+CARROTS: THE MANAGEMENT OF *ALTERNARIA* BLIGHT ON CARROTS

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Project leader	Dr Jane Thomas	
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Key workers	Dr Jane Thomas	plant pathologist
	Dr David Kenyon	plant pathologist
	Mr David Martin	vegetable agronomist
	Mr Mike Day	vegetable agronomist
Locations	NIAB Headquarters trial ground, Huntingdon Road Cambridge CB3 OLE Plantsystems Ltd, The Limes, 97 Hollycroft Road, Emneth, Wisbech, Cambs. PE14 8BB	
Project coordinator	Mr John Kenyon	
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Grower Summary

Headline

- *Alternaria* blight can cause large reductions in the yield of marketable roots, up to 31 t/ha depending on season and variety.
- Using a forecasting system to predict *Alternaria* risk can reduce spray frequency in some seasons without affecting the degree of disease control.
- Varieties vary significantly in partial resistance to *Alternaria*, and combining resistance with a fungicide programme will maximise disease control.
- Protectant fungicide applications were generally more effective than eradicant sprays in controlling disease, and sequences initiated with Amistar were more effective than those initiated with Folicur.

Background and expected deliverables

Foliar diseases of carrots have become of increasing concern in recent seasons, principally due to the occurrence of *Alternaria* blight, caused by the fungus *Alternaria dauci,* which has occurred progressively earlier in the life of the crop, and in a wide range of growing regions. Early infections in maincrop carrots are probably associated in some areas with disease originating from crops under cover. Yield and root quality losses have been attributed to *Alternaria* blight, and it may sometimes create harvesting difficulties due to weakened foliage. The extent of yield loss in the UK is not fully understood, and probably depends to a large extent on the time of appearance of the disease. A 5% yield loss would be worth in the region of £2.25 million to growers in the UK. Foliar fungicides can be applied to carrots for *Alternaria* control, but there is little information available which can identify high risk situations where yield and quality losses might be expected. Given the increasing pressure for appropriate use of fungicide, and the needs of the industry for economically justified inputs, there is now a need for a robust and practical system which can identify situations where control of *Alternaria* blight is warranted. The expected deliverables from this project are

- an understanding the effects of the disease on yield and quality*,*
- information on varieties which are at risk of developing high levels of *A dauci*
- an evaluation and validation of a developed forecasting system for *A dauci*,
- an assessment the effectiveness of new and existing products against *Alternaria*, applied as protectants or curatives, and in various sequences
- an appraisal of the incidence and severity of other foliar diseases of carrot.

Summary of the project and main conclusions

Effects of *Alternaria* on marketable yield

The effect of *Alternaria* on yield was examined in a total of three fungicide trials which were inoculated with *Alternaria*. Controlling the disease with fungicides produced yield benefits, but these varied greatly from year to year. Though relatively high levels of *Alternaria* had developed by the autumn in each year, a higher level earlier in the season was associated with a much larger yield response (see Table). There was no consistent relationship between foliar *Alternaria* and the development of root rots or root discoloration in any of the trials.

Time of ocurrence of *Alternaria* in excess of 20% leaf area cover in three seasons compared with mean yield increase (t/ha) over all fungicide sequences on Nairobi

	Date of 20% leaf area cover	Mean % yield increase
Year 1	12th October	2.7
Year 2	18th October	4.9
Year 3	23rd August	16.7

Disease forecasting

A total of 22 paired field sets of mainseason carrots representative of typical commercial crops in the principal growing areas were monitored over the three years of the project.. Weather data for each field or cluster of fields was collected using an Adcon Telemetry weather station with sensors for rain, temperature, humidity, windspeed and wind direction. One of each pair was treated with a fungicide program designed to control the main foliar diseases of carrots in accordance with normal practice. The other was treated in accordance with the advice generated by the PLANT-Plus system for *Alternaria* Untreated areas were left in each field so that *Alternaria* severity could be assessed. In two out of the three years, the forecast system reduced the number of sprays applied without affecting the degree of disease control (see table). *Sclerotinia* infections in carrot crops were locally severe in all years. Neither standard practice fungicide treatments, or PLANT-Plus *Alternaria* forecast treatments, gave control of *Sclerotinia* compared to untreated areas.

Comparison of spray frequency and Alternaria control in forecast risk and normal practice fields, 2000 to 2002

Year	Number of Sites	System	Alternaria % leaf area affected	Number of treatments	Presence of Sclerotinia (10= severe)
2000	8	Normal practice	1.6	4.3	5.1
	8	Untreated	6.0	0.0	5.1
	8	PLANT plus advice	0.8	3.4	7.6
	8	Untreated	4.8	0.0	7.8
2001	9	Normal Practice	0.2	5.1	2.0
	9	Untreated	1.8	0.0	2.0
	9	PLANT plus advice	0.2	2.5	2.8
	9	Untreated	2.0	0.0	2.8
2002	5	Normal Practice	1.7	4.4	3.2
	5	Untreated	8.7	0.0	4.4
	5	PLANT plus advice	2.0	4.2	4.6
	5	Untreated	8.7	0.0	4.8

Variety susceptibility

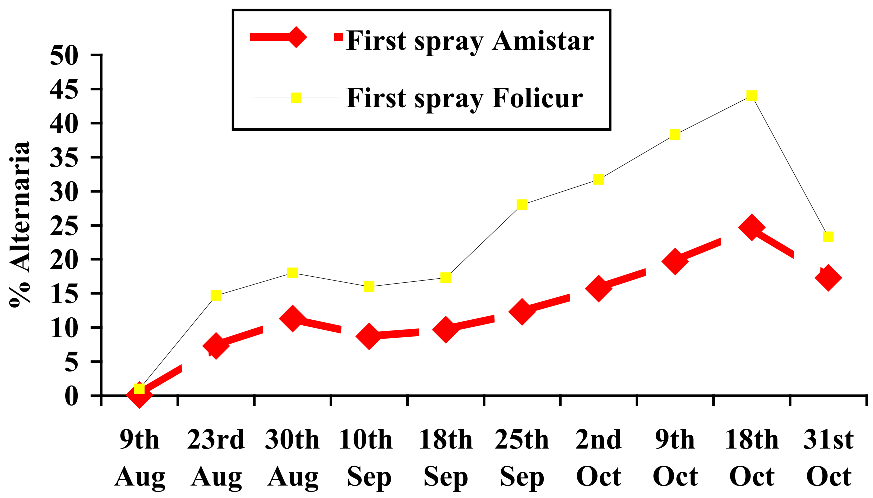
Varieties were inoculated with *Alternaria* spores and irrigated. This produced a uniform and relatively high "infection pressure". There were substantial differences in the levels of *Alternaria* developing on the varieties which were consistent over the three year trial period. The widely grown Nairobi is susceptible, but some newer varieties eg Nepal, Bristol, Maestro and Artemis have good partial resistance. Variety differences were maintained over the growing season, with little evidence of changes in variety ranking order as the season progressed and different varieties came to maturity. Variety resistance factors have been incorporated into the PLANT plus forecasting system, though in one year of trialling, the use of resistance information in the model did not trigger fewer spray applications for more resistant varieties. However, disease pressure was high in this trial, and partial resistance could probably be exploited more effectively in lower disease situations.

Fungicide efficacy

Four products, alone and in various alternating sequences, were tested in different experiments over the three years. Corbel gave only moderate control, whereas Amistar, Folicur, and Compass all gave very good, though not complete control of *Alternaria*. Throughout the project, disease control was generally more effective when sprays were applied before a forecast risk rather than afterwards, though Compass was relatively more effective as an eradicant than Amistar or Folicur. However, late applied sprays of both these products still gave relatively good disease control. Alternating sequences of Folicur and

Amistar were as effective as the same product used throughout under moderate disease pressure, but under higher disease pressure, a sequence started with a forecast spray of Amistar gave much better control of *Alternaria* than a sequence started with Folicur (see graph).

Disease progress with spray sequences started with either Amistat or Folicur, 2002



Financial benefits

Average losses due to *Alternaria* ranged from 1.8 t/ha in year 1 to 6 t/ha in year 2, and 14.8 t/ha in year 3 (all figures are for Nairobi). Taking a comprehensive spray sequence of five applications, at a cost of £33/ha, growers could benefit by up to £427/ha, at a price for marketable roots of £40/t. However, in year 1 when disease pressure was lower, the cost of a comprehensive spray programme would not be justified in terms of root yield. However, keeping foliage green at the end of the season would be an added benefit in some growing systems.

Currently many growers believe that the use of a disease forecasting system to reduce spraying when there is unlikely to be a benefit adds complexity to production and outweighs the benefits in terms of cost saving. Also, unlike some other crop producers, carrot growers do not currently have a fungicide residue issue which needs to be dealt with.

Effective use of a forecasting system requires the following to be available and implemented:-

- Accurate, accessible and reasonably priced local weather data and local weather forecast predictions.
- A predictive system which can utilise the above and which can integrate variety susceptibility information and which provides clear and concise output information to the grower or adviser.
- Sufficient spraying capacity so that the grower is able to separate the inputs of insecticide for carrot fly control (currently every 14 days) from the inputs required (occasional – weather related) for control of *Alternaria.*

Of these points, the latter presents the greatest challenge to the grower. For this to be implemented requires a change in thinking and in management practice, possibly some capital investment and a commitment to input reduction. In seasons of optimum infection conditions, such as 2002 in the South East, the savings will be marginal or not at all. In other seasons the savings can be substantial. This study has demonstrated that the following savings could have been made through the implementation of the forecast system without significant loss in disease control: 2000 - 0.9 treatments, 2001 - 2.6 treatments, 2002 - nil treatments

This iillustrates the benefits of using a forecasting system in terms of crop protection and input reduction and in justification of treatments.

<u>The PLANT Plus System</u>

PLANT Plus is a commercial software platform for the analysis of weather and weather forecast data. The *Alternaria* module evaluates the risk of infection by combining the weather data with crop infection information, crop development parameters and information on presence of infection sources in the area/region. The user is required to enter accurate crop data on a regular (7-14 days) cycle. The accession of weather data and weather forecast data is automated.

The user is presented with an assessment of risk, the decision to act based upon the risk is made together with the choice of type of fungicide (protective, local systemic, curative) by the user. The DSS provides guidance to the user of the need to act and of the most appropriate category of fungicide through its graphical and textural output.

