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1. PRACTICAL SECTION FOR GROWERS

1.1 Background and objectives

Fungal leaf spots diseases occurring on Brussels sprout buttons or on the wrapper leaves of cauliflowers can affect their saleability. There are many leaf-spot diseases of vegetable brassicas hence the need for crop protection inputs. Two of the most important fungal diseases affecting these crops are ringspot (*Mycosphaerella brassicicola*) and dark leaf spot (*Alternaria brassicae* and *Alternaria brassicicola*). Although two species of *Alternaria* can cause dark leaf spot only *A. brassicae* has been shown to be important in horticultural brassicas. Although applications of fungicide to the crop control these diseases, determining the timing of fungicide application and an appropriate control dosage is not straight forward given that the crop must be protected for long periods of time. For example long season Brussels sprouts crops can be planted in May and harvested at or after Christmas. With the advent of eradicant fungicides such as tebuconazole (Folicur) and difenoconazole (Plover), which can now be used on both Brussels sprouts and cauliflower crops, the grower has a greater range of options for controlling these diseases. However with increasing restrictions on the amount of each fungicide that can be applied to crops it is important that fungicide usage is properly targeted.

Disease forecasting can be used successfully to time fungicide applications. Additionally forecasts can suggest which might be an appropriate product and an appropriate control dosage. This will have an impact on the cost of production although the savings maybe variable between years with low and high disease pressure and also the locality in which the forecasts are used. For this reason production based in more intensive areas may have additional problems and therefore higher costs. However saving only one or two fungicide applications will have a significant impact on the cost of production. Additionally over use of fungicides may increase the likelihood of fungicide resistance in the pathogen. Reducing the over application of fungicides in the crop by using disease forecasters will reduce this possibility.

Scientific objectives

The objectives of this study was to develop methodologies for combining the dark leaf spot and ringspot forecasters in commercial crops. Using results from the commercial trials it was possible to evaluate if forecasts of dark leaf spot and ringspot inoculum

production could be used as a basis for applying protective fungicidal applications to commercial crops. Using the Brassica*spot* system in commercially grown late maturing varieties of Brussels sprouts, criteria were evaluated for using fungicide applications to control both diseases. The potential to use one application of an eradicant fungicide (i.e. Folicur/Plover) timed accurately to control both ringspot and dark leaf spot was assessed. Use of the Brassica*spot* system in different vegetable brassica growing regions where different disease pressures prevail was also evaluated.

1.2 Commercial benefits of the project

Fungicides are increasingly costly economically and environmentally. The brassica leaf spot forecasting system called Brassica*spot* contains models which can provide information on the optimal timing of fungicides for the control of dark leaf spot (*Alternaria sp*), ringspot (*Mycosphaerella brassicicola*) and *Albugo candida* (white blister (Table 1). Using Brassica*spot* will enable growers to accurately target applications of fungicide and give some information on dark leaf spot and white blister disease occurrence. Cost savings resulting from reduced crop walking would depend on the prevailing weather conditions. In areas of intensive crop production with higher disease pressures and higher numbers of fungicide applications there is a greater potential for cost savings by using Brassica*spot* .

1.3 Summary of results and conclusions

Field trials using the Brassica*spot* disease forecasting system were conducted in commercial crops over a three year period from 1997 to 1999 (Table 1). The system in each year was compared to the fungicide schedule used by growers to control dark leaf spot and ringspot in commercial crops of Brussels sprouts. In additional field experiments with cauliflowers the ringspot model was used to time fungicide applications in replicated plots in the field which had been inoculated. These experiments were carried out to determine the validity of this model on cauliflower crops.

Table 1 Schedule of Brassica*spot* models used in commercial field trials during 1997 - 1999

Brassica*spot* Model	Year		
	1997	1998	1999
Dark Leaf spot (*Alternaria*)	Disease warning and spray timing models	Disease warning and spray timing models	Disease warning and spray timing models
Ringspot (*Mycosphaerella*)	None	Spray timing model	Spray timing model
White Blister (*Albugo*)	None	None	Disease warning model

1.3.1 Field Trials in 1997

Reduction of fungicide costs 1997

At most sites in 1997 there was a reduced amount of fungicide used in comparison to the growers control practice. Although the results were variable, due to the trial design used (unreplicated plots) in experiments, control observed was equivalent to the growers regime. No statistics could be employed on the results as only one sample was collected from either area. At the best site used at Ross-on Wye for which there is sufficient data available the reduction in fungicide cost is shown in Table 2 based on prices of fungicide given in 1997 (Table 3). Using the dark leaf spot forecaster reduced the direct fungicide costs by over 50 %. This is a significant decrease in the costs of production. In inoculated experiments with ringspot at HRI it was demonstrated that a ringspot forecaster developed for use on Brussels sprouts could be used successfully to control this disease on cauliflowers. A single application of Folicur timed according to forecasts of ringspot inoculum production controlled the disease more effectively than three applications of Folicur applied according to a pre-determined schedule. In this experiment the ringspot disease levels on the unsprayed control plots were twice those on the sprayed plots. The dosage of Folicur of 0.5 litres ha^{-1} was used as the standard application rate.

Table 2 Disease at harvest, Ross-on-Wye 1998

(a) Mean percentage of buttons uninfected:

	Treatment	
	Spray Timing	Growers Control
Mean Uninfected (Buttons)	60	81
Mean Severity (score)	0.53	0.27

(b) Number of dark leaf spot sprays/cost:

	Treatment	
	Spray Timing	Growers Control
Spray Number	2	4
Cost (£ per hectare ex vat)	32	87

Table 3 Fungicides applied to field experiments in 1997

Chemica	Brand	Application	Cost ha^{-1} (£ ex. 1997
Iprodion	Rovral	510g $a.i.^{-1}$	22.05
Triadimen	Bayfida	125g $a.i.^{-1}$	14.8
Fenpropimorp	Corbel	750g $a.i.^{-1}$	19.8
Mancozeb +	Fubol	1125g $a.i.^{-1}$	15.65
Chlorothalonil +	Folio	1150g $a.i.^{-1}$	42.36
Chlorothalo	Bravo	1.5 litres $a.i.^{-1}$	46.1
Tebuconazol	Folicu	250g $a.i.^{-1}$	30.63

*except where specifically noted

1.3.2 General conclusions of fungicide trials in 1997

Trials conducted in 1997 demonstrated that under the heavy disease pressure experienced in this season using the dark leaf spot forecasting system reduced the number of fungicide applications. Quality of produce was maintained where valid assessments could be taken. Only forecasts of dark leaf spot were available but ringspot was present at most trial sites. It is unclear if this affected the results. However a conclusion of 1997 work indicated that it was necessary to conduct trials, which were replicated and more representative of the location so that statistical tests could be carried

out. In 1998 trials the addition of the ringspot forecaster as a criteria within grower trials on long season Brussels sprouts was also investigated.

