered by 12 h leaf wetness duration in the last 7 days) showed effective control of celery leaf spot throughout the season with a reduction of one spray, in agreement with field trial results from 2002. These results also support the findings of Lacy (1994) who showed that in 3 years of trials in the USA, two fewer sprays

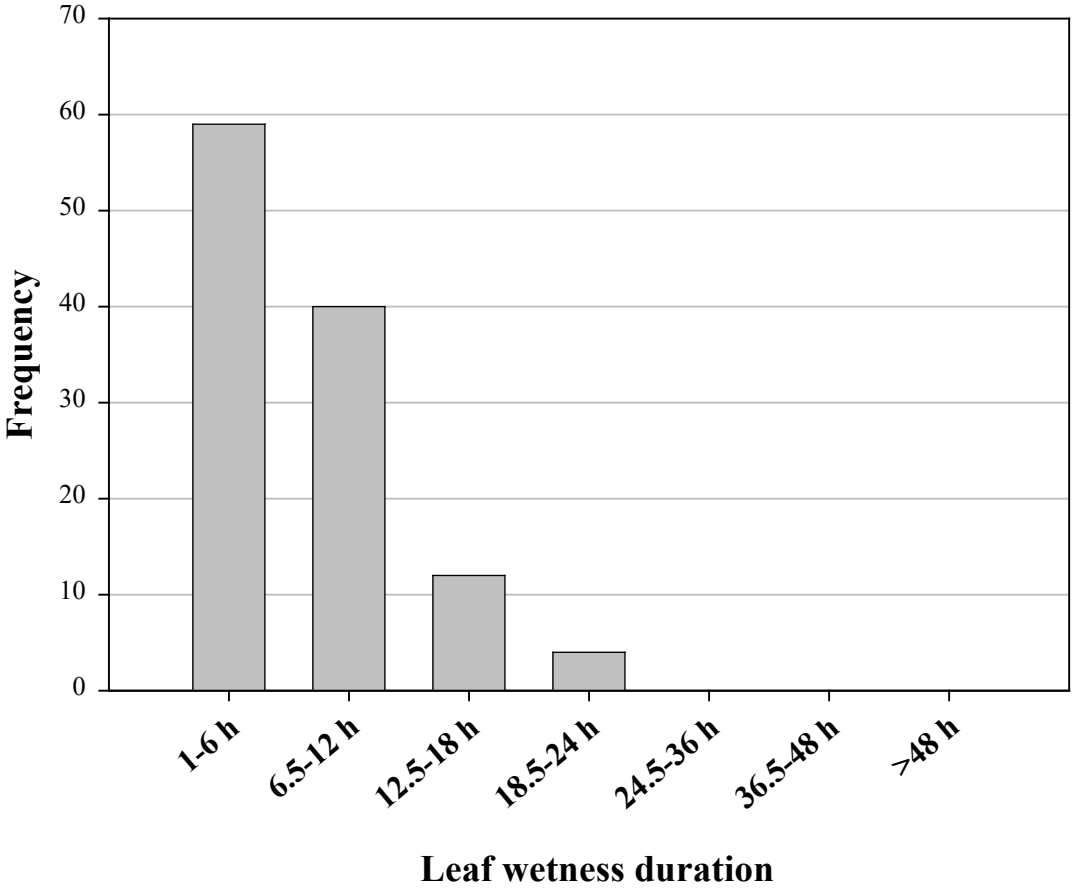
were applied annually with the 12 h wetness threshold than with a weekly schedule, without any sacrifice in efficacy of disease control. Due to the relative frequency of leaf wetness periods exceeding 12 h, it is likely that this programme would largely be similar to a prophylactic regime but with the scope for reducing the spray number if conditions are dry and settled. There is good potential for growers to use this system of timing sprays according to in-crop leaf wetness data, and selecting an appropriate product according to recent and forecasted precipitation (including irrigation).

In contrast to results from 2002, the medium and high risk leaf wetness regimes (Treatments 5 and 6) were ineffective in controlling disease throughout the trial. Although disease severity was low at the end of the trial, disease incidence had increased to >70 % for Treatment 5 and there was a yield reduction. It is likely that leaf wetness periods of between 12-24 h in late September, would have contributed to disease development in these plots, which had not received a fungicide application since July.

Treatment 7 (DSV model) resulted in a low disease severity but there was a rapid increase in disease incidence in the latter half of the season. The model would need trialling over several seasons, perhaps with the view to lowering the threshold of accumulated DSVs from 20 to e.g. 15, to determine its usefulness in celery-growing regions of the UK.