Once a treatment is made the system requires updating so that the wear-off and wash-off of the fungicide can be calculated.

During the period of the study the model has been modified as follows:-

- The variety susceptibility information generated at NIAB has been included into the variety database.
- The chemical database has been extended to include Amistar.
- The influence of new growth in the model has been suppressed reflecting more accurately the natural tolerance of new leaves to *Alternaria* infections. The effect of this in the system is to prolong the activity of applied treatments.

Economic Analysis

PLANT Plus is available on subscription from a range of consulting and support businesses. Depending on the number of data sources, weather forecasts and crop references used and the area of crop to which the system is applied the cost per hectare is generally £5 - £10. To this must be added the cost of the weather data and any scouting, data input and proactive advice that may be sought by the grower. In general terms the total cost of operating the system is of the order of £20 to £40 per ha per annum.

The studies have shown a potential financial saving generated by reduced fungicide spray application. Over three years this has been an average of 1.2 treatments at an average fungicide cost of £25 per treatment plus application costs of £8 per ha = a total value of £38/ha. If other benefits of lowered environmental loadings are ignored, the cost benefit is balanced over a number of varying seasons.

Action points for growers

- Growers should take action to control *Alternaria* developing from late July to mid September.
- The largest yield reductions occur when the disease develops rapidly in August. Smaller reductions occur with later disease development, but foliage can still be damaged, and this may affect some harvesting operations.
- Growers should use spray sequences which alternate Amistar and Folicur, but aim to use Amistar as a protectant to start the sequence. Compass gives good control of *Alternaria*, and could be included in sequences, particularly when applied after a high risk period for the disease

- Growers could reduce spray frequency in some seasons by subscribing to a disease forecasting system, using regional risks information or by using their own observations of weather and local disease pressure.
- Selection of more resistant varieties will help to reduce spray costs further in some seasons. However, the most widely grown commercial variety, Nairobi, is susceptible to the disease, and growers should be aware that *Alternaria* can increase very quickly on this variety.

Science section

Introduction

Alternaria blight of carrots, caused by *Alternaria dauci*, has recently increased in importance in the UK crop with growers applying frequent sprays to maintain disease free foliage. Infections are tending to appear earlier in the season than has previously been experienced, and the disease is found in all of the major carrot growing regions of the country. Disease which develops earlier in the season is more likely to have an effect on yield, though late season disease may also be significant, both in terms of direct yield loss and harvesting losses due to foliage breakdown. The disease is seed-borne, and can survive on carrot debris. Once introduced on seed, the disease probably becomes established in intensive carrot growing areas. Movement of inoculum from crops grown under covers to main season crops is also possible.

Though growers apply fungicides to control *Alternaria*, there is very little information available on the losses which the disease can cause, and therefore on the cost effectiveness of sprays applied. Disease forecasting systems are increasingly being used in the field vegetable sector in order to satisfy the drive towards justification of inputs, and reduce costs of production to the grower (eg Carrot Country, 2001) Though systems are available for prediction of *Alternaria* risks, there has been no independent evaluation of these in terms of their ability to reduce sprays compared to prophylactic approaches, and maintain disease control at acceptable levels. The use of resistant varieties has been advocated as part of integrated control systems for *Alternaria* elsewhere (Davis *et al*, 1993), but information on the relative susceptibilities of varieties used, or likely to be used, in the UK is extremely limited. This work was undertaken with four main objectives. Firstly, to evaluate and validate *Alternaria* blight forecasting systems; secondly, to investigate the range of susceptibility to *Alternaria* in varieties; thirdly to investigate the effectiveness of different fungicides for *Alternaria* control, and finally to establish the effects of the disease on carrot yield and quality.

Materials and Methods

Evaluation and validation of forecasting systems

Previous field evaluations have shown *Alternaria* in carrots is largely confined to production areas in the South and East of Britain due to more favourable conditions for the development of the disease. For this reason fieldwork in 2002 was confined to the Eastern counties of England.

The objective was to compare the degree of crop protection and the fungicide usage between prophylactic treatments for *Alternaria* and in accordance with warnings generated by use of the Dacom PLANT Plus forecasting system. Previous use of the forecast has demonstrated that a significant reduction in use of fungicides can be achieved with the maintenance of good levels of disease control. However both the seasons 2000 and 2001 did not prove ideal for the natural development of high levels of *Alternaria* disease in carrots.

Five pairs of fields were selected, managed and monitored in different growing areas from Yorkshire to the Suffolk coast. One of each pair was sprayed according to normal practice but contained a small plot in the centre of the field which received no fungicide sprays. The other partner was sprayed in accordance with the disease forecasting system again leaving an untreated area in the centre of the field.

The weather conditions for each pair of fields were continuously monitored throughout the period of study. The conditions of precipitation, temperature, humidity, wind direction and wind speed were recorded. The weather data files associated with each site are available on request.

The treated and untreated areas of each field were recorded for growth and development and the presence of *Alternaria* infections throughout the growing season. In October a final record from each site was obtained.

Evaluation of variety susceptibility

Twelve varieties of carrot were drilled on 13th May on a sandy clay loam site at NIAB, Cambridge. Plots were 4.5 m long and 4 rows wide on 1.8 m beds. The twelve were selected after consultation with the British Carrot Growers Group, and consisted of varieties found to be resistant and susceptible in years 2 and 3 of the project, which acted as controls, and a number of newer varieties where growers had requested information on resistance. Each variety was replicated three times in a randomised block design. Four pathogenic isolates of *Alternaria dauci*, obtained from seed samples submitted to the Official Seed Testing Station, UK culture collections and plant infections collected during 2001, were increased on malt agar plates at 22 °C, under 12h nuv light and 12h dark. Spores were removed from the plates by soaking in distilled water, scraping, and filtering the resulting suspension through a kitchen plastic mesh sieve, and then a single layer of muslin. The plots were inoculated with 250ml of an aqueous suspension containing 1 x 10^4 spores per ml on 19th and 31st July when foliage was meeting in the rows. The trial was irrigated just prior to inoculation and the suspension was directed downwards at the mid point of the foliage to ensure that the inoculum was protected by the upper leaf canopy. Alternaria was assessed at intervals throughout the season by estimating % foliage and petiole area infected with *Alternaria* on a per plot basis (ie taking all the foliage area in a plot into account) according to the key shown in Appendix I.

Evaluation of the effectiveness of fungicides, and interaction with variety resistance
The fungicide trial in 2002 was designed to examine the interaction between variety resistance and fungicide treatment, and to evaluate fungicide programmes which were likely to be used as sequences commercially. Eighteen plots each of the varieties Nairobi (susceptible), Maestro and Indiana (moderately resistant) were drilled at NIAB trial ground, Cambridge on 2nd May in a sandy clay loam soil. Plots were 9m long and 4 rows wide on 1.8m beds. Five fungicide programmes were applied to each variety. The trial was fully randomised, with each variety and fungicide programme being one treatment, and there were three replicates of each treatment. Discard plots were included at each end of the trial. An Adcon weather station was erected at Cambridge University Farm, Huntingdon Road, approximately 400m from the trial area. Data from the weather station, and observation of *Alternaria* in the plots, were used to forecast Alternaria risks through the PLANT Plus system. Plots were irrigated to promote establishment, and then just prior to inoculation (12mm rain equivalent) with *Alternaria* spores on 19th July. A further inoculation after a period of natural rainfall was made on 23rd July. The irrigation and inoculation constituted the first "forecast" risk, and plots were sprayed prior to inoculation on 17th July. Inoculation was carried out the same method and inoculum source as described for the variety trial at a rate of 500 ml of inoculum per plot. Spray programmes, and dates of application, are shown in Table 1, and product details in Table2. The plots were scored at intervals during the season for % Alternaria cover on the leaves, and at the end of the season for % green leaf cover of the plot area, and leaf retention as number of green petioles per plant..One of the five treatments consisted of programme 2 in Table 1 below, but with the *proviso* of different timings should the forecasting system trigger these for varieties with differing levels of resistance. However, the model indicated that risks were occuring at the same time regardless of variety resistance, and data for this treatment are not included in the results tables.

Table 1 Spray sequences, rates and dates of application on inoculated trial

Sequence	Spray 1	Spray 2	Spray 3	Spray 4	Spray 5
1 prophylactic	Amistar 1.0l 17th July	Folicur 1.0l 30th July	Amistar 1.0l 14th August	Folicur 1.0l 28th August	Amistar 1.0l 10th Sept
2 forecast	Amistar 1.0l 17th July	Folicur 1.0l 6th Aug	Amistar 1.0l 12th Aug	Folicur 1.0l 23rd Aug	Amistar 1.0l 10th Sept
3 forecast	Folicur 1.0l 17th July	Amistar 1.0l 6th Aug	Folicur 1.0l 12th Aug	Amistar 1.0l 23rd Aug	Folicur 1.0l 10th Sept
4 forecast	Amistar 1.0l 17th July	No spray*	Amistar 1.0l 12th Aug	Compass 2.0l 28th Aug**	Compass 2.0l 10th Sept

* second spray in sequence 4 was due to be Compass, applied after forecast to test curative effect, but this could not be applied due to wet conditions. The sequence was resumed with Amistar at the next forecast (12th August)

** Compass applied as "late spray", 5 days after forecast on 23rd August

Table 3. Product details for fungicide trials.

Product	Active ingredient	Current Status	Rate (l product/ha)	Application volume (l water/ha)
Folicur	Tebuconazole	On Label	1	400
Amistar	Azoxystrobin	On Label	1	400
Compass	Iprodione/ thiophanate methyl	SOLA	2	400

Effects of disease on yield

Plots in the fungicide trial for 2002 were harvested in the autumn on 4th November by lifting a 2m section across 4 rows, and recording total weight, root number (>19mm diameter), unmarketable roots (classified as undersized, ie < 19 mm, or affected by rots - wet rots, black surface rots and crown rot) and then calculating weight of marketable roots per hectare.

Results and Discussion

Evaluation and validation of forecasting systems

The occurrence of favourable conditions for disease development initiated a greater number of forecast treatments compared to previous years of this study. This resulted in an increase in use of fungicide materials in the forecast fields.The total use of treatments was similar between forecast and normal practice fields in 2002.

