Contract report for the Horticultural Development Council

Outdoor celery: Development of integrated strategies for the management of Septoria leaf spot and other diseases

FV 237

March 2003

Project title:	Outdoor celery: Development of integrated strategies for the management of Septoria leaf spot and other diseases
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Project leader:	Dr Tim O'Neill, ADAS Arthur Rickwood
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Location of project:	ADAS Arthur Rickwood Mepal, Ely Cambs. CB6 2BA
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The results and conclusions in this report are based on an investigation conducted over one year. The conditions under which the experiment was carried out and the results obtained have been reported with detail and accuracy. However because of the biological nature of this work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results especially if they are used as the basis for commercial product recommendations.

Authentication

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

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Signature……. Date…….

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Headline

Effective control of celery leaf spot can be achieved through alternating applications of Amistar (azoxystrobin), Bravo 500 (chlorothalonil) and Plover (difenoconazole) even under heavy disease pressure, although spray programme efficacy is dependent on application timing in relation to infection events and weather conditions.

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. 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 a more limited number of spray treatments. Firstly, to evaluate newer 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 to develop an integrated strategy for improved control of leaf spot in field crops of celery 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 used to study the effect of temperatures and leaf wetness durations representative of field conditions, on development of celery leaf blight. Plants were either incubated at constant temperatures (10 or 16.6ºC) or fluctuating temperatures (12 h 18.5ºC/12 h 13.5ºC), representing late summer diurnal variations.

Disease development on plants incubated at 10 or 16.6ºC was negligible at 14 days after inoculation and did not exceed 5 % after 28 days, irrespective of leaf wetness duration. In agreement with data from project year 1, the results indicate that at these constant temperatures and leaf wetness periods of <48 h, the risk of disease development is low. In contrast, disease severity was high (>35 %) on plants incubated under fluctuating temperature conditions. However, conclusions cannot be drawn at this stage about the effects of temperature fluctuation on disease development because other stress factors (e.g. plant age) may have also contributed to disease severity in these treatments.

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

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), 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. 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.

Plants were monitored during the season and at harvest for incidence of other celery diseases such as Rhizoctonia and Sclerotinia. At harvest, there was only one plant with symptoms of Sclerotinia and no Rhizoctonia was observed.

Financial benefits

Although there may be need to refine the risk criteria used to time sprays according to environmental conditions, there is clearly the potential to maintain effective control of septoria using a limited number of fungicide sprays, with corresponding financial benefits to growers.

Action points for growers

- Results from controlled environment experiments suggest that with average late summer day and night temperatures, infection of celery by *Septoria apiicola* can occur after only 6 h leaf wetness. This suggests that if inoculum of celery Septoria 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).*

- An alternating sequence of Amistar, Plover and Bravo 500 provided effective control of celery septoria when sprays were appropriately timed. 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.*

- The good curative activity of Plover was demonstrated in the field trial. *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).*

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 confirmed 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 (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 516 F to be used as a protectant fungicide for celery production.

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 report describes trials conducted from October 2001 – October 2002 (project year 2). 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 the controlled environment experiment carried out in year 1, using a narrower range of critical temperatures and leaf wetness durations selected based on year 1 results. In addition, Experiment 1 studied 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 aims of the experiment were 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. The timing of sprays applied according to environmental variables was determined according to a set of preliminary risk criteria developed using data from the year 1 controlled environment experiment and in-crop temperature and leaf wetness monitoring during 2001.

2. Materials and methods

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

Experiment design

Celery plants artificially inoculated with *S. apiicola* were incubated at three constant temperatures (10ºC, 16.6ºC and 20ºC) relevant to late summer field conditions. The treatment at 16.6ºC represented the 24 h mean temperature for the period July 1st – September 30th, based on 7 years meteorological data collected at ADAS Arthur Rickwood. In addition, the effect of fluctuating temperature on disease development was also tested using 12 h at 18.5ºC and 12 h at 13.5ºC. This 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, six leaf wetness periods were tested (6, 12, 18, 24, 36 and 48 h), representing the critical range of leaf wetness durations identified from Year 1 results. It was noted that plants incubated under the fluctuating regime for only 6 h or 12 h leaf wetness, would in effect receive a constant temperature incubation of 18.5ºC. However, it was considered that results from these treatments would provide a 'check' comparison for results from other constant temperature treatments.

The experiment was conducted over time, with one inoculation per temperature. At each temperature, 60 plants were inoculated, with ten plants per temperature-wetness combination. Leaf wetness treatments were in a randomised block design within a controlled environment

(CE) cabinet and the order of temperature treatments in sequential experiments was randomised.

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 all temperatures (>95 % germination). In addition, the experiment was repeated for a single treatment (12 h 18.5ºC/12 h 13.5ºC) to provide data to use for concordance or otherwise of the experimental technique.