Despite low levels of disease after Treatment 9 (reactive programme), it is considered too risky a programme to recommend to growers, given the speed with which disease development occurred in other plots once symptoms were first observed.

Figure 2. Frequency of leaf wetness durations (h) occurring in a celery field trial over 105 days, ADAS Arthur Rickwood, (11.07.03 – 23.10.03)



4. Overall conclusions

Conditions for infection

- Controlled environment studies showed that there was a trend for disease severity to increase with both temperature (5-25ºC) and leaf wetness duration (1-96 h).
- Disease development occurred at lower temperatures and shorter leaf wetness durations than has previously been reported, although disease severity remained low (<5 %).
- Under optimum conditions for infection (e.g. 20ºC, >24 h leaf wetness), septoria leaf lesions were seen on young celery plants just 10 days after inoculation.
- Under fluctuating temperature conditions relevant to a late season celery crop, there is the potential for high levels of disease severity (>5 %) to develop, following leaf wetness periods of 24 h or more. However, further work is required to determine more clearly the influence, if any, of fluctuating daily temperatures, compared with a constant temperature.

Fungicide efficacy

- Glasshouse experiments in year 1 provided detailed information regarding the relative protectant and curative activity of the fungicides tested. The results were closely supported by disease assessments in the field. The results highlighted the superior performance of Plover, which showed long term control when applied both pre- and post-infection. The results also demonstrated the efficacy of Amistar and Bravo 500, and the potential for BAS 516 F, now marketed as Signum (boscalid + pyraclostrobin), to be used as a protectant fungicide for celery production.
- The effective control demonstrated by Plover in both glasshouse and field trials in 2001 provided strong support for the successful SOLA application (SOLA 1320/02).

Spray timing and product choice

- In-crop monitoring of leaf wetness duration and temperature provided useful information on the frequency of different leaf wetness durations throughout the growing season and mean temperatures during these periods. Data was used to devise risk thresholds to guide spray decisions during field trials in 2002 and 2003.
- While prophylactic spray regimes (alternating fungicides, 14 day-interval, six sprays) provided effective disease control in 2001 and 2003, poor control in 2002 emphasised that disease control is also dependent on appropriate product choice in relation to environmental conditions. A simple system was devised to aid product choice based on recent and forecasted rainfall and was used effectively in 2003.
- The 2002 field trial results demonstrated that leaf wetness duration is likely to be a more accurate indicator of the risk of disease development than temperature, and could be used as the basis for a forecasting system for celery septoria.
- With optimal spray timing (based on leaf wetness periods ≥12 h), alternating applications of the fungicides Amistar, Bravo 500 and Plover (total of five sprays) in 2002 were effective in minimising the development of celery septoria (mean severity <2 %) even under heavy inoculum pressure. Very similar results were obtained in 2003 when spray timing was again based on leaf wetness periods ≥12 h), while fungicide products were chosen based on recent and forecasted rainfall/irrigation. A comparable system could be used by growers to achieve effective disease control using the minimum necessary spray applications.

5. References

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6. Technology transfer (2000-2004)

Publications

Article featuring HDC 237 in 'Grower magazine: 'Knocking Spots Off Celery', Grower, February 13, 2003.

Green, K.R. 2004. Integrated management of celery leaf spot (*Septoria apiicola*). Article for ADAS Science Review 2003 (in prep.).

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Green, K.R. & O'Neill, T.M. 2004. Knock spots of celery. HDC News, January 2004. Pp14-16.

Presentations

- Poster presentation (K. Green) at Brighton Crop Protection Conference, 19 November 2002.
- Presentation on ongoing research on celery Septoria for ADAS Research and Science Group, 6 March 2003, ADAS Arthur Rickwood.

Scientific progress meetings

2001 visits to ADAS Arthur Rickwood to see glasshouse and field trials for FV 237:

15.05.01, E. Garrod, P. Hooker (Project progress meeting)
16.05.01, D. Norman
28.09.01, HDC representatives
08.10.01, D. Norman
15.10.01, P. Hooker

Meetings and field visits 2002-2004:

- Project review meeting, 17.04.02, D. Norman, P. Hooker, T. O'Neill and K. Green
- Project progress meetings, 2-3.10.02
- Project review meeting, 27.03.03
- Project progress meeting (KG, DN), 15.10.03
- Project review meeting, 21.01.04 (TO, KG, EG, DN, PH, BL)