1.3.3 Field trials results in 1998

At two of three sites in 1998 use of the Brassica*spot* system (see Table 1 for models used in trials in 1998) improved control of dark leaf spot and ringspot while also reducing fungicide usage. Despite high initial levels of ringspot at one site near Frieston Shore using the Brassica*spot* system to time applications of fungicide reduced significantly the percentage of infected buttons at this site in comparison to the growers control programme. There was also a reduction in the number of lesions per infected button. All harvested buttons at this site were grade I marketable. When the Brassica*spot* models were used at another site at Skegness, fungicide usage was reduced by 33 % with no loss of disease control (Table 4). All buttons at this site were grade I marketable. Control of ringspot and dark leaf spot was improved as the infected buttons had fewer numbers of lesions per button in comparison to buttons harvested from the grower's area. When the cost of fungicide applications, were tabulated, using the fungicide costings listed in Table 5 there was a reduction in 18 £ ha^{-1} to cost of the forecast programme in comparison to the growers control programme (Table 4). This represents a 27 % reduction in the cost of disease control inputs. The results from the second year of development of a ringspot forecaster for cauliflower crops confirmed that the forecaster developed on Brussels sprouts could be used on cauliflower crops to reduce sprays and maintain control. Disease development on the wrapper leaves of the curd was very low on the unsprayed plots. However the timing of cauliflower harvest affects the potential for the disease to transfer on to the wrapper leaves. This is potentially important as the harvest interval after application of eradicant fungicides such as Folicur (3 weeks) must be considered when deciding if a fungicide application is beneficial. As the forecaster can determine the likelihood of inoculum production before it occurs an alternative strategy may be to use high dosages of protectant chemicals such as chlorothanonil.

Table 4 Disease at harvest, Skegness 1998

(a) Mean percentage of buttons uninfected:

	Treatment	
	Spray Timing	Growers Control
Mean Uninfected (Buttons)	61	63
Mean Severity (score)	1.17	1.26

(b) Number of dark leaf spot sprays/cost:

	Treatment	
	Spray Timing	Growers Control
Spray Number	4	6
Cost (£ per hectare ex vat)	49.5	67.5

Table 5 Fungicides applied to field experiments in 1998

Chemica	Brand	Application	Cost ha^{-1} (£ ex. 1998
Iprodione	Rovral	510g $a.i.^{-1}$	22.0
Triadimeno	Bayfidan	0.5 litres $a.i.^{-1}$	13.5
Mancozeb +	Fubol 58	1.5 kg $a.i.^{-1}$	30
Difenconazol	Plover	0.3 litres $a.i.^{-1}$	12
Chlorothalonil +	Folio	1.5 kg $a.i.^{-1}$	48
Chlorothaloni	Bravo	1.5 litres $a.i.^{-1}$	9
Tebuconazol	Folicur	0.5 litres $a.i.^{-1}$	13.5

*except where specifically noted

1.3.4 General conclusions of fungicide trials in 1998

The results indicate that use of disease forecasts (Brassica*spot*) will reduce the numbers of applications of fungicide necessary to control ringspot and dark leaf spot. The potential for cost savings will be substantial if forecasts could be applied to larger areas of production. The trials described in this report give probably minimum amounts of fungicides that can be saved in crop protection programmes.

1.3.5 Field Trials in 1999

At all test sites in 1999 use of the Brassica*spot* system improved control of dark leaf spot and ringspot while also reducing fungicide usage. Despite high initial levels of ringspot at Frieston Shore use of the Brassica*spot* system to time applications of fungicide reduced significantly the percentage of infected buttons at this site in comparison to the growers control programme. Use of the Brassica*spot* system reduced the numbers of spray applications at this site. Control of ringspot and dark leaf spot was improved as the infected buttons had fewer numbers of lesions per button in comparison to buttons harvested from the grower's area. All harvested buttons at this site were grade I marketable. When Brassica*spot* models were used at another site at Skegness, fungicide usage was reduced by 50 % with no loss of disease control. All buttons at this site were grade I marketable. Disease development on cauliflowers was low and consequently tests with the ringspot forecaster on commercial caulifower crops were inconclusive.

1.3.6 General conclusions of Brassica*spot* trials 1997 - 2000

Replicated trials conducted in 1997, 1998 and 1999 show that under the heavy disease pressures experienced in these season using the Brassica*spot* system (the combined dark leaf spot, ringspot and white blister forecasting models) reduced fungicide costs. The quality of all Brussels sprouts buttons in these trials was grade I marketable. In all year there was an approximate saving of 50 % fungicide usage while maintaining or improving quality. The model will be tested within grower trials on long season Brussels sprouts crops to evaluate the impact of three disease forecasts on crop protection inputs within Brussels sprout crops.

1.4 Action points for growers

With increasing consumer demand for reductions in pesticide usage by using the Brassica*spot* system growers will be able to optimise there usage of fungicides on both Brussels sprouts and cauliflowers crops where affected by ringspot, dark leaf spot and white blister. The cost savings in using the system through reduced crop protection inputs will have a significant effect on the cost of production. These costs may need to be off set against those required to purchase environmental data logging equipment. The Brassica*spot* system is now fully automated with MORPH and can be scheduled by MORPH to run at preset times automatically. Further more the system can be linked to automated download systems which exist for all data loggers. This means that there will be few extra costs to the grower in keeping the system running. Information can be disseminated at preset times which can help the grower rationalise his crop protection inputs.

1.5 Anticipated practical and financial benefits

In field trials with Brassica*spot* system it has been demonstrated that it is effective in controlling two major foliar pathogens (ringspot and dark leaf spot) and can provide information on spray timings for white blister. Although other commercial systems are available these have not been well tested under a range of measured. In view of the major changes, which are occurring in the approval of pesticides to crops it is important that the grower uses all approved chemicals to their maximum effectivesness. This means that by timing chemical applications optimally fewer chemical applications will be required to control diseases. With reduced numbers of chemicals approved in future and with commercial changes to existing formulations growers will have a reduced range of products available for control in the future. It is therefore essential that growers adopt the Brassica*spot* system if they are improve profitability and traceability.

2. INTRODUCTION

2.1 Foliar fungal diseases of vegetable brassicas

Long season Brussels sprouts are particularly badly affected by fungal leaf spots. To maintain the high quality of produce demanded by the market there is heavy reliance on regular and routine fungicide applications. Three major leaf spots, white blister (*Albugo candida*), dark leaf spot (*Alternaria spp*.) and ringspot (*Mycosphaerella brassicicola*) affect Brussels sprouts and other vegetable brassicas. However powdery mildew (*Erysiphe cruciferarum*), light leaf spot (*Pyrenopeziza brassicae*), and *Phoma* sp. are also problematical. Autumn and winter cauliflowers are also badly affected by leaf spot diseases however on these crops only ringspot is economically important due to the production of large lesions on the packing (wrapper) leaves of the cauliflower. Regular applications of fungicides are necessary to control these diseases. At the moment fungicides are used in response to a build up of each disease within the crop according to the experience of the individual grower. In areas of intensive vegetable brassica cultivation, control of these diseases is difficult because of the air-borne nature of the inoculum and the prevalence of favourable environmental conditions required for infection and disease development. The ability of the pathogen to spread from heavily infected over-wintered crops on to sequentially transplanted crops in the same area will have a major impact on control of leaf diseases during the season. The occurrence of environmental factors favouring disease development will also determine the amount of disease occurring in the crop. Leaf spot diseases are favoured by specific environmental conditions.