Plant material

For each temperature tested, young celery plants cv. Celebrity, unsprayed with fungicide were obtained from Delflands Nurseries, Cambs. The plants had 6-7 true leaves when the trial commenced.

Preparation of inoculum

10-30 g dried celery leaves 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 approximately 10^6 conidia/ml using a haemocytometer. The actual spore concentration was recorded for each experiment.

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. At the lower temperatures, misting for 1 min every 3 h was sufficient to maintain continual leaf wetness, while at higher temperatures the spraying frequency was increased to 2 min every 1 h. Temperature and relative humidity within the

mist chamber were monitored with a data logger. The plants received a 12 h day/12 h night light regime.

At the end of each wetness period, ten plants and the uninoculated control 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 6th and 7th 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. Temperatures and relative humidity in the glasshouse were 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 14 and 28 days after inoculation, percentage leaflet area affected by Septoria lesions was estimated for each of the 3 leaflets of the two previously marked leaves.

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

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: Nats Meadow, ADAS Arthur Rickwood.
Soil: Previously cropped with narcissus
pH 5.7
P 38 mg/l (index = 3)
K 374 mg/l (index = 3)
Mg 37 mg/l (index =1)
Bo 2.34 mg/l

Fertilisers applied prior to transplanting:

N 75 kg/ha

P 125 kg/ha

K 300 kg/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 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 1 week 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 and was used to ensure that precipitation from irrigation together with rainfall was at least 2.5 cm per week for the duration of the trial.

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, relative humidity and leaf wetness (type SWS). The logger was set to record at hourly intervals and data was collected in the crop from 09/07/02 until 15/10/02. The leaf wetness sensor was placed at canopy level, the RH sensor at ground 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 seven fungicide programmes and a double replication of the untreated control, giving a

total of 36 plots. Each plot comprised a bed measuring 1.8 m (width) x 3.5 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 7 days after transplanting:

1. Untreated control.
2. Amistar/Plover/Bravo 500 alternated at fortnightly intervals.
3. Amistar applied before inoculation, followed by Plover/Bravo 500 according to leaf wetness (low risk threshold).
4. Amistar applied before inoculation, followed by Plover/Bravo 500 according to leaf wetness (medium risk threshold).
5. Amistar applied before inoculation, followed by Plover/Bravo 500 according to leaf wetness (high risk threshold).
6. Amistar applied before inoculation, followed by Plover/Bravo 500 according to mean night temperature (low risk threshold).
7. Amistar applied before inoculation, followed by Plover/Bravo 500 according to mean night temperature (medium risk threshold).
8. Amistar applied before inoculation, followed by Plover/Bravo 500 according to mean night temperature (high risk threshold).
9. Untreated control.

Details of treatments are described under 'fungicide programmes' section below.

Inoculation

The experiment was inoculated with *S. apiicola* 3 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 10 l at a concentration of 3 x 10^4 spores/ml. The spore suspension was applied to all plants in all plots (250 ml/plot) using a pump action

hand-held mister. Leaf debris used for spore suspension preparation was distributed evenly between the middle three plant rows of each plot. The trial was irrigated three times on the day of inoculation and twice on the two following days.

Fungicide programmes

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 all treatments, the sequence of fungicide applications was Amistar, Plover, then Bravo 500, irrespective of spray timing. The first Amistar spray was applied 7 days after transplanting and 3 days prior to inoculation of celery plants with *S. apiicola*. For treatment 2, fungicide sprays were subsequently applied at fortnightly intervals (prophylactic spray regime), up to a maximum of six sprays. For treatments 3, 4 and 5, spray timing was based on leaf wetness durations (h) calculated from in-crop logger data. For treatments 6, 7 and 8, spray timing was based on mean night temperature (18:00 h – 06:00 h) calculated from in-crop logger data. The thresholds for individual treatments are shown in Table 1 and the process used to make spray decisions is outlined in Figure 1.

Table 1. Risk criteria used as the basis for spray-timing decisions for treatments 3-8 in 2002 field trial

Treatment	Leaf wetness criteria:
3	Spray if at least one leaf wetness duration ≥12 h ('low risk')
4	Spray if at least one leaf wetness duration ≥18 h ('medium risk')
5	Spray if at least one leaf wetness duration ≥24 h ('high risk')
	Temperature criteria:
6	Spray if mean canopy temperature for any night (18:00 – 06:00 h) is 5-10ºC ('low risk')
7	Spray if mean canopy temperature for any night (18:00 – 06:00 h) is >10-15ºC ('medium risk')
8	Spray if mean canopy temperature for any night (18:00 – 06:00 h) is >15ºC ('high risk')

Disease assessments

Approximately 1 and 2 months after crop inoculation, the percentage leaf area affected by leaf spot was recorded for the central 11 plants per row in the middle three rows of each plot. The incidence of disease symptoms due to other pathogens (e.g. *Rhizoctonia* and *Sclerotinia*) on these plants was also recorded. In addition, an assessment of percentage plot area affected by celery leaf spot was made by calculating the mean of four estimates of disease severity per plot. This assessment was repeated at twice monthly intervals until harvest (six assessments in total).