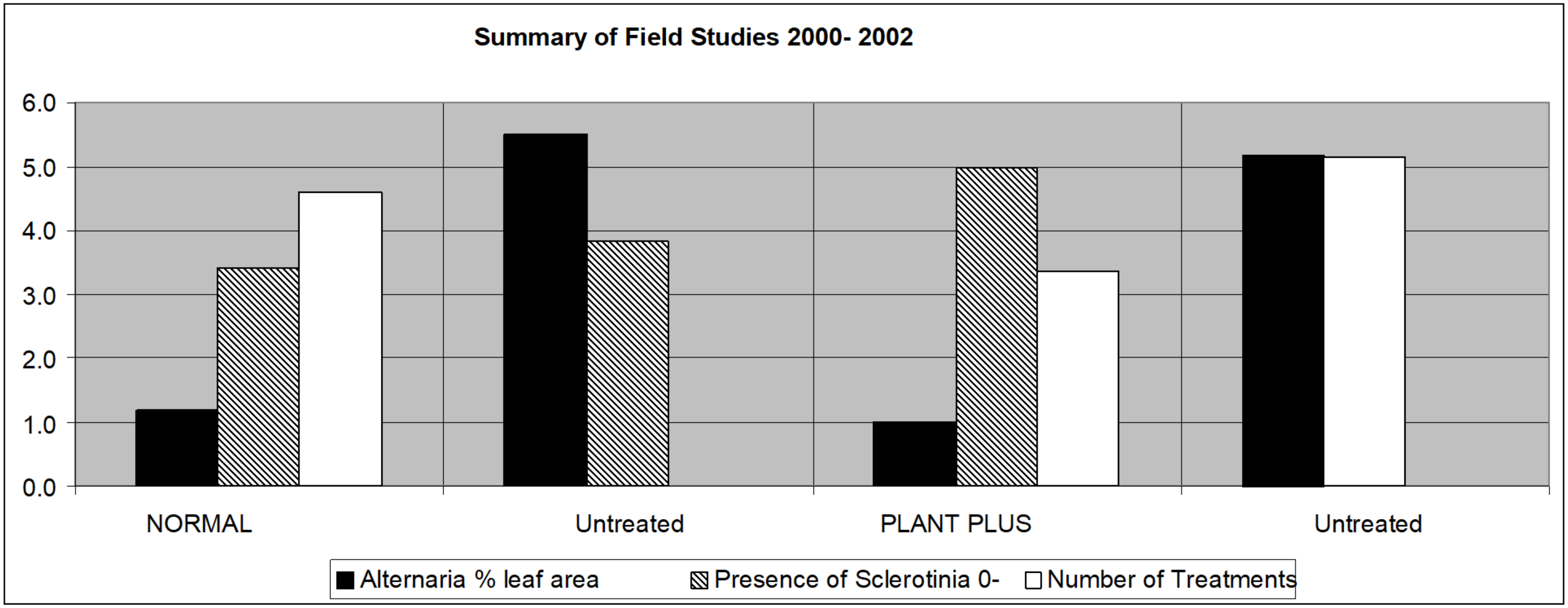
The occurrence of natural infection of *Alternaria* was moderate - a similar pattern to that recorded in the year 2000. Again *Sclerotinia* appeared at damaging levels in some fields. Detailed descriptive results and spray applications from monitored sites for 2002 are presented in Appendix II. A summary of monitored sites in from 2000 to 2002 is shown in Fig 1, (details in Appendix III) and a summary for 2002 alone in Fig 2.

The occurrence of *Alternaria* in carrots is sporadic and may not be as common as previously. This may well be due to the improvement in seed health as this can be an important source of initial infections. Nevertheless the disease can be damaging in favourable (warm, wet) seasons and with the gradual progression towards warmer climatic conditions the disease could again be severe as it is in some areas of France, The Netherlands and Belgium.

Alternaria is currently effectively controlled using a number of applications of Amistar, Folicur and Compass. For convenience under normal practice, these treatments are initiated at the start of the normal treatments for carrot fly (late July in the South, mid August in Scotland) and the fungicide is applied as a tank mix with Hallmark Zeon. This approach using fortnightly treatments has given effective control of both carrot fly and *Alternaria* but has resulted in the use each season of 4 to 5 treatments. In addition it is normal practice to finish the fungicide program with an application of Corbel which is believed to be giving effective control of crown rot (possibly *Itersonilia* sp.)

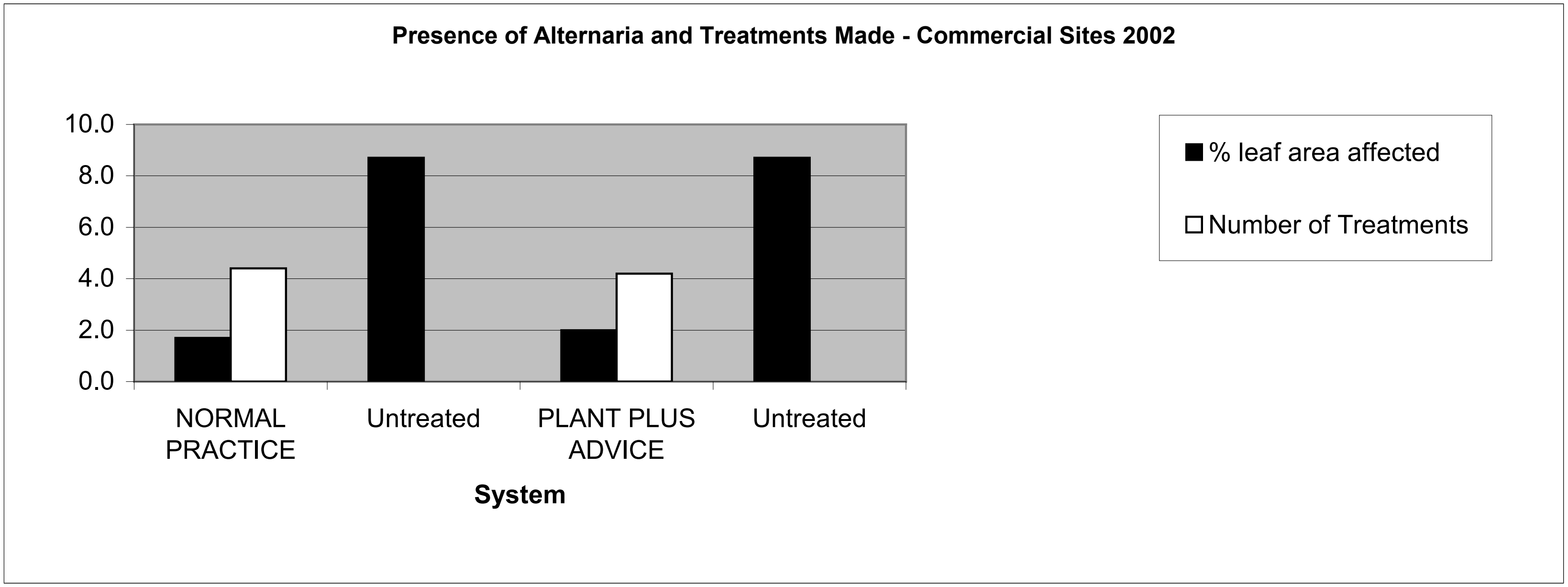
Whilst it may be necessary to apply routine treatments of insecticide, this work has shown that it is often unnecessary to apply such treatments for *Alternaria* disease control. The use of the PLANT Plus forecasting system has shown that in favourable seasons, the fungicide input can be significantly reduced without the reduction in crop yield, quality, or harvest ability.

During this study, the opportunity to observe the presence of Sclerotinia has been taken. The incidence of this disease has not been equally spread between study sites nor between study pairs or between years. There is a suggestion of improved control of this disease where Amistar has been applied early in the treatment season. Clearly further studies are required as this disease is proving to be commercially significant.



Number of Sites	Summary of Averages	Presence of Alternaria PP Score	Alternaria % leaf area affected	Presence of Sclerotinia 0-10	Number of Treatments
22	NORMAL PRACTICE	5.9	1.2	3.4	4.6
22	Untreated	8.0	5.5	3.8	0.0
22	PLANT PLUS ADVICE	5.8	1.0	5.0	3.4
22	Untreated	7.9	5.2	5.1	0.0

Fig 1 Summary of forecast and normal practice treatments for 2000 to 2002, mean Alternaria severity, and Sclerotinia observation



Summary of all Commercial Sites 2002						
Number of Sites	**Summary of Averages**		Presence of Alternaria PP Score	% leaf area affected	Number of Treatments	Presence of Sclerotinia
5	NORMAL PRACTICE		6.4	1.7	4.4	3.2
5	Untreated		9.2	8.7	0.0	4.4
5	PLANT PLUS ADVICE		6.6	2	4.2	4.6
5	Untreated		9.2	8.7	0.0	4.8

Fig 2 Summary of forecast and normal practice treatments for 2002, mean Alternaria severity, and Sclerotinia observation

Evaluation of variety susceptibility to Alternaria

There were large and significant differences in the level of *Alternaria* developing on varieties, and in general the ranking order was maintained over the season (Table 3).Since the trial was not irrigated in 2002, disease increased during periods of wet weather, but remained static in drier periods, or decreased as a % since newer growth was not infected However, the susceptibility of popular varieties such as Nairobi and Nerac seen in 2000 and 2001 trials was confirmed, as was the partial resistance in Maestro and Indiana. Newer varieties included in 2002 after consultation with the British Carrot Growers Association did not appear to have resistance levels greater than Maestro, though Artemis had an approximately equivalent level of partial resistance.