2.2 Environmental factors favouring fungal diseases of brassicas

Dark leaf spot (*Alternaria brassicae*) requires free water for spore germination and infection (Louvette & Billotte, 1964, Kennedy & Graham, 1995). At optimal temperatures of 20 ºC, infection by *A. brassicae* may occur within 6 h but for substantial disease development at least 10 h of wetness is required (Humpherson-Jones, 1991). Both fungi require at least 12 – 14 h with a relative humidity of greater than 90 % for sporulation to occur (Humpherson-Jones & Phelps, 1989). However ringspot infection requires only short periods of leaf wetness at optimal temperatures, (Kennedy et al., 1999). Ringspot requires prolonged periods of temperature and wetness to complete spore production within fungal structures on the lesion (Cullington, 1995). At temperatures of 16 - 24 ºC only 3 - 4 h of wetness is required for infection by white blister (Humpherson-Jones, 1991). Once the disease is established relatively short dewfall periods can be very favourable for white blister development. High temperatures result in relatively short periods of time elapsing between infection and symptom

appearance on the plant. Mathematical relationships (models) describing the effect of temperature and wetness on important life-cycle stages have been developed by HRI. These can be used directly by the grower to provide further information on the occurrence of these critical stages in the crop. However these models require validation and further development under commercial conditions if they are to be used as a basis for timing fungicide applications to the crop. The use of models within Brassica*spot* with information on several diseases requires a format where weather information from several locations can be used in conjunction with several different disease forecasting models. The use of different disease models simultaneously gives rise to the likelihood of a critical timing of fungicide applications made in response to several disease. This approach also requires further information on how combined forecasts on two or more diseases within the crop should be used to rationalise fungicide usage.

2.3 Development of the Brassica*spot* System

At time of writing of this report the Brassica*spot* system comprises of three models covering ringspot (*Mycosphaerella brassicicola*) dark leaf spot (*Alternaria brassicae*) and white blister (*Albugo candida*) as follows:

a) Dark leaf spot infection criteria (Crop walking output)
b) Dark leaf spot disease development criteria (Spray timing output)
c) Ringspot sporulation criteria (Spray timing output)
d) White blister infection criteria (Crop walking output)

The system can be used to identify periods when there was increased risk of disease development within the crop. Information on the potential infection by all diseases (not yet available) or the critical fungicide application timings can be shown on the same output (available for dark leaf spot and ringspot). The dark leaf spot models were developed (FV53b) and validated within HDC contract FV53c (Kennedy & Graham, 1994, 1996) and MAFF project HH1927SFV before usage within the Brassica*spot* system. Weather information collected from within the crop can be used to determine the likelihood of disease occurrence or critical fungicide application timings only if target diseases are present.

The database within which the forecast models work is called MORPH. MORPH is a single computing environment which allows rapid effective development of shared models in one system. It has the flexibility to respond to new technology. MORPH can gather information from weather stations, databases for use in disease forecasts. It is now possible to use the Global System for mobile communication (GSM) and radio off-loading for acquiring weather data for storage within MORPH. This saves time by reducing the need to physically visit the station making data transfer easier. There is also the possibility of data sharing, however the model can still be made to run manually. However MORPH can now be programmed to run the model or models at preset times automatically. This change in technology is currently being investigated and improved.

2.4 Models used within the Brassica*spot* system in commercial Brussels sprouts crops during 1997 - 1999

The addition of models to the Brassica*spot* system during 1997 – 1999 for use in commercial crops is shown in Table 6. In 1997 the Brassica*spot* system comprised of only the dark leaf spot models which were made available to growers participating in trials using commercial crops of Brussels sprouts. In 1998 the ringspot spray timing model was added to the system which was followed by the white blister disease warning model in 1999. By March 1999 the Brassica*spot* system contained information on the three major disease affecting horticultural brassicas.

Table 6 Brassica*spot* models used in commercial field trials during 1997 - 1999

Leaf spot disease	Model		
	1997	1998	1999
Dark Leaf spot (*Alternaria*)	Disease warning and spray timing models	Disease warning and spray timing models	Disease warning and spray timing models
Ringspot (*Mycosphaerella*)	None	Spray timing model	Spray timing model
White Blister (*Albugo*)	None	None	Disease warning model

2.5 Scientific objectives of trials 1997 - 1999

The scientific objectives of the work were as follows:

(a) Investigate the forecasts of ringspot inoculum production as a basis for applying protective fungicidal applications to commercial crops.

(b) Investigate the usage of the Brassica*spot* system in commercially grown late maturing varieties of Brussels sprouts. When can fungicide applications for two or more diseases be combined or treated separately for control of each disease?

(c) Investigate the use of fungicides in conjunction with disease forecasts. Is there potential to use one application of an eradicant fungicide (i.e. Folicur/Plover) timed accurately to control two diseases? What is the spray window for effective control of two diseases?

(d) Determine strategies for the usage of the ringspot and dark leaf spot forecasters in different vegetable brassica growing regions where different disease pressures prevail.

(e) Promote the uptake of disease prediction systems in commercial practice as on farm systems in grower operated trials. In conjunction with the Computing Department at HRI Wellesbourne investigate the improved automation of data processing within Brassica*spot*.

3. MATERIALS & METHODS

3.1 Grower usage of dark leaf spot forecasts in Commercial Trials in 1997 - 1998

3.1.1 Experimental Design 1997 - 1998

Trial sites (4 – 8 locations) were established in Lincolnshire in co-operation with Marshall Brothers, (Butterwick, Boston Lincs.), Univeg (Manor Rd., Kirton, Lincs.), Olga (Old Leeke, Boston, Lincs.), Elgro (The Firs, Kirton, Lincs.). Additional trial sites were located in co-operation with Kettle Produce (Balmalcolm, Cupar, Fife) and GMS/Technicrop (Ross-on-Wye, Herefordshire). The cultivars used in trials at each site are listed in Table 7. Natural infection by dark leaf spot occurred at all sites within each trial area. Experimental plots were positioned within commercial fields of Brussels sprouts at randomly selected field positions (Figure 1). Pests were controlled with insecticides according to the growers control programme at all sites. At each trial location a comparison was made between the following:

(a) Growers control practice (whole field)
(b) The dark leaf spot disease forecasting system, in one plot at the same location (15 m x 15 m section of a field or as stated in (Figure 1).

3.1.2 Dark Leaf spot Forecast usage

Trials were conducted by the grower (or his agent) using the PC version of the dark leaf spot forecasting models (within the Brassica*spot* system) provided by HRI. A SKYE Datahog portable logger (Skye Instruments Ltd, Llandrindod Wells, Powys), was used to collect and monitor the within crop weather data. The latest PC version of the dark leaf spot system within the user interface MORPH was supplied by HRI (Foliar Pathogen Group). Growers' participating in the trial used a computer capable of running the dark leaf spot forecasting software.

3.1.2.1 Disease Warnings Forecasts

Where applicable Brassica*spot* was used to predict when the crop should be walked to determine if disease had occurred. Using the forecaster the risk of infection by dark leaf spot could be determined during prevailing weather conditions which occurred at the site.