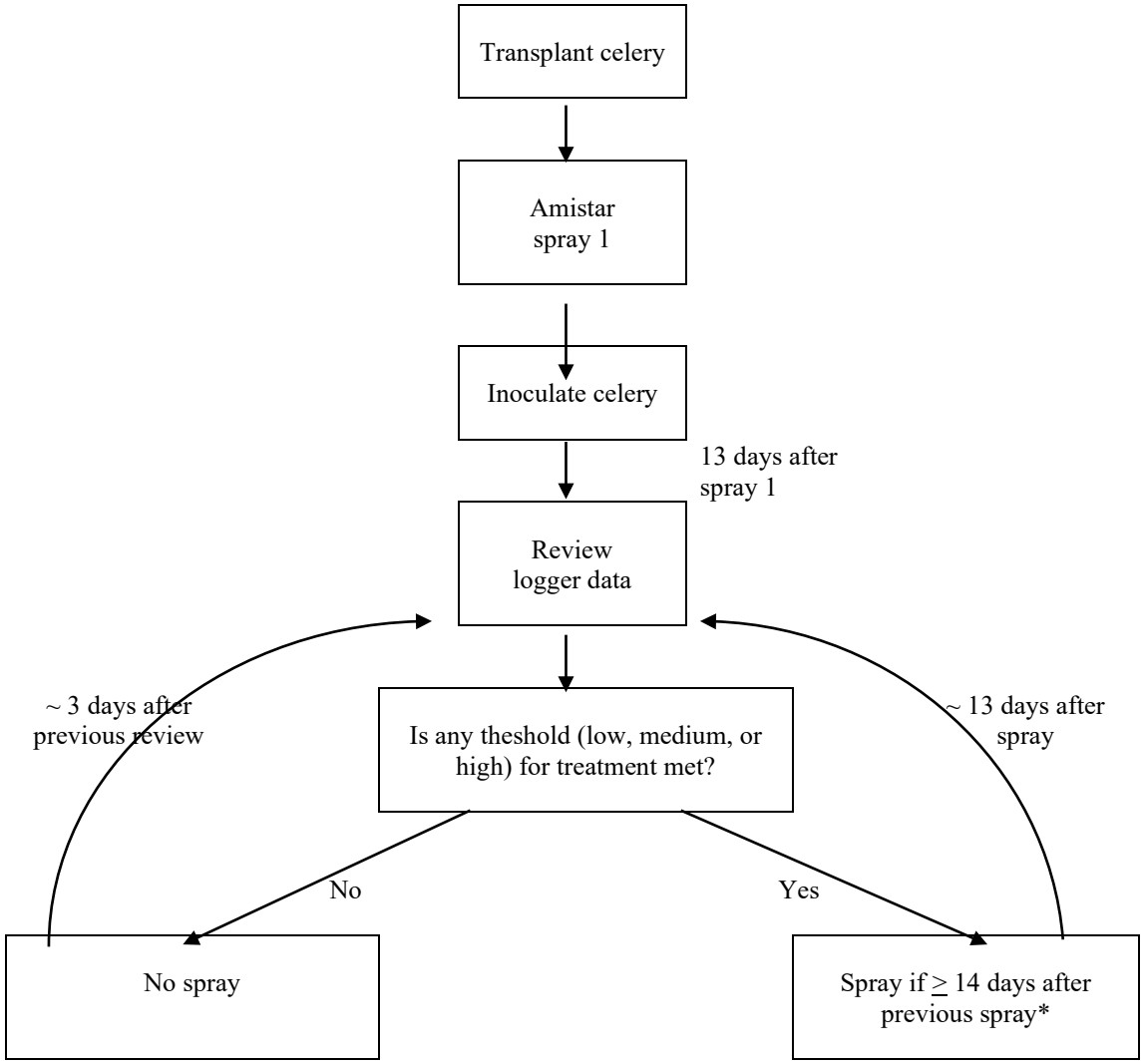
Harvest and yields

The trial was harvested 14 weeks after transplanting. From each plot, 24 plants were cut from the centre of the middle three rows (eight plants per row), using celery cutting knives. The total weight for the 24 harvested plants was recorded and used to calculate mean plant weight. The plants were then trimmed to market specifications (30 cm petiole, no blemishes) and weighed. Plants weighing >500 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 3-8 in Experiment 2 (2002 field trial)



- Spray sequence for all fungicide treatments is Amistar, Plover then Bravo, up to a maximum of 6 sprays in total.
- Ignore leaf wetness data for temperature risk plots; ignore temperature data for leaf wetness spots.