Table 3 Severity of *Alternaria* infection (% foliage area infected) in 12 carrot varieties, 2002

	10th Sept	18th Sept	18th Oct	31st Oct
NUN 8872	21.3	21.7	63.3	38.3
Eskimo	21.0	29.0	53.3	33.3
Maestro	5.0	10.7	50.0	41.7
Artico	28.3	35.0	70.7	33.3
Trevor	15.7	21.7	61.7	46.7
CLX 3175	15.7	23.3	65.0	40.0
CLX 3176	14.0	16.7	51.7	45.0
Artemis	8.0	13.3	40.0	40.0
Nerac	14.7	20.0	65.0	46.7
Nairobi	15.0	21.7	81.7	58.3
Nepal	13.3	19.3	53.3	46.7
Indiana	6.7	8.0	50.0	31.7
Lsd (p=0.05)	9.31	10.92	13.58	16.54

Evaluation of the effectiveness of fungicides

Alternaria increased rapidly during mid-August. All fungicide programmes reduced the disease (Table 4, Plate 1 and 2, Appendix IV). There were no significant differences on the majority of scoring occasions in disease control between the comparable prophylactic and forecast treatments (sequence 1 and 2, both beginning with Amistar), though the prophylactic sequence generally gave slightly better control throughout. However the forecast sequence beginning with Folicur gave significantly less effective control than that beginning with Amistar (sequence 3 and 2 respectively) on the majority of scoring occasions. This was not seen in similar sequences applied in 2001, though disease pressure then was lower earlier in the season, and may not have been sufficient to discriminate between initial product effects. Sequence 4 in 2002, which consisted of four sprays, two forecast Amistar sprays and two Compass sprays, gave approximately equivalent disease control to the forecast Amistar and Folicur sequence, with a total of five sprays. One spray of Compass was also applied five days after forecast risk, confirming the efficacy of this product as an eradicant spray. Differences between disease control within spray sequences were most apparent on Nairobi, though the poorer control with the sequence beginning with Folicur was also evident on Maestro and Indiana.

Differences in green leaf cover in 2002 generally reflected the disease scores. All spray sequences improved leaf retention as measured by green petiole number per plant at harvest. (Table 5)

Table 4 Progress of *Alternaria* (% foliage infected) under different fungicide regimes, inoculated trial, Cambridge, 2002.

Treatment	9th Aug	23rd Aug	30th Aug	10th Sep	18th Sep	25th Sep	2nd Oct	9th Oct	18th Oct	31st Oct
Nairobi Untreated	3.0	20.7	25.7	27.3	36.7	49.3	58.3	73.3	80.0	61.7
Nairobi Sequence 1	0.1	5.3	4.7	7.3	8.0	9.0	9.0	13.3	17.3	12.3
Nairobi Sequence 2	0.1	7.3	11.3	8.7	9.7	12.3	15.7	19.7	24.7	17.3
Nairobi Sequence 3	1.0	14.7	18.0	16.0	17.3	28.0	31.7	38.3	44.0	23.3
Nairobi Sequence 4	0.1	8.0	9.0	8.0	9.7	17.7	20.7	20.7	26.7	20.7
Maestro Untreated	1.0	8.3	8.0	14.0	22.3	24.7	33.3	48.3	54	41.7
Maestro Sequence 1	0.1	0.2	0.7	1.3	2.3	3.7	4.0	5.0	5.7	7.0
Maestro Sequence 2	0.1	1.7	1.7	1.0	2.3	3.7	4.0	6.7	8.7	6.3
Maestro Sequence 3	0.1	2.2	3.7	5.0	10.7	8.3	11.7	16.7	21.7	17.3
Maestro Sequence 4	0.1	2.0	2.7	1.4	6.3	5.3	5.7	9.0	10.7	10.0
Indiana Untreated	1.0	15.7	14.7	20.0	21.7	26.3	33.3	45.0	53.3	43.3
Indiana Sequence 1	0.1	5.8	4.3	3.3	5.7	7.3	9.0	12.3	15.3	11.7
Indiana Sequence 2	0.1	4.3	5.7	5.0	5.0	8.3	9.0	12.3	14.0	9.0
Indiana Sequence 3	0.1	9.0	11.3	12.3	11.3	15.0	16.7	19.0	22.3	14.7
Indiana Sequence 4	0.1	3.4	4.0	2.7	5.0	8.3	9.0	10.7	13.3	15.0
lsd (p=0.05)	0.01	4.54	5.47	4.56	6.28	5.95	6.58	6.87	8.04	8.53

Table 5 % green leaf area cover remaining at harvest, and leaf retention, assessed as mean number of green petioles per five plants, Cambridge 2002

Treatment	% green leaf area cover	Mean petiole number
Nairobi Untreated	8.0	1.0
Nairobi Sequence 1	61.7	3.7
Nairobi Sequence 2	50.0	4.3
Nairobi Sequence 3	35.0	2.3
Nairobi Sequence 4	60.0	2.3
Maestro Untreated	21.7	2.0
Maestro Sequence 1	88.3	5.7
Maestro Sequence 2	85.0	6.3
Maestro Sequence 3	76.7	4.3
Maestro Sequence 4	80.0	5.0
Indiana Untreated	43.3	2.0
Indiana Sequence 1	78.3	4.3
Indiana Sequence 2	75.0	5.0
Indiana Sequence 3	70.0	3.3
Indiana Sequence 4	68.3	5.0
lsd (p=0.05)	6.76	1.33

Effects of disease on yield

Effects of *Alternaria* on yield were measured in the fungicide trial.There were large, significant effects (p=0.05) of treatment on the yields of marketable roots (Table 6). The largest increases in yield occurred with spray sequences 1 and 2 which gave the best overall disease control for both Nairobi and Maestro. Though spraying significantly improved the yield of Indiana as well, the increase was smaller, and there were only small differences between spray sequences as might be expected given the degree of partial resistance in this variety.

Increased yield for Nairobi was up to 23 t/ha, and for Maestro up to 31 t/ha, while the largest increase for Indiana was 14 t/ha. These increases are considerably more than those seen in 2001 and 2000, and reflect the much earlier onset of severe disease in 2002. In 2000, the mean yield increase in response overall all treatments was 1.8 t/ha, and in 2001, 6 t/ha for Nairobi only. Though these mean figures mask higher responses to some treatments, they illustrate that disease increasing late in the season has much less effect on yield potential than early season disease. In 2000, plant populations were rather variable in the trial. The variation did not appear to be associated with treatment. Yields per root were increased by treatment, though not significantly. When yield per root was used as an indicator of *Alternaria* damage, there was a mean increase of 10% for all treatments over untreated controls. There was less variation in root number in 2001 and 2002, and yield per root values were not used.

None of the fungicide sequences in 2002 gave complete control of the disease. This was particularly evident with the susceptible variety Nairobi and probably limited the magnitude of the yield response for this variety.

Table 6. Effects of fungicide treatment on yield (t/ha) of marketable and unmarketable root categories.

Treatment	Marketable	Rots	Undersize
Nairobi Untreated	89.6	0.5	2.7
Nairobi Sequence 1	113.2	1.1	3.2
Nairobi Sequence 2	109.9	0.7	3.1
Nairobi Sequence 3	97.9	2.2	3.1
Nairobi Sequence 4	97.2	1.4	3.6
Maestro Untreated	92.6	1.6	2.2
Maestro Sequence 1	119.4	0.2	1.6
Maestro Sequence 2	123.8	0.4	1.8
Maestro Sequence 3	108.7	0.4	1.9
Maestro Sequence 4	112.6	0.0	2.2
Indiana Untreated	74.6	1.8	0.9
Indiana Sequence 1	84.5	2.2	1.1
Indiana Sequence 2	88.5	4.8	1.1
Indiana Sequence 3	87.1	1.9	1.8
Indiana Sequence 4	80.2	5.4	1.8
lsd (p=0.05)	9.35	2.7	ns

Conclusions

Based on this year's results, and those from 2000 and 2001, the following conclusions can be made:

- PLANT Plus forecasting systems can significantly reduce the number of sprays applied for *Alternaria* while retaining acceptable levels of control, offering growers the opportunity to reduce production costs. In 2000, with moderate disease levels ocurring in commercial crops, an average reduction of 0.9 sprays was possible. In 2001, with lower disease pressure, an average of 2.6 sprays over a number of growing regions could be omitted without affecting disease levels. In 2002, disease levels were higher, and the forecast spray number on average was the same as normal practice prophylactic spraying.
- Varieties differ substantially and consistently in resistance to *Alternaria*. This information was incorporated into the PLANT-Plus forecasting system, but forecast risk occasions remained the same for three varieties of varying resistance tested in 2002. Nevertheless, the combined effects of spraying and partial resistance gave the best overall disease control, and yield responses.
- Amistar, Folicur, and Compass all controlled of *Alternaria*, in a number of sequences, and whether applied as protectants or eradicants. Protectant sprays were generally more effective than eradicant applications. Alternating sequences of Folicur and Amistar controlled *Alternaria* as effectively as the same product used throughout the season, thus confirming that anti-resistance strategies should not compromise disease control. However, it was clear in 2002 under high disease pressure that a sequence beginning with Folicur as protectant was not as effective as one begun with Amistar.
- Controlling *Alternaria* gave significant yield benefits. These were relatively small in 2000 and 2001, but much larger in 2002, when levels of *Alternaria* increased rapidly during mid August, compared to later season increase in 2000 and 2001. This demonstrated clearly that *Alternaria* is a damaging disease on carrots in the UK, but that infections developing after about mid to late September will have a relatively small effect on yield.. However, foliage may still be damaged, and this could affect green top lifting operations.

Technology transfer

This work was presented to British Carrot Growers Association seminar meetings in 2001 and 2002. A poster describing the first year's results was demonstrated at the UK Carrot and Onion Conference, Spalding, 2001. A fact sheet based on the results of the first two years was prepared for HDC members and issued in summer 2002. An HDC project news summary article was published in summer 2002. Live links to forecasting models were provided through the HDC website in summer 2002, and links to within year summaries in winter 2002. Further presentations on the project are planned for the UK Carrot and Onion Conference in November 2003, and a paper has been offered to the BCPC Conference in Glasgow, November 2003.