Figure 1 Experimental Trial Designs used at sites in 1997

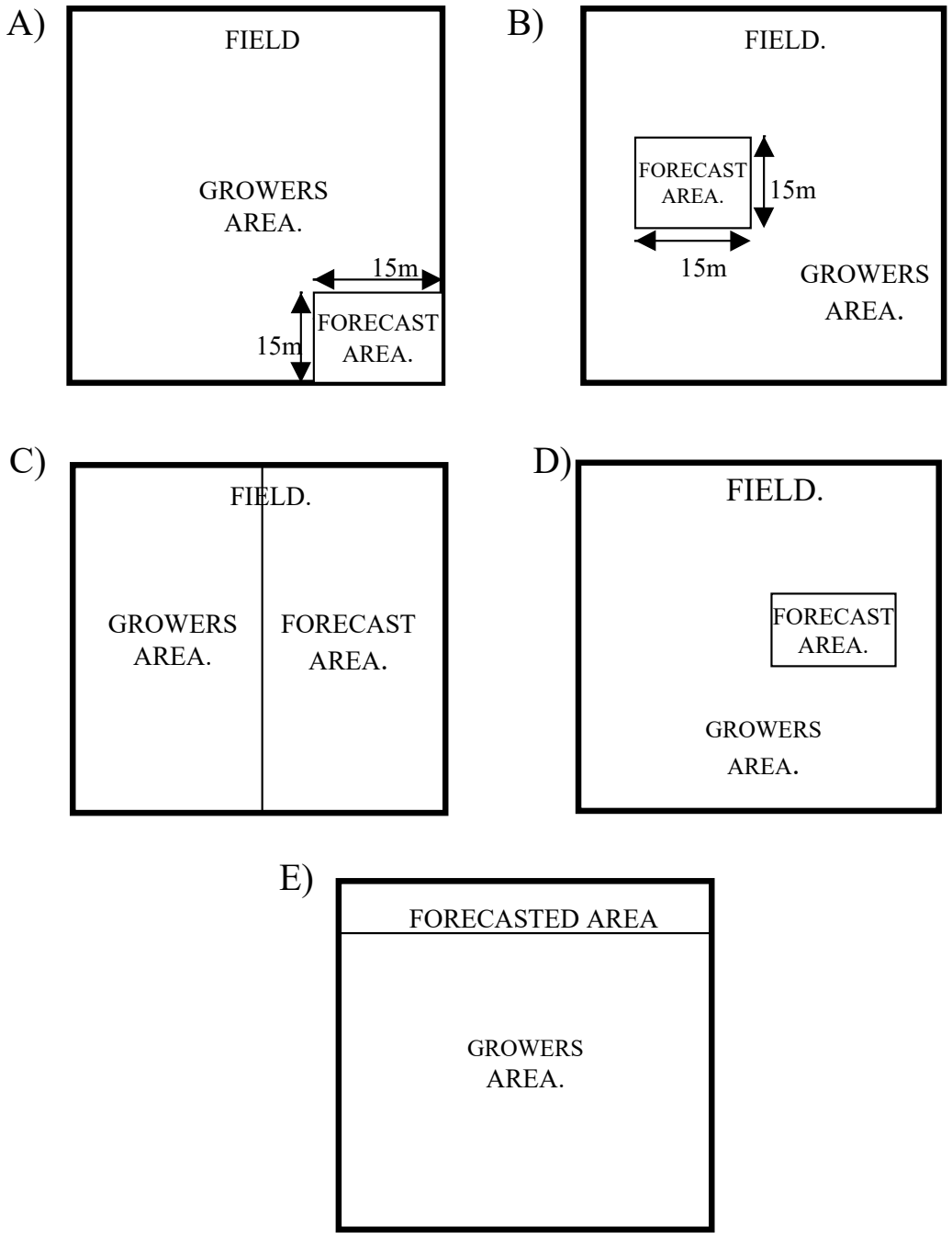


Table 7 Site experimental design, cultivar and sprayer operations in 1997

Site	Cultivar	Experimental Site Plan Type	Spray Operator Forecast Site
Frampton	Diablo	E	Research Sprayer (Hardy)
Holbeach	Stephen	D	Grower
Donington	Adonis	B	Grower
Butterwick	Diablo	A	Research (Hardy Knapsack)
Ross-on-Wye	Adonis	C	Grower
St Andrews Scotland	Adonis	B	Grower

3.1.2.2 Spray Timing Forecasts in 1997

When dark leaf spot had been detected within the crop, Brassica*spot* was used to determine the timing of chemical treatments to the crop. The choice of spray used to control dark leaf spot varied in both forecast and grower treatment areas at each site (spray decisions were determined by each individual grower and by available fungicide).

3.1.2.3 Micro-climate measurements

Measurements of temperature, humidity leaf surface wetness and rainfall were collected at 30 min intervals from crop transplanting using a SKYE Datahog II 4 channel logger. Measurements were collected manually in the field using a portable computer at weekly intervals. Information was checked before being made available to individual growers by placing the information from each logger (site) for each time period on the Internet at the HRI web site (http://www,hri.ac.uk/frames/research.htm). The Brassica*spot* forecasting system in 1997 contained models forecasting dark leaf spot only.

3.1.3 Spray Application

Sprays were applied to the forecast plots using the same systems employed by the individual growers to treat the other areas of the crop. At the Butterwick site a Hardy Knapsack sprayer was used to apply the single spray to the forecast plot. At the Frampton site a Hardy sprayer with 10 m boom width was used to treat the forecast area. All fungicides were applied at the rate recommended on the label unless stated in the text. The dosages used where sprays of Folicur were applied are stated in the text as with this fungicide there is a maximum amount permitted to the crop. Sprays of insecticides were applied according to the growers' regime used on the entire area.

3.1.4 Disease assessments in 1997 (Harvest only)

Disease assessments were taken from Brussels sprouts buttons collected from the top, middle and bottom of 200 plants taken at random in each of the two treatment areas. The following measurements were taken from each site at harvest for each area of the stem.

(i) The number of buttons in the following grades: <12 mm, 12-20 mm, 21-30 mm, 31-40 mm and >40 mm.
(ii) The number of buttons with dark leaf spot lesions.
(iii) The number of buttons without dark leaf spot lesions.
(iv) The number of dark leaf spot lesions present on each button of each grade
(iv) Lesion number of other diseases present (if applicable)

Isolations were taken from lesions on buttons which were difficult to distinguish from other leaf spots. Isolations were taken on V8 agar (200 mls vegetable juice, 20 g Agar, 2g Calcium carbonate litre^{-1}). Leaf material (from which isolations were produced) was surface sterilised prior to dipping in 10% sodium hychloride solution and air drying before placing on V8 agar. At some sites the number of dark leaf spot lesions on each button was assessed using the following scale.

Score	Dark leaf spot lesion number
0	0
1	1 - 5
2	6 - 25
3	26 - 50
4	51 - 75
5	76 - 100
6	100+

3.2 Development and validation of ringspot forecasts in cauliflower crops 1997.

3.2.1 Experimental Design (1997)

The experiment comprised of twelve plots of cauliflower (cv. Belot) each 9m square grown at 50cm spacing. These were arranged as three replicate plots treatment^{-1} in a randomized block design with a 4m spacing between blocks. Untreated control plots were located within each replicate block however the within block interference between untreated and treated plots was reduced by adopting a semi-systematic trial design within blocks (Figure 2). Seeds were sown in Hassy 308 trays (14 May 1997) and transplanted into the field during June 1997.

3.2.2 Plot Inoculation

Plots were infected with *M. brassicicola* by distributing ringspot-infected trash collected from an infected cauliflower crop in Cornwall on the 17 March 1997. Collected trash was dried at room temperature (for 4 – 6 weeks) before being reduced to a ground form. Plots were inoculated by spreading dried trash evenly between rows over the entire length of the row. Approximately 26 g of dried trash was spread between each row of cauliflowers in each plot on the 28 August 1997.