* If low risk - spray only low risk plots
If medium risk - spray medium & low risk plots
If high risk - spray high, medium and low risk plots

Results and discussion

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

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

For inoculated plants incubated at 20°C and all leaf wetness durations, disease severity was negligible even after 28 days (data not shown). For reasons that are unclear, this result was in contrast to data obtained in the previous year's experiment (HDC 2002) and previous research (Mathieu & Kushalappa, 1993).

For plants incubated at 10°C, there was no symptom development until 19 days after inoculation. Symptoms continued to develop on individual plants until the end of the experiment (29 days after inoculation) and the final disease incidence was <100 % (Tables 2 and 3). Symptom expression occurred more quickly on plants incubated at 16.6°C, commencing about 15 days after inoculation, and with a final disease incidence of 100 % for leaf wetness durations of 18 h and 36 h. For plants incubated under the fluctuating temperature regime and leaf wetness durations of 18 h or more, symptom development was rapid (commencing from 12 days), with 100 % incidence occurring after 15-19 days.

Table 2. 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)					
Temp (°C)	6	12	18	24	36	48
10	19-29	22-29	22-29	19-29	19-29	19-29
16.6	15-29	18-29	15-29	15-29	15-29	15-29
18.5/13.5[b]	15-19	15-19	12-19	12-19	12-19	12-19
18.5/13.5[b]	15-22	15-22	15	15	15	15

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

[b]Duplicate runs.

Shaded areas indicate combinations where all plants developed symptoms within 29 days.

Table 3. Effect of temperature and leaf wetness duration on the incidence of Septoria lesions, 25 days after inoculation of celery plants with *Septoria apiicola.*

	% Disease incidence[a] for different leaf wetness durations					
Temp (ºC)	6h	12h	18h	24h	36h	48h
10	30	10	30	30	20	20
16.6	70	70	100	90	100	80
18.5/13.5[b]	100	100	100	100	100	100
18.5/13.5[b]	100	100	100	100	100	100

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

[b]Duplicate runs.

Shaded areas indicate combinations where all plants developed symptoms within 25 days.

Disease development on plants incubated at 10 or 16.6ºC was negligible at 14 days after inoculation and did not exceed 5 % after 28 days, irrespective of leaf wetness duration (Tables 4 and 5). In contrast, plants incubated under fluctuating temperature conditions already showed low levels of disease at 14 days, and were severely infected (>35 %) by the end of the experiment. Disease severity was highest (>50 %) on plants that had been exposed to 24 h leaf wetness or less. In both runs for this treatment, there was a slight drop in disease severity following incubation at leaf wetness durations of 48 h or more (Table 5).

Table 4. Effect of temperature and leaf wetness duration on % leaf spot severity 14 days after inoculation of celery plants with *Septoria apiicola*

	% Disease severity[a] for different leaf wetness durations					
Temp (ºC)	6h	12h	18h	24h	36h	48h
10	0.0	0.0	0.0	0.0	0	0
16.6	0.0	0.0	0.0	0.0	0.0	0
18.5/13.5[b]	0.3	0.3	1.3	1.4	1.1	0.6
18.5/13.5[b]	8.4	3.6	2.2	3.1	1.6	1.7

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

[b]Duplicate runs.

Shaded areas indicate disease severity >1%

Table 5. 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)	6h	12h	18h	24h	36h	48h
10	0.0	0.1	0.0	0.1	0.0	0.1
16.6	0.3	1.0	0.5	3.2	1.2	0.6
18.5/13.5[b]	58.8	62.0	70.0	57.4	45.7	37.0
18.5/13.5[b]	59.5	51.1	60.5	61.5	42.6	36.5

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

[b]Duplicate runs.

Shaded areas indicate disease severity >5 %

Disease severity developing after incubation at 10°C or 16.6°C was generally similar to that obtained under comparable leaf wetness conditions in the year 1 experiment, although slightly higher disease severity would have been expected after 48 h leaf wetness. In combination with year 1 data, the results indicate that at these constant temperatures and leaf wetness periods of <48 h, the risk of disease development is low.

The high levels of disease severity on plants under fluctuating temperatures (18 h leaf wetness or more) in comparison with constant temperature incubation, was in agreement with the results of Lacy, 1994. However, severe disease on plants receiving 6 h or 12 h leaf wetness at 18.5°C, compared with negligible disease for other constant temperature treatments at 6 or 12 h leaf wetness, suggests that factors other than temperature fluctuation could have contributed to disease development on plants from these treatments. For example, it is hypothesised that results could have been confounded by depleted nutrient status in plants used for the fluctuating temperature treatments, since plants were at least 3 weeks older than those used for the constant temperature treatments. Further experiments in 2003 are needed to confirm this hypothesis and it would be inappropriate to draw conclusions about the effect of fluctuating temperatures on disease development at this stage.