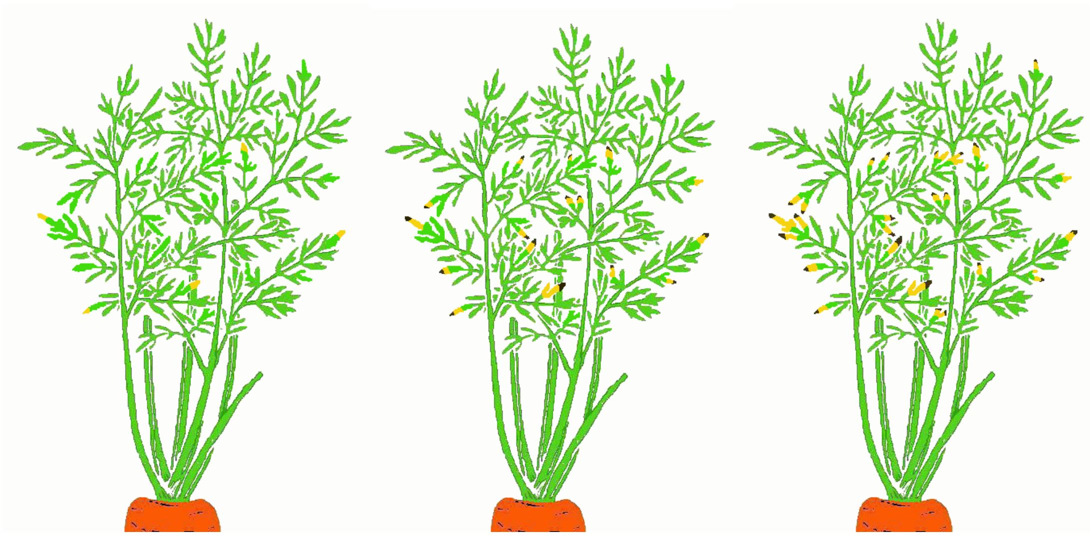
References

Anon 2001 "Leaf blight was a focus in New York" in Carrot Country, pp 10-14, Summer 2001.

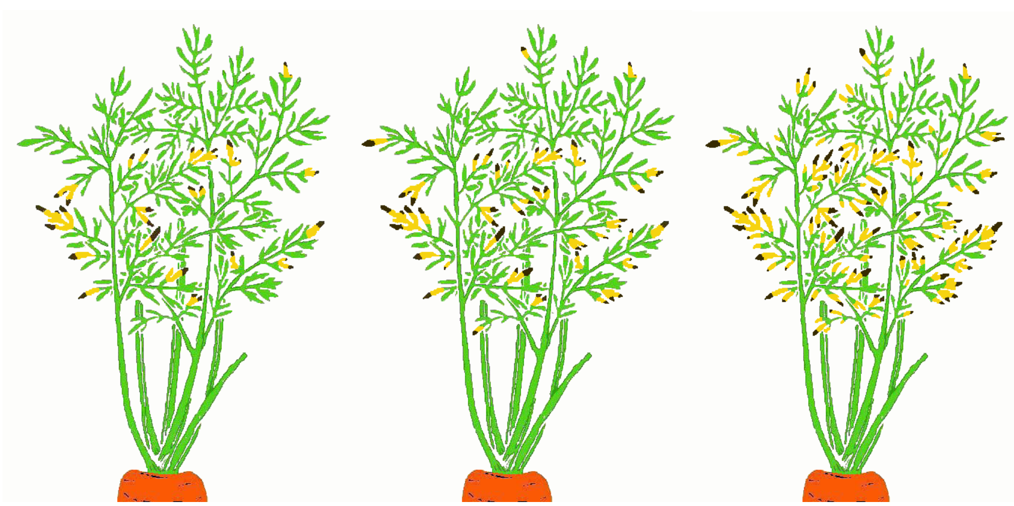
Davis M; Gilbertson B; Nunez J; Pryor B; Strandberg J. 1993 *Alternaria* disease of carrots. Bulletin of the University of California-Davis, December 1993

APPENDIX I

Scale for Alternaria assessment



1% 5% 10%



15% 20% 40%

- Interpolate between % points
- Score all yellowing and blackening confirmed as *Alternaria*
- Include petiole area
- Examine the whole of the plot, and assign mean scores

APPENDIX II

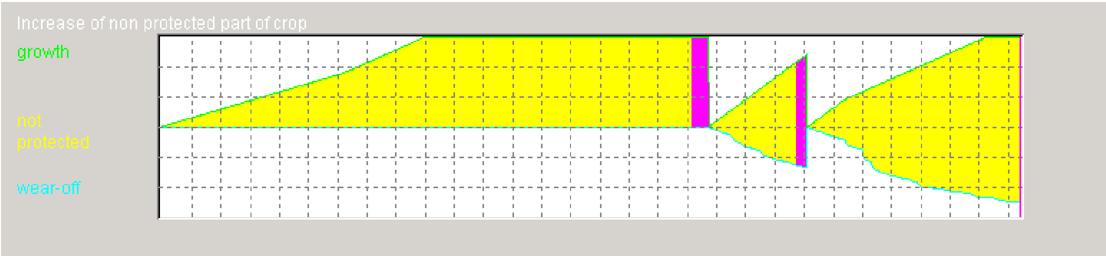
PLANT Plus output and graphics from representative sites

Trial Site and Field Site Season Reviews – Alternaria advice graphics

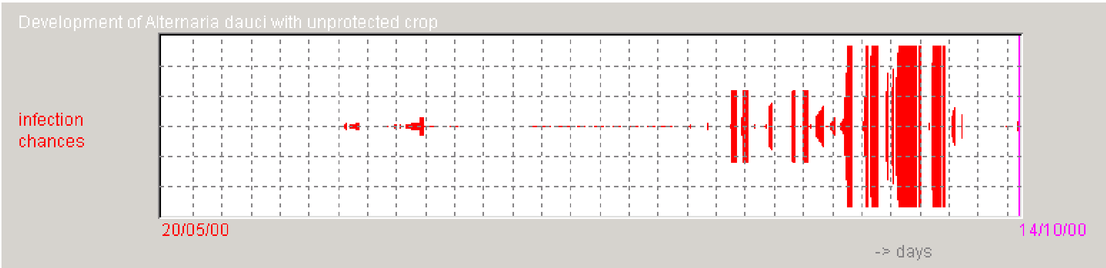
Interpretation of PP Advice Graphics

PP graphics are presented in pairs and represent changes in crop status and in disease risk over a specific time period. The graphics presented in this report are season reviews, which cover the time period between early June and mid October.

The top graphic of the pair illustrates the rate of growth of the crop foliage together with the wear off of the fungicide treatments applied to control disease.



The bottom graphic illustrates the infection events, which have been identified by the PP system assuming the crop is unprotected.



Optimum crop protection is achieved when the treatments (top graphic, vertical bars) are timed just in advance of or to coincide with the most significant infection events.

Detailed Descriptive Results from Field Sites Monitored in 2002

1.) Yorkshire

Forecast carrot crop

In response to a first forecast infection event, the first fungicide was applied at end of July at a reduced rate. The DSS judged the protection to crop was insufficient from this treatment and a large number of infection chances were recorded for the following three days. Eleven days later the model recommended a second fungicide treatment. By the end of August a third fungicide was applied and a fourth by early September. The crop remained largely free of Alternaria and Sclerotinia infections.

Total number of sprays = 4
DSS states all sprays necessary.
Average interval between sprays = 14 days.
Longest interval = 20 days.

The no spray zone was lightly infected with Alternaria at around 4-5% infected foliage.

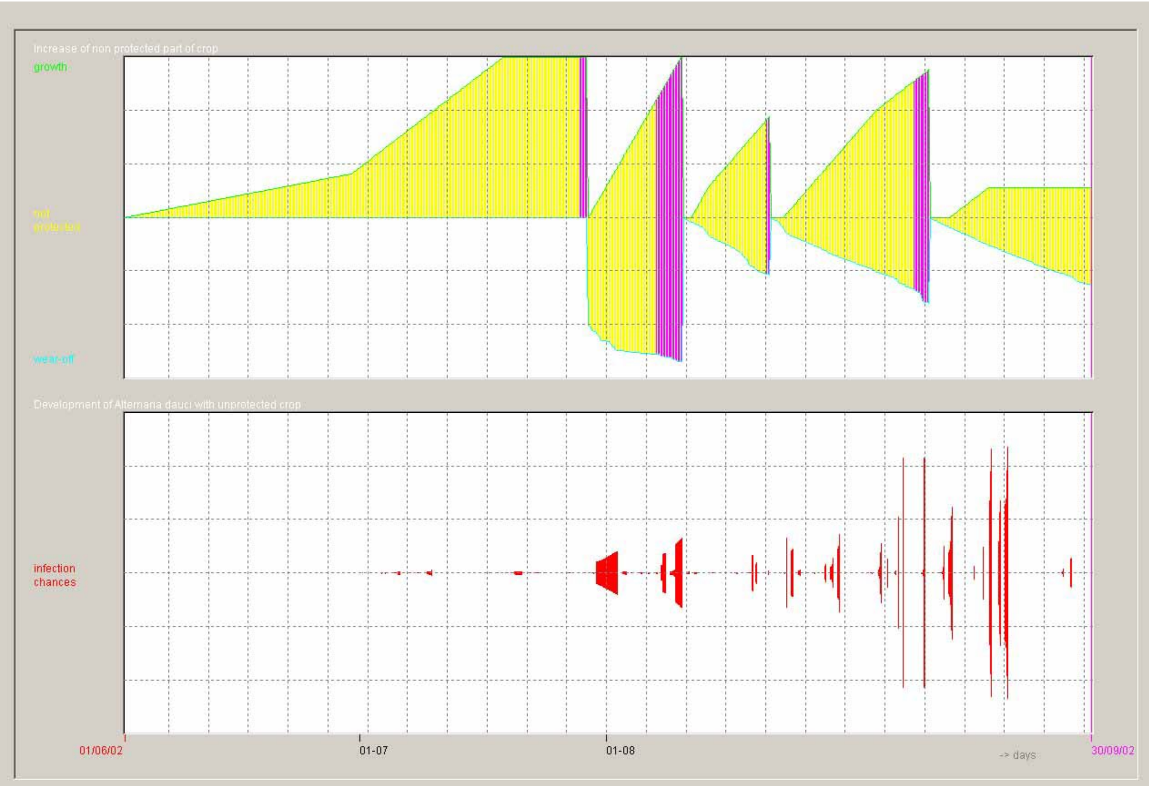
Normal grower practice treatment

Conventional prophylactic fungicide programs of Amistar and Folicur treatments were applied during the period late July to mid September. These treatments were combined with insecticides for carrot fly. The crop remained largely free of Alternaria and Sclerotinia symptoms although there were significant infections of Sclerotinia in other fields in the area.

Total number of sprays = 5
Average interval between sprays = 11 days
Longest interval = 16 days

The no spray zone was showing similar light Alternaria infection to the forecast untreated plot.