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APPENDIX 1

Experiment diaries

Experiment 1: Controlled environment experiment to determine the effect of temperature and leaf wetness duration on infection of celery by *Septoria apiicola*

Date	Activity
27.08.03	Week 1 cabinet 1 : 18ºC set up
	Week 1 cabinet 2 : 18ºC/13ºC set up
03.09.03	Week 2 cabinet 1 : 18ºC/13ºC set up
	Week 2 cabinet 2 : 18ºC set up
01.10.03	Week 6 cabinet 1 : 18ºC/13ºC set up
	Week 6 cabinet 2 : 18ºC set up
08.10.03	Week 7 cabinet 1 : 18ºC set up
	Week 7 cabinet 2 : 18ºC/13ºC set up

Experiment 2: Field trial to evaluate fungicide programmes for the control of celery leaf spot (*Septoria apiicola*)

Date	Activity
04.07/03	N, P and K applied to trial site
08.07.03	Bo applied to trial site
10.07.03	Trial site power harrowed and beds formed
11.07.03	Celery transplanted, data logger installed and irrigation equipment set up
22.07.03	Gaps filled where plants had died
23.07.03	Soil samples collected from trial site and sent for analysis
23.07.03	Fungicide application 1 and insecticide (Hallmark) applied
25.07.03	Treatments 2-8 inoculated with *Septoria apiicola*
05.08.03	N re-applied to trial site
06.08.03	Fungicide application 2 (treatments 2, 3, 4 and 8)
12.08.03	Septoria symptoms first observed
14.08.03	Fungicide application 1 (treatment 9)
20.08.03	Fungicide application 3 (treatments 2, 3, 4 and 8)
	Fungicide application 2 (treatment 9)
	Manganese sulphate application 1
21.08.03	Disease assessment 1 (% plant severity)
02.09.03	Fungicide application 4 (treatments 2 and 3)
	Fungicide application 3 (treatment 9)
	Manganese sulphate application 2
11.09.03	Fungicide application 4 (treatments 4 and 8)
18.09.03	Fungicide application 5 (treatments 2 and 3)
	Manganese sulphate application 3
24.09.03	Fungicide application 1 (treatment 7)
	Fungicide application 5 (treatments 4 and 8)
	Manganese sulphate application 4
25.09.03	Disease assessment 2 (% plant severity)
03.10.03	Fungicide application 6 (treatments 2 and 3)
10.10.03	Disease assessment 3 (% plant severity)
22.10.03	Disease assessment 4 (% plant severity)
23.10.02	Blocks 1 and 2 harvested for yield assessments
24.10.02	Blocks 3 and 4 harvested for yield assessments

APPENDIX 2

Experiment 1. Temperature/Leaf wetness celery trial - logger data for polytunnel, ADAS Arthur Rickwood, 2003

	Polytunnel logger data – Daily summary

Date	Temperature (°C)
09-Sep-03	19.19
10-Sep-03	14.66
11-Sep-03	14.44
12-Sep-03	17.62
13-Sep-03	17.34
14-Sep-03	18.40
15-Sep-03	17.91
16-Sep-03	19.31
17-Sep-03	19.35
18-Sep-03	16.76
19-Sep-03	19.10
20-Sep-03	18.74
21-Sep-03	18.15
22-Sep-03	14.89
23-Sep-03	11.53
24-Sep-03	10.99
25-Sep-03	12.72
26-Sep-03	11.66
27-Sep-03	13.39
28-Sep-03	12.45
29-Sep-03	11.46
30-Sep-03	13.54
01-Oct-03	13.33
02-Oct-03	11.36
03-Oct-03	14.09
04-Oct-03	11.25
05-Oct-03	10.36
06-Oct-03	13.28
07-Oct-03	11.39
08-Oct-03	11.18
09-Oct-03	16.75
10-Oct-03	14.63
11-Oct-03	12.33
12-Oct-03	11.24
13-Oct-03	11.51
14-Oct-03	11.52
15-Oct-03	10.02
16-Oct-03	9.27
17-Oct-03	9.04
18-Oct-03	9.26
19-Oct-03	8.75
20-Oct-03	8.82
21-Oct-03	6.09
22-Oct-03	5.08

23-Oct-03	6.76
24-Oct-03	5.29
25-Oct-03	6.09
26-Oct-03	7.21
27-Oct-03	5.74
28-Oct-03	6.07
29-Oct-03	7.29
30-Oct-03	7.95
31-Oct-03	8.37
01-Nov-03	8.56
02-Nov-03	9.45
03-Nov-03	9.93
04-Nov-03	9.01
05-Nov-03	11.59
06-Nov-03	10.68
07-Nov-03	9.51
08-Nov-03	8.53
09-Nov-03	7.09
10-Nov-03	9.78