Experiment 4: Field trial to evaluate fungicide programmes for the control of celery leaf spot (*Septoria apiicola*)

The timing of fungicide spray treatments is shown in Table 6. It had been anticipated that the different risk criteria deployed would result in a different spray timings for all treatments. However, environmental conditions were such, that each time logger data were reviewed, all risk criteria were met, with the exception of leaf wetness criteria on 30.07.02. For this reason, there were effectively three spray schedules that were used:

- Spray schedule 1 on untreated controls (no sprays)
- Spray schedule 2 on treatments 2 (standard), 6, 7 and 8 (temperature criteria), applied at fortnightly intervals throughout the season (6 sprays in total).
- Spray schedule 3 on treatments 3, 4 and 5 (leaf wetness criteria), applied at fortnightly intervals apart from a 3-week interval between the first two sprays (5 sprays in total).

Table 6. Timing of fungicide sprays applied to 2002 field trial, ADAS Arthur Rickwood

	Treatment	16.07	30.07	05.08	13.08	23.08	29.08	05.09	10.09	20.09	25.09
1	Control										
2	Standard	A1	P1		B1		A2		P2		B2
3	LW low risk	A1		P1		B1		A2		P2	
4	LW medium risk	A1		P1		B1		A2		P2	
5	LW high risk	A1		P1		B1		A2		P2	
6	Temp low risk	A1	P1		B1		A2		P2		B2
7	Temp medium risk	A1	P1		B1		A2		P2		B2
8	Temp high risk	A1	P1		B1		A2		P2		B2
9	Control										

Key:
LW Leaf wetness
A Amistar
P Plover
B Bravo

Septoria leaf spot was first observed on 7 August, 19 days after inoculation and developed rapidly to give 100 % incidence and approximately 30 % disease severity on the untreated control treatments, 2 months after inoculation (Table 7). Spray schedule 2 led to a significant reduction in disease incidence (1 month after inoculation) and disease severity (2 months after inoculation) compared with the untreated controls. The lowest disease levels were seen on plots sprayed according to leaf wetness criteria; disease incidence was still zero after one month, and even 2 months after inoculation, severity did not exceed 2 %.

The treatment effects on disease incidence (1 month) and severity (2 months) were closely reflected by the yield data (Table 8). The mean marketable plot yield and % marketable sticks was significantly higher for treatments applied according to leaf wetness criteria compared with all other treatments.

Incidence of other celery diseases was negligible in this field trial. Sclerotinia and Rhizoctonia were not observed during the growing season. At harvest, there was only one plant showing symptoms of Sclerotinia and no plants with Rhizoctonia.

It was interesting to note that just one week difference in spray schedules 1 and 2 had a significant impact on disease development and marketable yield under conditions of high inoculum pressure and the environmental conditions recorded in Appendix 2. In hindsight, it is evident that the timing of fungicide applications in relation to infection events and environmental conditions in the first few weeks after inoculation was optimal for treatments (3, 4 and 5). An initial protectant spray (Amistar) was applied prior to artificial inoculation with *S. apiicola*. The subsequent fortnight was dry, such that leaf wetness criteria were not met and a spray was not applied. The second spray was eventually applied 3 weeks after spray 1, and 1 week after heavy rain, using Plover. In year 1 trials, this product was shown to have excellent curative activity, even when applied 10 days after an infection event (HDC, 2002). In contrast, spray schedule 2 was not ideal. Two weeks after the initial Amistar application, spray 2 (Plover) was triggered by high temperatures and immediately preceded heavy rain. The third spray a fortnight later was with Bravo 500, which does not have extensive curative activity.

Figure 2 shows the high frequency with which leaf wetness periods of up to 12 h occurred during the 2002 field trial, based on in-crop logger data.

The 2002 trial results demonstrated the following:

- 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 with spray schedule 3 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 moderate disease severity that developed on plots using the same fungicide sequence applied according to spray schedule 2, indicates that the effective management of celery septoria is highly dependent on both the choice of product and the timing of application in relation to infection events and environmental conditions.