Season Review Graphic – Yorkshire



2.) Nottinghamshire

<u>Forecast carrot crop</u>
The first fungicide application was triggered in late July. The DSS showed conditions for infection were severe from then onwards. The second fungicide was applied as soon as realistically feasible. A total of six separate periods of infection chances were recorded as missed which may have resulted in Alternaria being identified in the no spray zone, but the forecast crop remained clear of infection. Sclerotinia was identified in the forecast crop and in the no spray zone.

Total number of sprays = 5
DSS states all sprays necessary.
Average interval between sprays = 13 days.
Longest interval = 16 days.

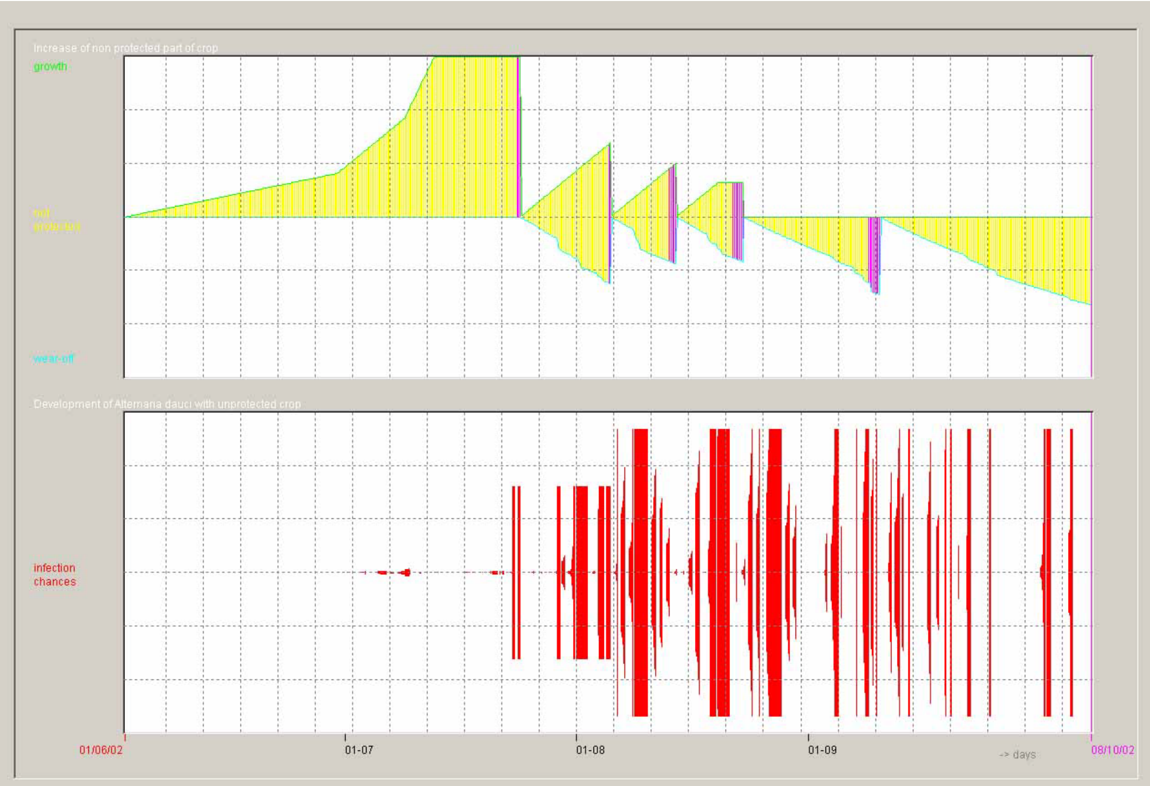
The no spray zone was infected with Alternaria with around 10% infected foliage and Sclerotinia was present in small discrete areas causing localized foliar damage.

<u>Normal grower practice treatment</u>
A prophylactic fungicide program of Amistar Compass and Folicur treatments were initiated in mid July. These were applied in conjunction with carrot fly treatments. The program was completed in early September. The crop remained free of Alternaria and Sclerotinia symptoms.

Total number of sprays = 5
Average interval between sprays = 10 days.
Longest interval = 13 days.

The no spray zone was infected with Alternaria at around the 10% infected foliage and Sclerotinia was present in small discrete areas causing localized foliar damage

Season Review Graphic - Nottinghamshire



3.) Norfolk

<u>Forecast carrot crop</u>
In late July the crop was first treated in response to risk statement by the DSS. There was an increase in risk again during first few days of August, triggering the system to recommend a second fungicide application which was delayed. Large infection chances were missed again and by early September the crop was showing foliage infection of 5 -10 % Alternaria . Further application delay exposed the crop to further risk and by early October Alternaria leaf infection levels of >10% were recorded. In addition Sclerotinia infections were significant and localized foliar damage was common throughout the crop.

Delays in fungicide applications during periods of ideal infection conditions may well have resulted in Alternaria infection levels identified in crop foliage.

Total number of sprays = 5
DSS states all sprays necessary.
Average interval between sprays = 12 days.
Longest interval = 18 days.

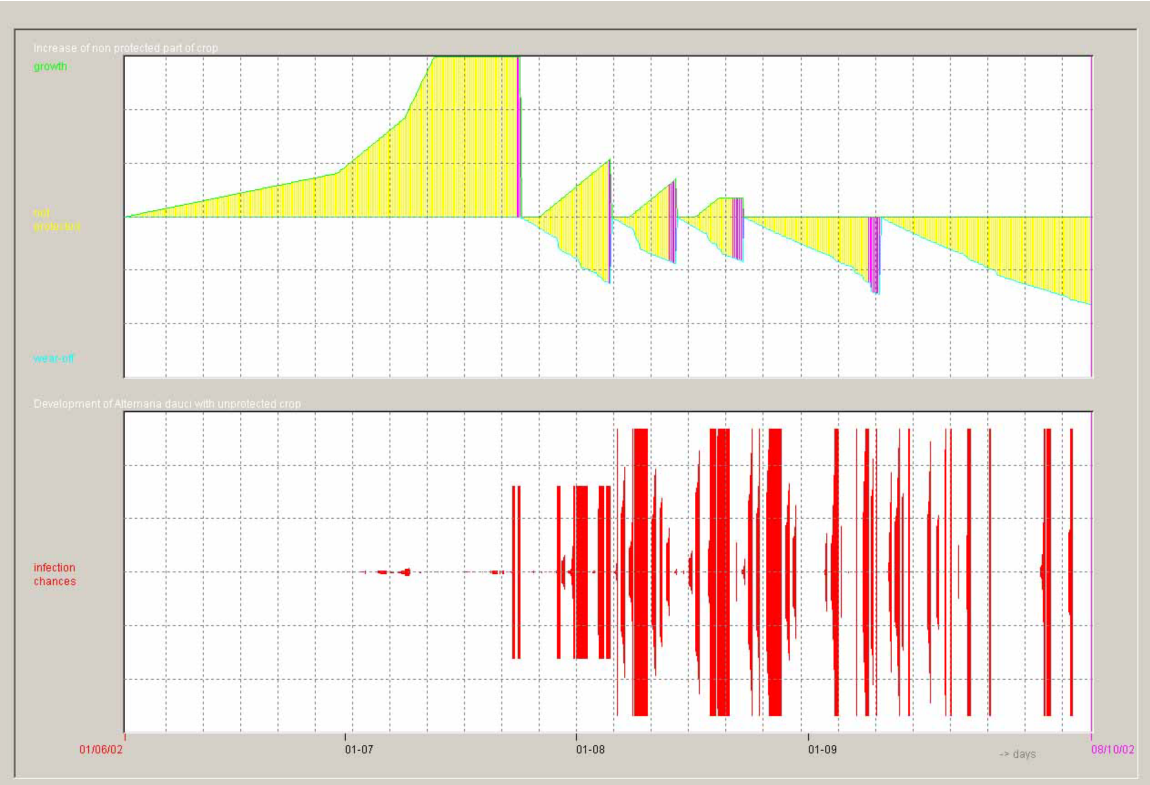
The no spray zone was infected with Alternaria and by early August leaf infection levels were at 5 - 10%. By mid August dead leaf was recorded at 25% due to a combination of Alternaria, Sclerotinia and Powdery mildew infections. This increased to 35% by early September, and 60% by early October. At this stage it was impossible to record the significance of individual diseases but it was felt that Sclerotinia was the most significant cause of foliage loss.

Normal grower practice treatment

A routine prophylactic fungicide program of alternated Folicur and Amistar was applied together with the carrot fly insecticide treatments. By early August Powdery mildew and Alternaria leaf infections were present at 1-2%. Dead Leaf increased by mid August to 10 – 15% due to high levels of Sclerotinia. By early September Alternaria increased to 5-10% leaf area affected (equal to forecast crop at this stage). Infection remained at this level into early October. Dead leaf was finally recorded at 15%, mainly due to Sclerotinia infection.

The no spray zone was heavily damaged with a combination of Alternaria, mildew and Sclerotinia, similar to the forecast no spray zone.

Season Review Graphic – Norfolk



4.) Suffolk

Forecast carrot crop

No disease risk was identified until early August, when as a result the DSS initiated the first fungicide application. The actual treatment was delayed by 4 days, therefore exposing crop to large infection chances but by the time the fungicide was applied the risk period had passed, making the fungicide an unnecessary treatment. Disease pressure built up again after mid August and the system recommended the next treatment which was again delayed, this time by 6 days, exposing the crop once more to risk of infection.
A two week period of low pressure followed before model recommended third and final fungicide treatment during mid September. Response time with fungicide application was good this time. No further pressure was recorded until early October and it was decided that it was too late to treat this event.

Total number of sprays = 3

DSS states two out of three sprays necessary – the first treatment was delayed.
Average interval between sprays = 10 days.
Longest interval = 15 days.

In the no spray zone the first symptoms of Alternaria were identified in mid July and 20% dead leaf was recorded by early August. This increased to 30% by mid August, with greater than 10% Alternaria leaf infection and Powdery mildew and Sclerotinia recorded. By early October the no spray zone was clearly identifiable within the field, with 70% dead leaf and high populations of aphids present.