3.2.3 Spray Timing Treatments

Forecasts based on predictions of inoculum availability in the crop were used as the basis for applying control sprays to the crop. The ringspot forecaster was used to predict the time taken for 5 % or 50 % of lesions in the crop to produce inoculum according to prevailing within crop weather conditions..

a) Threshold 1 (5% inoculum production from lesions): Eradicant spray (low dosage)
b) Threshold 2. (50% inoculum production from lesions): Eradicant spray (high dosage)
c) Routine spray: Eradicant spray (low dosage)
d) Unsprayed control

Figure 2. Trial design for the cauliflower experiment at HRI Wellesbourne 1997.

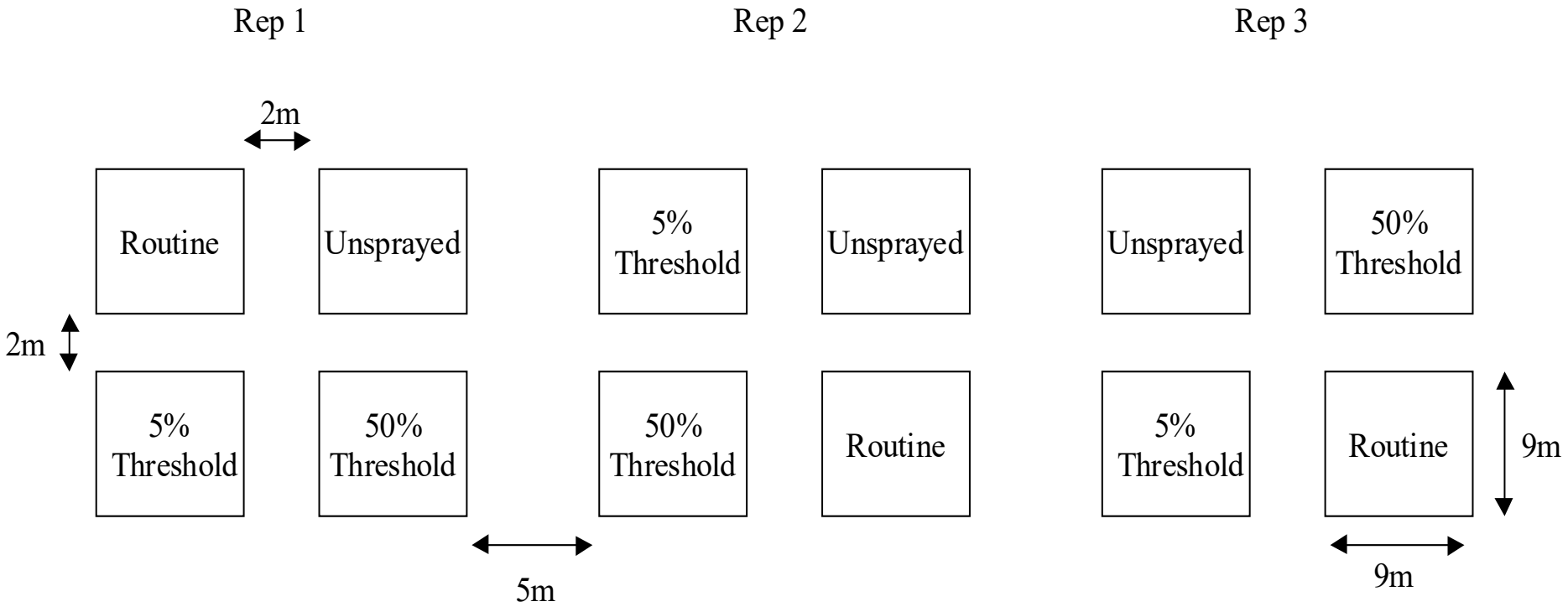
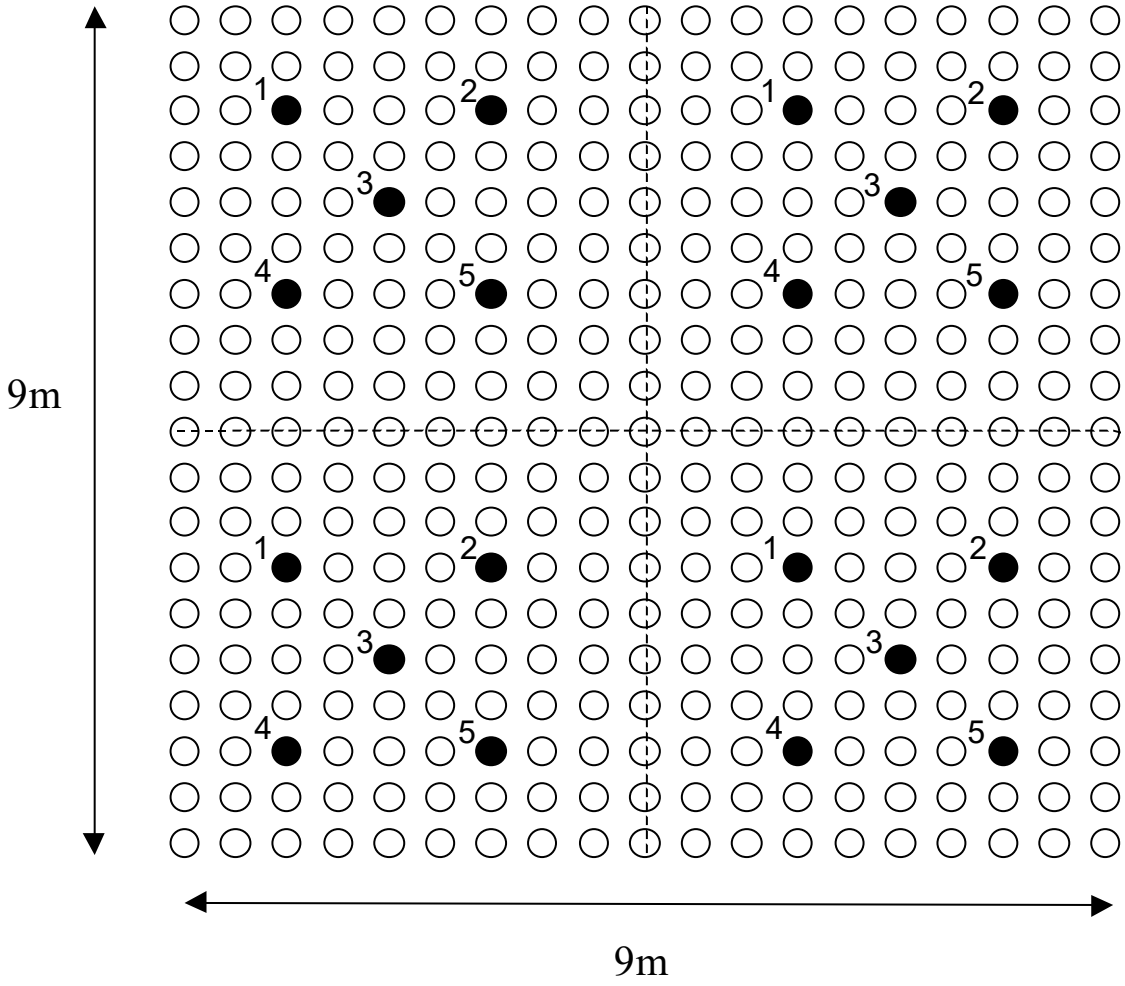


Figure 3. Layout of quadrats in cauliflower plots.