Table 7. Effect of fungicide programmes on the incidence and severity of celery leaf spot (*Septoria apiicola*), assessed twice during the growing season

Treatment	1 month after inoculation		2 months after inoculation	
	% disease incidence[a]	% disease severity[b]	% disease incidence[a]	% disease severity[b]
Untreated control	75.0	1.5	100.0	27.8
Routine programme	30.3	0.2	100.0	10.1
Leaf wetness (low risk)	0.0	0.0	99.2	1.8
Leaf wetness (medium risk)	0.0	0.0	94.7	1.5
Leaf wetness (high risk)	0.0	0.0	100.0	2.0
Temperature (low risk)	8.3	0.0	100.0	7.2
Temperature (medium risk)	21.2	0.1	100.0	8.1
Temperature (high risk)	3.0	0.0	100.0	4.9
Untreated control	100.0	1.2	100.0	31.0
Significance (24 df)	<0.001	ns*	ns*	<0.001
SED	5.00	0.286	0.819	1.75

[a]Mean % of plants (out of 33) with leaf spot symptoms

[b]Mean % plant area affected with leaf spot symptoms

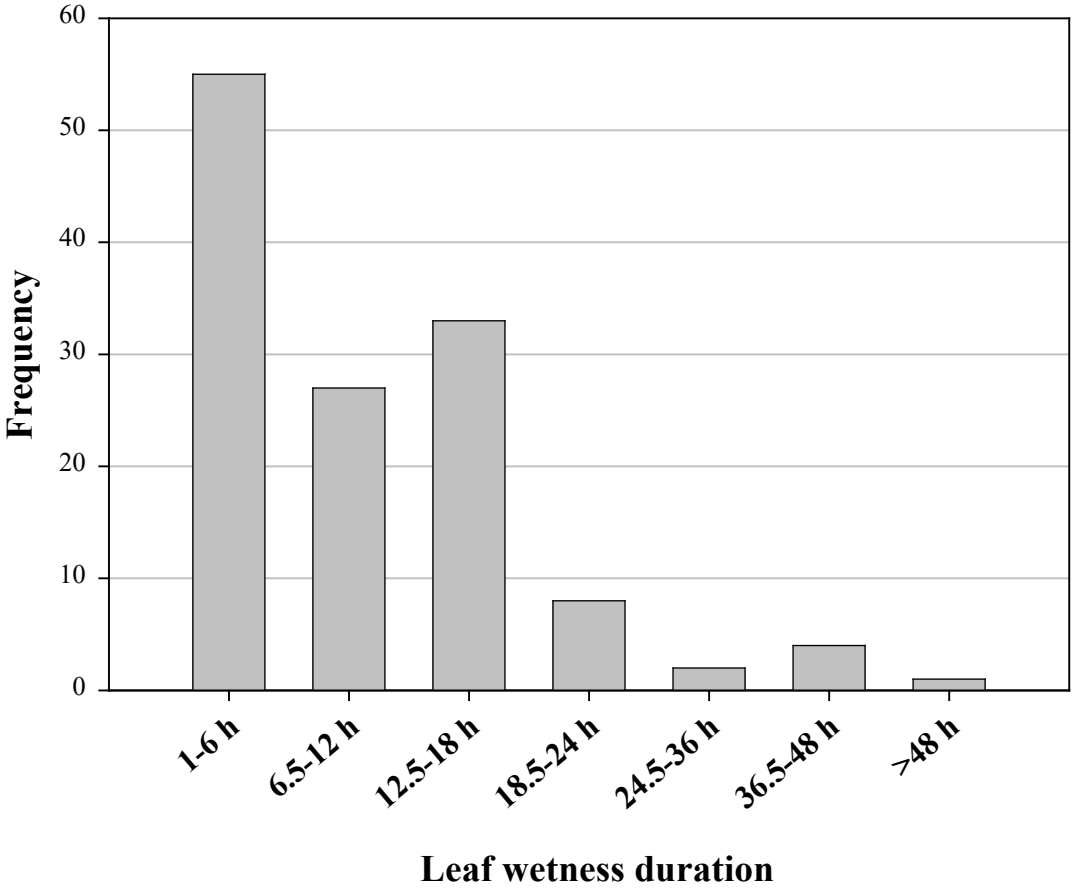
*Based on Friedmans' tests

Table 8. Effect of fungicide programmes on yield and marketability of celery, ADAS Arthur Rickwood, 2002

Treatment	Yield at harvest (kg per plot)	Marketable yield (kg per plot)	Mean weight of marketable sticks (g)	% Marketable sticks[a]
Untreated control	10.37	0	0	0
Routine programme	17.70	0.80	260	8.3
Leaf wetness (low risk)	20.38	3.90	560	29.2
Leaf wetness (medium risk)	20.68	4.62	540	33.3
Leaf wetness (high risk)	22.48	4.11	570	29.2
Temperature (low risk)	20.98	1.99	570	16.7
Temperature (medium risk)	18.65	2.52	560	16.7
Temperature (high risk)	20.63	2.42	560	16.7
Untreated control	8.70	0	0	0
Significance (24 df)	<0.001	0.003	<0.001	0.002
SED	1.99	1.19	0.07	2.07

[a]Above minimum weight of 450 g and minimum height of 28-30 cm, with no *Septoria* present.