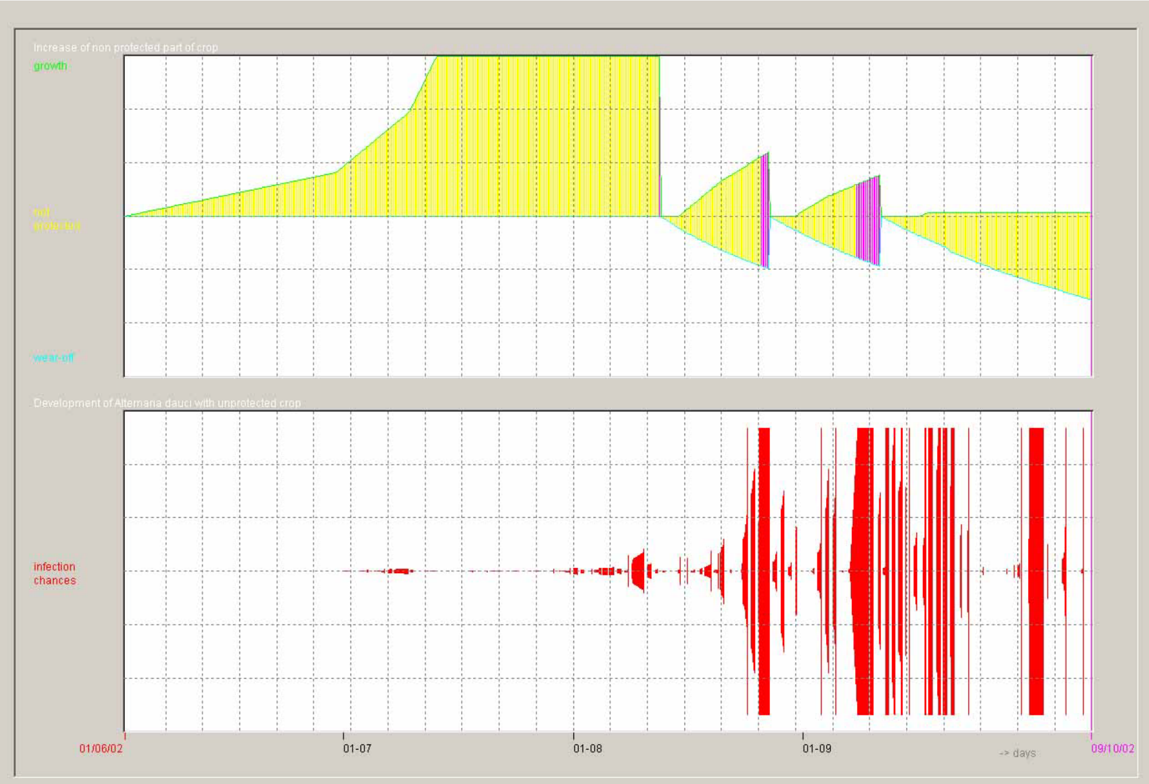
Normal grower practice treatment

A prophylactic fungicide program starting with Amistar and following with Folicur was adopted together with treatments for carrot fly. The first spray was applied on the 21st of July and the last in mid September. Alternaria symptoms were first identified in the crop in early August with 2% leaf infection. Specific Alternaria leaf infection between 5 – 10% was recorded two weeks later. Infections increased again by early October to > 10% Alternaria infection and 30% dead leaf. In common with the forecast crop, small areas of Sclerotinia ware present causing limited foliar damage.

Total number of sprays = 4
Average interval between sprays = 12 days.
Longest interval = 20 days.

In the no spray zone disease development was rapid. By mid July first symptoms of Alternaria identified and 20% dead leaf was recorded by early August. This continued to increase throughout August and September. Alternaria, mildew and Sclerotinia were present. By early October the no spray zones were clearly identifiable within the field with high levels of foliar damage.

Season Review Graphic – Suffolk



5). Cambridgeshire

<u>Forecast carrot crop</u>
The first risks of infection were seen by the DSS in late July and early August and again towards the middle of the month. The first treatment was possibly a few days late on the fifth of August and the second was applied on the 12th. The third treatment was timed just before a sequence of infection events by which time very light levels of infection could be found in the crop. A final treatment on the 10th of October finished the required treatments although the risks continued to occur throughout the latter part of the month.

Total number of sprays = 4
DSS states three out of four sprays necessary.
Average interval between sprays = 11 days.
Longest interval = 15 days.

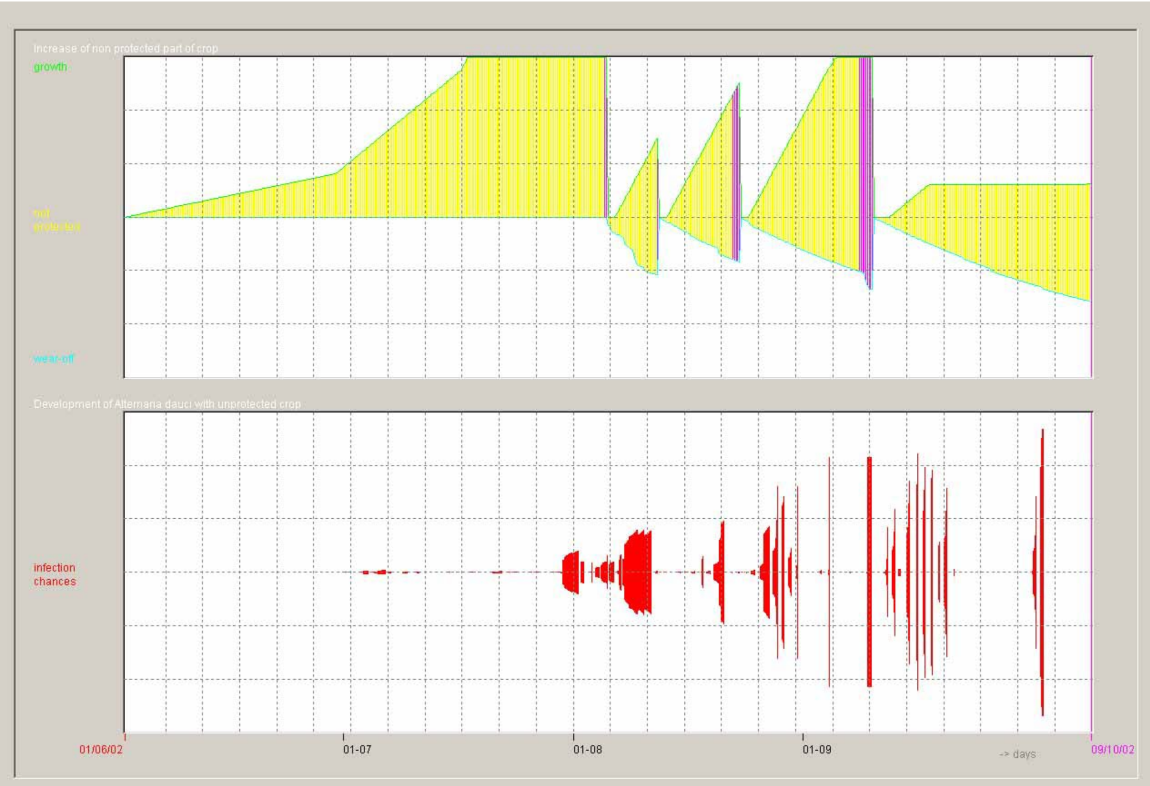
Untreated plots were badly affected with Alternaria dauci, which by mid October had resulted in significant leaf die back.

<u>Normal grower practice treatment</u>
A prophylactic fungicide program starting with one application of Amistar and following with 3 half-rate applications of Folicur was adopted together with treatments for carrot fly. The first spray was applied on the 19th of July and the last in mid September. Traces of Alternaria symptoms were first identified in the crop in mid August. Specific Alternaria leaf infection of approximately 10% was recorded in mid October. In common with the forecast crop, no areas of Sclerotinia were found in this crop.

Total number of sprays = 4
Average interval between sprays = 13 days.
Longest interval = 20 days.

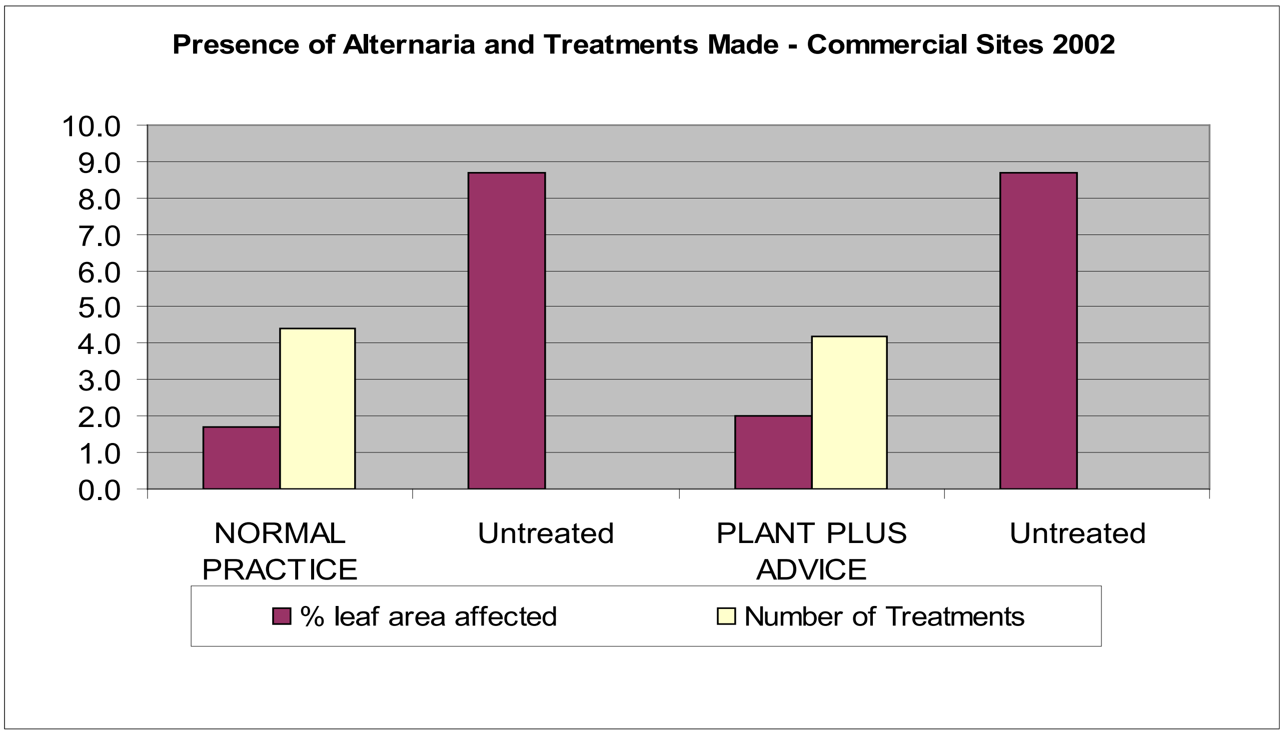
Disease development in the no spray zone progressed steadily from mid August and more rapidly in September. By the final record in mid October there was high levels of Alternaria present together with associated leaf die back. The infection score on completion gave > 10% Alternaria which was comparable with the untreated zone in the forecast area.