3.2.4 Disease Assessments on cauliflower trials in 1997 - 1998

3.2.4.1 Assessment of *M. brassicicola* on cauliflower leaves

The layout of plants and their location within quadrats of each plot used for severity assessments is shown in Figure 3. A total of 20 plants (5 in each quadrat) were assessed for the occurrence of ringspot on leaves. At approximately two week intervals five leaves on each of the twenty tagged plants in each plot were assessed and scored for the number of ringspot lesions. Leaves on each tagged plant were numbered with a marker at the beginning of the experiment. On alternate assessments the five oldest odd numbered leaves or even numbers leaves were assessed on each plant. The same leaf numbers were assessed on plants of each plot regardless of treatment. At each new assessment time leaves (odd or even) which had not been assessed previously were used in assessments as due to the growth of the cauliflowers older leaves were continuously shed. Assessments began after ringspot was first observed in the plots and continued until harvest. The number of ringspot lesions on each leaf was assessed using the following scale:

Score	*Mycosphaerella* lesion number
0	0
1	1 - 5
2	6 - 25
3	26 - 50
4	51 - 75
5	76 - 100
6	100+

3.2.4.2 Harvest assessments

At harvest approximately 50 – 60 plants in total were harvested from each plot (time of harvest depending on curd maturity). Plants were taken from the four central rows in each plot (rows 9,10,11,12, see Figure 3). Each cauliflower head was trimmed for market before assessment. The trimmed heads were assessed for the severity of *Mycosphaerella* infection on the wrapper leaves by counting the number of ringspot lesions. The head weight of each individual plant harvested was taken.

3.2.4.3 Micro-climate measurements

Measurements of temperature, humidity, leaf surface wetness and rainfall were collected at 30 minute intervals from crop transplanting using a SKYE Datahog I, 4 channel data logger. Measurements were collected, using a portable computer, at weekly intervals. Environmental data, was used with the ringspot disease predictor, to predict the rate of ringspot inoculum production.

3.3 Grower usage of dark leaf spot forecasts in Commercial Trials in 1998- 1999

3.3.1 Experimental Design in 1998 (Replicated trials)

Trial sites (4 locations) were established in Lincolnshire in co-operation with Olga (Old Leeke, Boston, Lincs.), Tasco (T. A. Smith & Co, The Elms, Croft, Skegness, Lincs.), Huntapac (Coe House Farm, Marsh Rd, Hesketh Bank, Preston, Lancashire). An additional trial site was located in co-operation with GMS/Technicrop (Ross-on-Wye, Herefordshire). The cultivars used in trials at each site are listed in Table 8. Natural infection by dark leaf spot and ring spot occurred at all sites within each trial area. Experimental plots were positioned within commercial fields of Brussels sprouts at randomly selected field positions (Figure 4a). Pests were controlled with insecticides according to the growers control programme at all sites. At each trial location a comparison was made between the following:

(a) Growers control practice (three plots positioned along one spray boom width as stated in Figure 5).

(b) The Brassica$_{spot}$ system (three plots positioned along one spray boom width as stated in Figure 5).

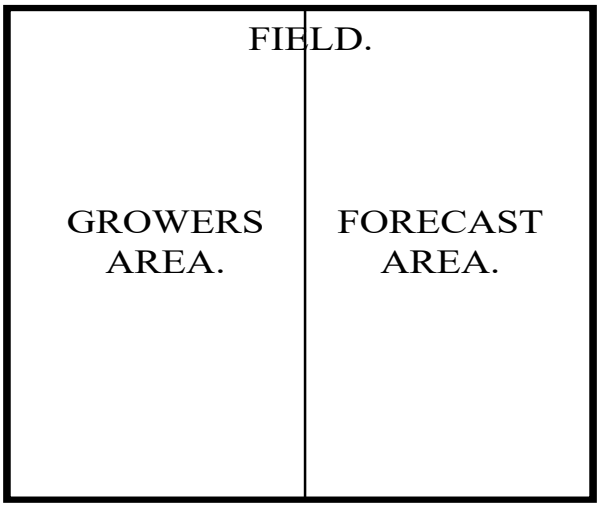
Replicated trials were located in Lincolnshire and Lancashire however at the trial site located at Ross-on-Wye. A non-replicated trial design was used and only harvest assessments were taken (Figure 4b).

3.3.2 Experimental Design in 1998 (Non-replicated trials)

Additional weather information was obtained at sites supplied by Kettle Produce (Balmalcolm, Cupar, Fife), Marshall Brothers, (Butterwick, Boston Lincs.) and Univeg (Manor Rd., Kirton, Lincs.). Trials were conducted by the grower/consultant using the PC version of the Brassica$_{spot}$ system provided by HRI. In 1998 this contained information on disease risk for *Alternaria brassicae* (dark leaf spot) and spray timing information for *Alternaria brassicae* and *Mycosphaerella brassicicola* (ringspot). The trial design used at non-replicated trial sites is shown in Figure 4b. Trial sites consisted of single plots (15 x 15 m) from which data on environmental conditions were taken using a Skye data logger (as described previously). Observations were taken on disease levels on Brussels sprout buttons at harvest only. Growers' participating in the trial used a computer capable of running the Brassica$_{spot}$ system. Cultivars used in non replicated trials are listed in Table 9.