Experiment 2. In-crop logger data and rainfall measurements (ADAS Arthur Rickwood meteorological station) for duration of celery field trial, ADAS Arthur Rickwood, 2003

Figures in parentheses show irrigation (in mm)

Celery Septoria Field Logger Data - Daily Summary

Little Rough Lots

	Rain	Leaf wetness	Air Temperature
Date	**MmRain**	**Hours in 24 h period**	**deg C**
11/07/03	0	2	19.01
12/07/03	0	6	20.93
13/07/03	0	2	23.08
14/07/03	0	10	20.40
15/07/03	0	6	24.12
16/07/03	0.9	11	23.86
17/07/03	0.4 (17)	15	16.61
18/07/03	0.4	2	19.35
19/07/03	0	8	22.77
20/07/03	0	5	22.20
21/07/03	0.2	1	20.49
22/07/03	0	6	20.40
23/07/03	0	0	19.89
24/07/03	3.4	0	20.26
25/07/03	11.3	19	15.85
26/07/03	0	11	17.38
27/07/03	0	12	17.53

28/07/03	0	7	18.72
29/07/03	2.8	13	18.38
30/07/03	5.1	23	18.51
31/07/03	6.4	15	19.11
01/08/03	0	13	17.00
02/08/03	0.9	4	19.91
03/08/03	0	2	21.54
04/08/03	0	5	22.82
05/08/03	0	5	22.40
06/08/03	0	7	27.94
07/08/03	0	11	23.57
08/08/03	0	9	20.05
09/08/03	0	10	23.37
10/08/03	0	7	26.39
11/08/03	0	8	24.27
12/08/03	0	12	22.52
13/08/03	0	8	22.20
14/08/03	0	4	18.99
15/08/03	0	8	17.98
16/08/03	0	10	18.44
17/08/03	0	8	19.15
18/08/03	0 (20)	8	20.27
19/08/03	0	6	15.73
20/08/03	0	9	16.23
21/08/03	0	3	18.46
22/08/03	0	1	21.09
23/08/03	0	0	21.99
24/08/03	0	3	19.74
25/08/03	0	2	17.48
26/08/03	0	2	19.22
27/08/03	0.3	0	18.22
28/08/03	0 (20)	5	14.92
29/08/03	0	0	14.98
30/08/03	0	10	12.52
31/08/03	0	5	12.41
01/09/03	0	15	13.13
02/09/03	0	8	15.97
03/09/03	0	0	16.26
04/09/03	0 (20)	6	15.04
05/09/03	0	9	16.62
06/09/03	0.3	8	14.98
07/09/03	0	10	13.05
08/09/03	0	8	14.46
09/09/03	4.7	0	15.82
10/09/03	0	13	12.71
11/09/03	0.6	14	12.80
12/09/03	0 (25)	8	14.17
13/09/03	0	9	15.32
14/09/03	0	9	15.66

15/09/03	0	13	14.86
16/09/03	0	13	15.58
17/09/03	0	8	16.90
18/09/03	0	11	14.93
19/09/03	0 (25)	13	16.11
20/09/03	0	10	16.34
21/09/03	0	10	15.61
22/09/03	19.5	20	13.29
23/09/03	0	17	8.14
24/09/03	0	12	8.40
25/09/03	0	10	9.45
26/09/03	0	18	10.41
27/09/03	0	11	10.27
28/09/03	0	19	10.43
29/09/03	0	10	9.46
30/09/03	0	10	11.23
01/10/03	0	13	11.06
02/10/03	0	20	9.83
03/10/03	0.1	10	12.97
04/10/03	0.1	6	9.40
05/10/03	0	2	8.15
06/10/03	2.3	7	11.15
07/10/03	0	5	9.58
08/10/03	0	10	10.99
09/10/03	0	0	15.16
10/10/03	0	0	13.16
11/10/03	0	6	9.87
12/10/03	0	7	9.78
13/10/03	0	8	10.02
14/10/03	0	7	9.80
15/10/03	0	10	8.16
16/10/03	0 (25)	18	6.69
17/10/03	0	15	6.93
18/10/03	0	16	7.52
19/10/03	0	10	7.35
20/10/03	0.2	12	6.70
21/10/03	0.1	18	3.25
22/10/03	5.1	22	3.72
23/10/03	1.2	3	4.14