Figure 2. Frequency of leaf wetness durations (h) occurring in a celery field trial, ADAS Arthur Rickwood, (09.07.02 – 15.10.02)



4. Overall conclusions

- Data from controlled environment experiments carried out in this reporting period and year 1 indicated that at constant incubation temperatures in the range 10-17ºC, and leaf wetness periods of <48 h, the risk of celery septoria development is low.
- With optimal spray timing, alternating applications of the fungicides Amistar, Bravo 500 and Plover (total of five sprays) were effective in minimising the development of celery septoria (mean severity <5 %) even under heavy inoculum pressure.
- However, the difference in disease severity and marketable yields that resulted from use of these fungicides in two differently-timed schedules, emphasised that effective management of celery septoria is highly dependent on both the choice of product and the timing of application in relation to infection events and environmental conditions.

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Technology transfer

Publications

K Green & T. O'Neill (2002). Management of celery leaf spot. Factsheet 06/01 (update). East Malling, UK: HDC.

Green, KR, O'Neill, TM & Wilson, D. (2002). Effect of leaf wetness duration and temperature on the development of leaf spot (*Septoria apiicola*) on celery. Proceedings of the BCPC Brighton Conference, 2002. Pp 225-230.

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

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.

Progress Meeting at ADAS Arthur Rickwood

- 2 October 2002: D. Norman, P. Hooker, T. O'Neill and K. Green
- 3 October 2002: E. Garrod, K. Green
- 27 March 2003: E. Garrod, D. Norman, P. Hooker, B. Lincoln, T. O'Neill, K. Green, A. Shepherd.

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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
01.07.02	Run at 16.6ºC set up
03.07.02	Run at 10ºC set up
10.07.02	Run at 20ºC set up
31.07.02	Run at 18.5/13.5ºC set up
05.08.02	Run at 18.5/13.5ºC set up

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

Date	Activity
01.04.02	N, P, K and Bo applied to trial site before power harrowing and bed formation
04.07.02	Soil samples collected from trial site and sent for analysis
08.07.02	Celery transplanted
09.07.02	Data logger installed
09.07.02	Irrigation equipment installed
	Gaps filled where plants had died
16.07.02	Fungicide application 1
18.07.02	Insecticide (Hallmark) applied
19.07.02	All plots inoculated with *Septoria apiicola*
20.07.02	Plots irrigated twice per day
29.07/02	Disease assessment 1 (% plot severity)
30.07.02	Fungicide application 2 (treatments 2, 6, 7 and 8)
05.08.02	Fungicide application 2 (treatments 3, 4 and 5)
07.08.02	Septoria symptoms first observed
13.08.02	Disease assessment 1 (% plant severity)
	Disease assessment 2 (% plot severity)
	Fungicide application 3 (treatments 2, 6, 7 and 8)
14.08.02	Manganese sulphate application 1
23.08.02	Fungicide application 3 (treatments 3, 4 and 5)
27.08.02	Manganese sulphate application 2
	Disease assessment 3 (% plot severity)
29.08.02	Fungicide application 4 (treatments 2, 6, 7 and 8)
05.09.02	Fungicide application 4 (treatments 3, 4 and 5)
10.09.02	Fungicide application 5 (treatments 2, 6, 7 and 8)
	Disease assessment 4 (% plot severity)
11.09.02	Manganese sulphate application 3
20.09.02	Fungicide application 5 (treatments 3, 4 and 5)
23.09.02	Manganese sulphate application 4
24.09.02	Disease assessment 2 (% plant severity)
	Disease assessment 5 (% plot severity)
25.09.02	Fungicide application 6 (treatments 2, 6, 7 and 8)
07.10.02	Disease assessment 6 (% plot severity)
14.10.02	Blocks 1 and 2 harvested for yield assessments
15.10.02	Blocks 3 and 4 harvested for yield assessments

Appendix 2. In-crop logger data for duration of celery field trial, ADAS Arthur Rickwood, 2002