Figure 4. Trial Designs used in 1998 - 1999 experiments

A) Replicated sample



B) Non Replicated Sample

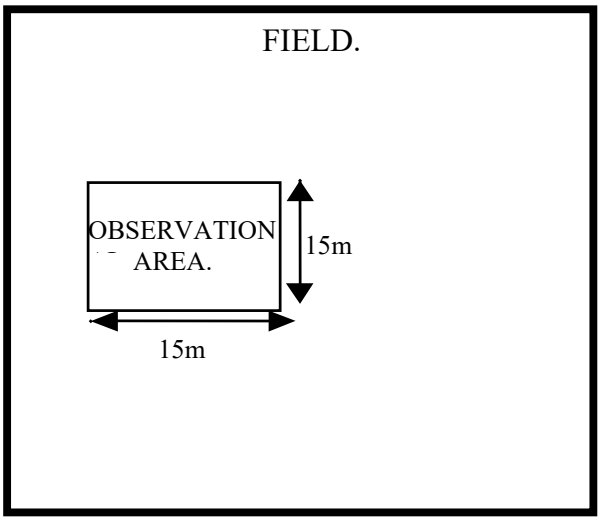
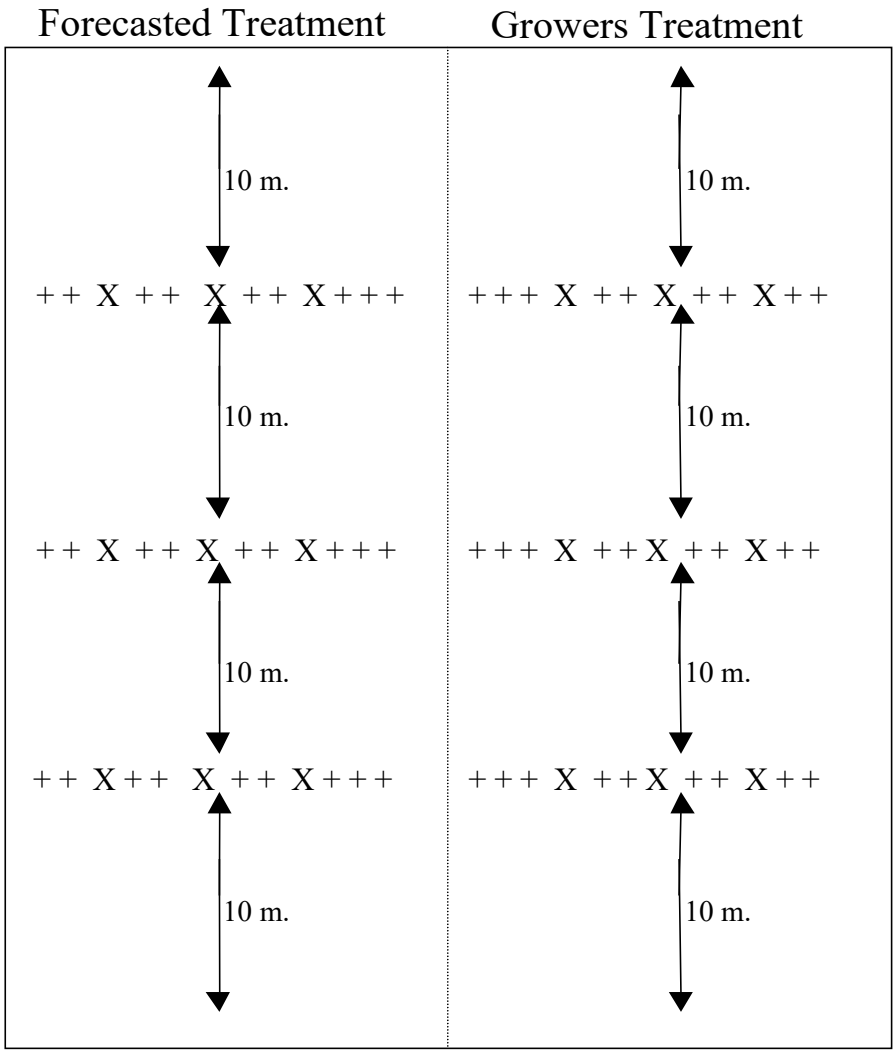


Figure 5. Brassica trial design 1998 - 1999



"X" = sprout plants tagged for assessing.

Each plot has a 50 m gap between them and the next plot.

3.3.2.1 Disease Warnings Forecasts

Where applicable the Brassica*spot* system was used to predict when the crop should be walked to determine if disease had occurred. Using the forecaster the risk of infection by dark leaf spot could be determined from collected environmental data at each site.

Table 8 **Site experimental design, cultivar and sprayer operation used in 1998 - 1999 (replicated sample sites)**

Site	Cultivar	Experimental Site Plan Type	Spray Operator Forecast Site
Frieston Shore	Diablo	Fig 4A	Grower
Skegness	Adonis	Fig 4A	Grower
Hesketh Bank	Helimus	Fig 4A	Grower
Ross-on-Wye	Adonis	Fig 4A	Grower

Table 9 **Observational sites used in 1998 - 1999 trials (non – replicated samples)**

Site	Cultivar	Experimental Site Plan Type	Spray Operator
Butterwick	Diablo	Fig 4B	Grower
Donington	Adonis	Fig 4B	Grower
St Andrews	Helimus	Fig 4B	Grower
Holbeach	Adonis	Fig 4B	Grower

3.3.2.2 Spray Timing Forecasts

When dark leaf spot and ringspot had been diagnosed within the crop, the timing of chemical treatments were determined using the Brassica*spot* system. The choice of spray used to control dark leaf spot or ringspot varied in both forecast and grower treatments areas at each site (spray decisions were determined by each individual grower and by available fungicide). Choice of chemical used to control disease in the forecast plots was under the control of researchers. Chemicals used to control disease in the forecast plots (using the Brassica*spot* system) are shown in Table 10.

Table 10 Fungicides used to control diseases in 1998 - 1999

Disease	Chemical Name	Trade Name	Dosage
Dark leaf spot (*Alternaria spp*)	Tebuconazole (early season)	Folicur	500 mls ha^{-1}
	Difenconazole (late season)	Plover	300 mls ha^{-1}
	Chlorothalonil	Bravo	1.5 kg ha^{-1}
Ringspot (*Mycosphaerella brassicicola*)	Tebuconazole (early season)	Folicur	500 mls ha^{-1}
	Difenconazole (late season)	Plover	300 mls ha^{-1}
	Chlorothalonil	Bravo	1.5 kg ha^{-1}
White Blister (*Albugo candida*)	Chlorothalonil/ Metalaxyl	Folio	1.5 kg ha^{-1}
Powdery Mildew (*Erysiphe cruciferarum*)	Triadimenol	Bayfidan	500 mls ha^{-1}
Light Leaf spot (*Pyrenopeziza brassicae*)	Difenconazole	Plover	300 mls ha^{-1}

3.3.2.3 Micro-climate measurements

See section 3.2.4.3

3.3.3 Application of sprays at trial sites

Sprays were applied to forecast areas using the same systems employed by the individual growers to treat the other areas of the crop at replicated sample sites (Figure 4a). At observation sites it was not possible to ascertain the fungicides used in control programmes (Figure 4b). All fungicides were applied at the rate recommended on the label unless stated in the text. The dosages used where sprays of Folicur and Plover were applied are stated in the text (Table 10) as with these fungicides there is a maximum amount of chemical that can be applied to the crop. Sprays of insecticides were applied according to the growers' regime used on the entire area. All other agronomic practices did not differ between forecast and growers areas.

3.3.4 Disease assessments

3.3.4.1 Leaf Disease Assessments

Leaf disease assessments were carried out in all replicated sample trial areas (Figure 4a). No leaf assessments were taken from plants in observational trial areas (Figure 4b). The number of ringspot and dark leaf spot lesions on leaves of nine tagged plants per plot per treatment (Figure 5) were counted at two time periods during the trial. At each assessment time the four oldest leaves of each tagged plant were assessed for the number of ringspot and dark leaf spot lesions. The tenth leaf of each assessed plant was marked with a plastic tag. At each assessment time the leaf age of the assessed leaves was checked for each assessed plant by referencing it against the leaf number of the closest tagged leaf. Isolations were taken from lesions on leaves to confirm the presence of dark leaf spot or ringspot. Isolations were taken on V8 agar (200 mls vegetable juice, 20 g agar, 2g calcium carbonate litre^{-1}). Leaf material (from which isolations were produced) was surface sterilised by dipping in a 10% sodium hychloride solution and air drying before placing on V8 agar.

3.3.4.2 Brussel sprout button disease assessments in 1998-1999

Two methods of assessing disease on Brussels sprout buttons at harvest were used in 1998 trials. Disease assessments were taken from Brussels sprouts buttons collected from the top, middle and bottom of 48 plants taken at random in each of the three plots in each of the two treatments (growers and forecast areas). In the second button assessment method 9 plants were harvested from each plot of each treatment (27/treatment in total). All buttons from the whole Brussels sprout shank of each plant were removed and assessed for disease. The disease levels, on harvested buttons, (for both methods) were assessed by assigning them to one of the following categories.