Season Review Graphic – Cambs.



Summary of all Commercial Sites

Number of Sites	**Summary of Averages**	Presence of Alternaria PP Score	% leaf area affected	Number of Treatments	Presence of Sclerotinia
5	NORMAL PRACTICE	6.4	1.7	4.4	3.2
5	Untreated	9.2	8.7	0.0	4.4
5	PLANT PLUS ADVICE	6.6	2	4.2	4.6
5	Untreated	9.2	8.7	0.0	4.8



For Key to infection scores see Table below

PLANT-Plus Infection Rating Presence of Alternaria dauci	
First sign of disease in the area - within 25km radius	1
No infection in the crop but a few infected fields in the area	2
No infection in the crop but several infected fields in the area	3
No infection in the crop but many infected fields in the area	4
No infection in the crop but conditions favourable for disease spread	5
Disease found in the crop, less than 1% infected foliage	6
Disease found in the crop, 5-10% infected foliage	8
Disease found in the crop, >10% infected foliage	10

PLANT-Plus Infection Rating Presence of Sclerotinia	
First sign of disease in crop	1
Disease found in the crop, widespread infection	3
Disease found in the crop, limited foliar damage	6
Disease found in the crop, extensive foliar damage	8
Disease found in the crop, extensive foliar damage, core rot present	10

Yorkshire

NORMAL PRACTICE Treatments							October Inspection before Straw	
Date	25/07/2002	08/08/2002	22/08/2002	03/09/2002	19/09/2002		Alternaria (0 -10)	Sclerotinia (0 -10)
Product	Amistar	Compass	Folicur	Folicur	Folicur			
Rate	1 ltr/ha	1 ltr/ha	1.0 ltr/ha	1.0 ltr/ha	1.0 ltr/ha		5	0
Untreated	nil	nil	nil	nil	nil		7	0

PLANT PLUS ADVICE Treatments								
Date	29/07/2002	10/08/2002	21/08/2002	10/09/2002				
Product	Folicur	Compass	Amistar	Folicur				
Rate	0.5 ltr/ha	2 ltr/ha	1.0 ltr/ha	1.0 ltr/ha			5	0
Untreated	nil	nil	nil	nil			7	0

Nottinghamshire

NORMAL PRACTICE Treatments								
Date	13/07/2002	25/07/2002	07/08/2002	22/08/2002	03/09/2002		Alternaria (0 -10)	Sclerotinia (0 -10)
Product	Amistar	Compass	Folicur	Folicur	Folicur			
Rate	1ltr/ha	2ltr/ha	1 ltr/ha	1.0 ltr/ha	1.0 ltr/ha		5	0
Untreated	nil	nil	nil	nil	nil		9	6

PLANT PLUS ADVICE Treatments								
Date		28/07/2002	08/08/2002	21/08/2002	06/09/2002	14/09/2002		
Product		Folicur	Compass	Compass	Folicur	Compass		
Rate		1.0 ltr/ha	1 l/ha	2 l/ha	1.0 ltr/ha	2 l/ha	5	7
Untreated		nil	nil	nil	nil	nil	9	7

Norfolk

NORMAL PRACTICE Treatments

Date	20/07/2002	05/08/2002	18/08/2002	03/09/2002		Alternaria (0 -10)	Sclerotinia (0 -10)
Product	Amistar	Folicur	Amistar	Folicur			
Rate	1 ltr/ha	1 ltr/ha	1 ltr/ha	1 ltr/ha		8	10
Untreated	nil	nil	nil	nil		10	10

PLANT PLUS ADVICE Treatments

Date	24/07/2002	05/08/2002	14/08/2002	23/08/2002	10/09/2002		
Product	Amistar	Amistar	Folicur	Folicur	Folicur		
Rate	1 ltr/ha	1 ltr/ha	1 ltr/ha	1 ltr/ha	1 ltr/ha	8	10
Untreated	nil	nil	nil	nil	nil	10	10

Suffolk

NORMAL PRACTICE Treatments

Date	21/07/2000	10/08/2000	24/08/2000	09/09/2000		Alternaria (0 -10)	Sclerotinia (0 -10)
Product	Amistar	Folicur	Folicur	Folicur			
Rate	1 ltr/ha	0.5 ltr/ha	0.5 ltr/ha	0.5 ltr/ha		6	6
Untreated	nil	nil	nil	nil		10	6

PLANT PLUS ADVICE Treatments

Date		12/08/2002	27/08/2002	11/09/2002			
Product		Amistar	Folicur	Compass			
Rate		1 ltr/ha	1 ltr/ha	1 ltr/ha		7	6
Untreated		nil	nil	nil		10	7

Cambs

NORMAL PRACTICE Treatments

Date	19/07/2000	08/08/2000	25/08/2000	10/09/2000		Alternaria (0 -10)	Sclerotinia (0 -10)
Product	Amistar	Folicur	Folicur	Folicur			
Rate	1 ltr/ha	0.5 ltr/ha	0.5 ltr/ha	0.5 ltr/ha		8	0
Untreated	nil	nil	nil	nil		10	0

PLANT PLUS ADVICE Treatments

Date		05/08/2002	12/08/2002	23/08/2002	10/09/2002		
Product		Amistar	Amistar	Folicur	Folicur		
Rate		1 ltr/ha	1 ltr/ha	1 ltr/ha	1 ltr/ha	8	0
Untreated		nil	nil	nil	nil	10	0

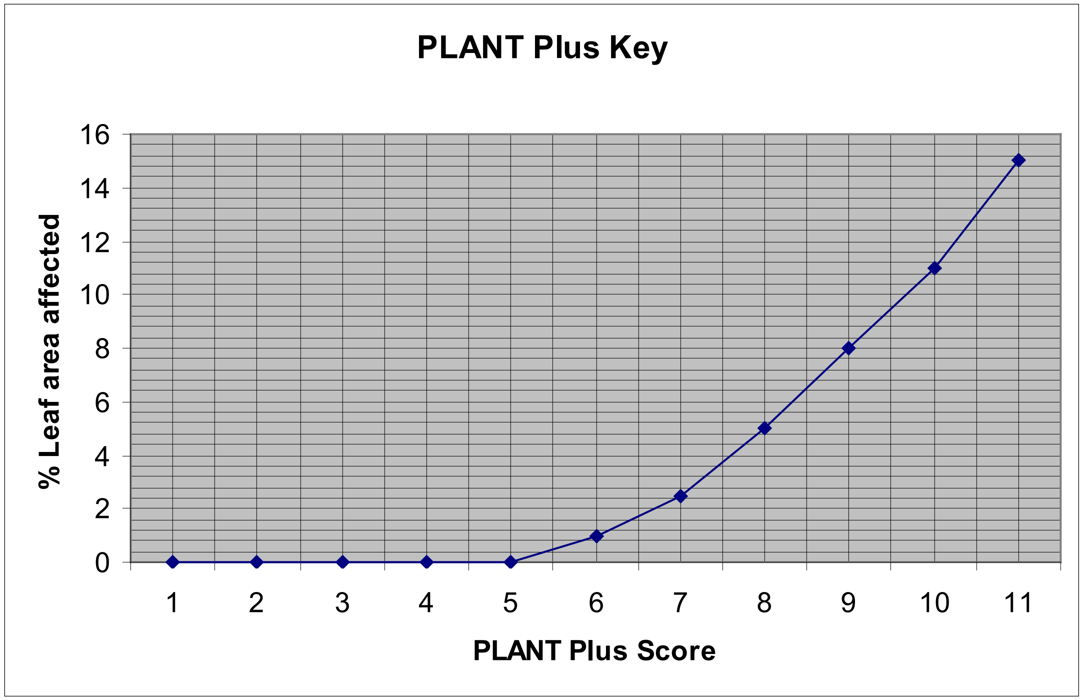
APPENDIX III

Summary of 2000-2002 Commercial site monitoring

Summary of all Commercial Sites

Year	Number of Sites	Summary of Averages	Presence of Alternaria PP Score	Alternaria % leaf area affected	Number of Treatments
2000	8	NORMAL PRACTICE	6.3	1.6	4.3
	8	Untreated	8.3	6.0	0.0
	8	PLANT Plus advice	5.8	0.8	3.4
	8	Untreated	7.8	4.8	0.0
2001	9	NORMAL PRACTICE	5.1	0.2	5.1
	9	Untreated	6.5	1.8	0.0
	9	PLANT Plus advice	5.1	0.2	2.5
	9	Untreated	6.7	2.0	0.0
2002	5	NORMAL PRACTICE	6.4	1.7	4.4
	5	Untreated	9.2	8.7	0.0
	5	PLANT Plus advice	6.6	2.0	4.2
	5	Untreated	9.2	8.7	0.0

Mean of 3 Years Studies	Number of Sites	Summary of Averages	Presence of Alternaria PP Score	Alternaria % leaf area affected	Presence of Sclerotinia 0-10
	22	NORMAL PRACTICE	5.9	1.2	3.4
	22	Untreated	8.0	5.5	3.8
	22	PLANT Plus advice	5.8	1.0	5.0
	22	Untreated	7.9	5.2	5.1



PLANT Plus Score	% Leaf
1	0
2	0
3	0
4	0
5	0
6	1
7	2.5
8	5
9	8
10	11
11	15

APPENDIX IV

Plate 1

Nairobi – Untreated

Nairobi – forecast Amistar/Folicur

Plate 2

Maestro – untreated

Maestro - Amistar/Folicur forecast sequence