Celery Septoria Field Logger Data - Daily Summary				
Nats Meadow				
	Rain	**Leaf wetness**	**Air Temp**	**Relative humidity**
Date	**MmRain**	**Hours in 24 h period**	**deg C**	**%RH**
09/07/02	**3.90**	4	17.63	78.74
10/07/02	**1.10**	12	15.50	73.82
11/07/02	**2.70**	12	15.70	73.34
12/07/02	**0.00**	10	15.18	73.77
13/07/02	**0.00**	10	17.56	68.24
14/07/02	**0.00**	8	19.76	63.01
15/07/02	**0.00**	7	22.59	58.33
16/07/02	**0.00**	0	22.10	63.69
17/07/02	**0.00**	1	19.92	62.90
18/07/02	**0.00**	4	19.81	62.97
19/07/02	**0.00**	9	18.90	60.19
20/07/02	**1.20**	4	17.06	71.28
21/07/02	**0.00**	11	13.84	81.34
22/07/02	**0.50**	8	15.53	71.43
23/07/02	**0.20**	5	17.64	75.60
24/07/02	**0.00**	6	17.55	64.75
25/07/02	**0.00**	1	19.42	61.73
26/07/02	**0.00**	5	21.40	66.93
27/07/02	**0.00**	7	21.51	69.51
28/07/02	**0.00**	8	23.88	65.11
29/07/02	**0.40**	10	23.93	70.69
30/07/02	**48.60**	20	19.67	88.41
31/07/02	**1.60**	18	18.60	90.16
01/08/02	**0.00**	19	15.75	87.06
02/08/02	**0.00**	10	19.28	71.53
03/08/02	**0.00**	17	16.26	83.69
04/08/02	**0.00**	20	15.23	85.68
05/08/02	**5.40**	17	16.79	86.55
06/08/02	**0.20**	14	18.44	82.85
07/08/02	**6.40**	17	19.51	81.24
08/08/02	**8.60**	14	17.16	86.35
09/08/02	**3.80**	24	15.36	90.14
10/08/02	**0.00**	14	17.96	84.30
11/08/02	**0.00**	12	17.73	80.16
12/08/02	**0.00**	11	17.55	75.65
13/08/02	**0.00**	12	18.40	72.74
14/08/02	**0.00**	17	20.25	75.03
15/08/02	**0.30**	11	22.03	72.35
16/08/02	**0.00**	10	20.46	71.45
17/08/02	**2.20**	11	23.80	67.41
18/08/02	**0.00**	15	20.23	79.15
19/08/02	**4.60**	16	20.32	82.24
20/08/02	**2.80**	24	16.66	93.02
21/08/02	**0.00**	14	16.36	78.23
22/08/02	**1.10**	16	16.12	80.97
23/08/02	**0.20**	15	16.32	80.94
24/08/02	**0.00**	15	16.41	79.88
25/08/02	**0.00**	13	16.17	82.90
26/08/02	**0.00**	15	13.76	85.91
27/08/02	**0.10**	14	15.49	83.79
28/08/02	**0.00**	21	16.28	86.41
29/08/02	**0.00**	16	18.06	83.11
30/08/02	**0.00**	15	19.07	80.61
31/08/02	**0.70**	10	15.10	71.47
01/09/02	**0.00**	9	14.54	70.93
02/09/02	**0.10**	14	14.09	75.14
03/09/02	**0.05**	15	15.80	75.89
04/09/02	**0.00**	22	13.71	86.59
05/09/02	**0.00**	7	16.91	71.54
06/09/02	**0.00**	5	17.90	71.40
07/09/02	**4.40**	12	15.33	77.87
08/09/02	**0.00**	15	13.92	80.48
09/09/02	**19.40**	24	12.33	93.58

	Rain	Leaf wetness	Air Temp	Relative humidity
Date	**MmRain**	**Hours in 24 h period**	**deg C**	**%RH**
10/09/02	**0.00**	17	14.04	81.52
11/09/02	**0.00**	19	13.91	85.24
12/09/02	**0.00**	16	17.68	83.06
13/09/02	**0.00**	18	17.15	80.42
14/09/02	**0.00**	7	14.97	81.04
15/09/02	**0.00**	8	14.42	78.77
16/09/02	**0.40**	18	13.57	82.77
17/09/02	**0.05**	16	14.09	85.31
18/09/02	**0.00**	15	13.36	81.90
19/09/02	**0.00**	7	14.51	82.06
20/09/02	**0.00**	11	13.94	80.89
21/09/02	**0.00**	12	14.53	78.40
22/09/02	**1.40**	10	13.06	78.70
23/09/02	**0.10**	15	12.95	77.02
24/09/02	**0.00**	12	11.59	78.48
25/09/02	**3.00**	8	12.91	74.66
26/09/02	**0.00**	14	11.63	80.43
27/09/02	**0.00**	24	10.49	88.71
28/09/02	**0.00**	15	13.60	82.17
29/09/02	**0.00**	17	12.53	80.09
30/09/02	**0.00**	18	11.89	77.71
01/10/02	**0.00**	18	13.53	80.39
02/10/02	**0.60**	20	14.66	85.42
03/10/02	**0.00**	19	14.85	79.86
04/10/02	**0.00**	19	9.85	79.66
05/10/02	**0.00**	8	13.96	79.17
06/10/02	**0.00**	19	11.92	78.88
07/10/02	**0.00**	18	10.00	81.19
08/10/02	**0.00**	10	10.05	80.38
09/10/02	**0.00**	19	9.11	79.28
10/10/02	**0.00**	12	11.64	77.68
11/10/02	**0.00**	6	10.34	77.82
12/10/02	**7.00**	24	8.57	93.05
13/10/02	**7.00**	24	6.31	91.69
14/10/02	**1.60**	22	9.71	92.01
15/10/02	**41.30**	24	8.95	96.25