(i) The number of buttons in the following grades: <12 mm, 12-20 mm, 21-30 mm, 31-40 mm and >40 mm.
(ii) The number of buttons with ringspot and dark leaf spot lesions.
(iii) The number of buttons without ringspot and dark leaf spot lesions.
(v) The number of ringspot and dark leaf spot lesions present on each button of each grade.
(vi) Lesion number of other diseases present on buttons of each grade (if applicable)

Where possible isolations were taken from lesions on buttons which were difficult to distinguish from other leaf spots. Isolations were taken on V8 agar (200 mls vegetable juice, 20 g agar, 2g calcium carbonate litre^{-1}). Where lesion numbers were high disease on buttons was assessed by using the following scale.

Score	Dark leaf spot/ringspot lesion number
0	0
1	1 - 5
2	6 - 25
3	26 - 50
4	51 - 75
5	76 - 100
6	100+

3.4 Development and validation of ringspot forecasts in cauliflower crops in 1998 -1999

3.4.1 Inoculated Cauliflower Trials (Non-Commercial)

3.4.1.1 Experimental Design 1998 -1999

The experiment was sited at HRI Kirton and comprised of sixteen plots of winter cauliflower (cv. Jerome) each 9 m square grown at 50 x 50 cm spacing. These were arranged as four replicate plots treatment^{-1} in a randomized block design with a 4 m spacing between blocks (Figure 6). Untreated control plots were located within each replicate block however the within block interference between untreated and treated plots was reduced by adopting a semi-systematic trial design within blocks. Seeds were sown in Hassy 308 trays (9 June 1998) and transplanted into the field during on the 30 July 1998.

3.4.1.2 Plot Inoculation

Cauliflower trials were infected with *M. brassicicola* by distributing ringspot-infected trash collected from an infected cauliflower crop in Cornwall on the 17 March 1997. Collected trash was dried at room temperature (for 4 – 6 weeks) before being reduced to a ground form. Plots were inoculated by spreading dried trash evenly between rows over the entire length of the row. Approximately 26 g of dried trash was spread between each row of cauliflowers in each plot on the 17 September 1998.

3.4.1.3 Spray Timing Treatments

Forecasts based on predictions of inoculum availability in the crop were used as the basis for applying control sprays to the crop (as in year one). However trials used over-wintered cauliflower variety Jerome. The cauliflower ringspot forecaster was used to predict the time taken for 50 % of lesions to produce inoculum according to prevailing within crop weather conditions. The use of appropriate disease forecast thresholds in conjunction with either protectant or eradicant chemicals was compared to routine applications of an eradicant fungicide for control of ringspot prior to harvest. The following treatments were applied:

a) Ringspot model threshold 1 (5% of lesions producing inoculum): Protectant spray (spring application)
b) Ringspot model threshold 1 (5% inoculum production from lesions): Eradicant spray (spring application)

c) Routine spray: Eradicant spray (3 sprays applied: spring application)
d) Unsprayed control

3.4.1.4 Fungicide application rates

Difenconazole as Plover was applied at 0.3 litres ha^{-1} in 450 litres ha^{-1} of water as the eradicant spray to routinely sprayed plots (Treatment c). Protectant sprays of chlorothalonil as Bravo at 3 litres ha^{-1} in 600 litres ha^{-1} of water (Treatment a) or eradicant sprays of Plover at 0.15 litres ha^{-1} in 600 litres ha^{-1} of water (Treatment b) were applied at to ringspot forecast plots when inoculum production was forecasted.

3.4.2 Disease Assessments

3.4.2.1 Assessment of *M. brassicicola* on cauliflower leaves

The arrangement of tagged plants and their location within quadrats of each treatment plot used for severity assessments is shown in Figure 7. Twenty plants (5 in each quadrat) were assessed at approximately fourteen-day intervals for the occurrence of ringspot on five leaves per plant, in each plot, of each treatment. Leaves on each tagged plant were numbered directly on the leaf using a permanent marker before the first assessment. On alternate assessments the five oldest odd numbered leaves or even numbers leaves were assessed on each plant. The same leaf numbers were assessed on plants of each plot regardless of treatment. At each new assessment time leaves (odd or even) which had not been assessed previously were used in assessments as due to the growth of the cauliflowers older leaves were continuously shed. Assessments began after ringspot was first observed in the plots and continued until harvest. The number of ringspot lesions on each leaf was assessed using the following scale:

Score	*Mycosphaerella* lesion number
0	0
1	1 - 5
2	6 - 25
3	26 - 50
4	51 - 75
5	76 - 100
6	100+

Figure 6. Experimental design of cauliflower spray timing experiment (Kirton 1998 - 1999)

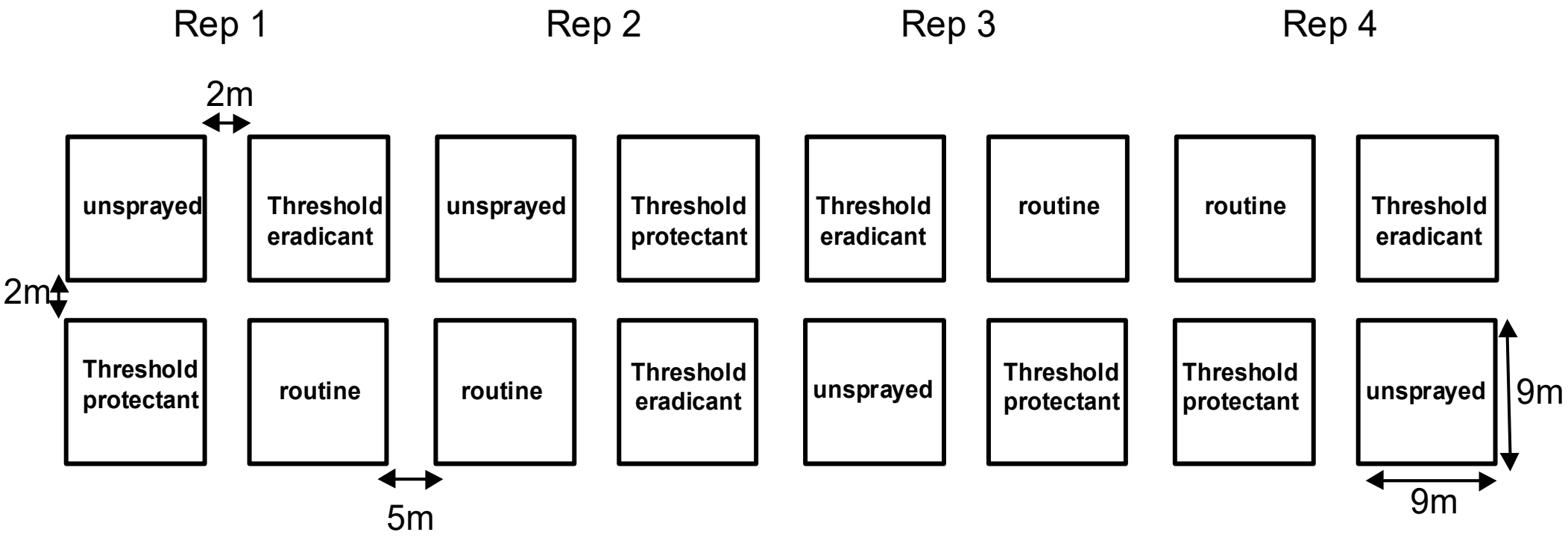
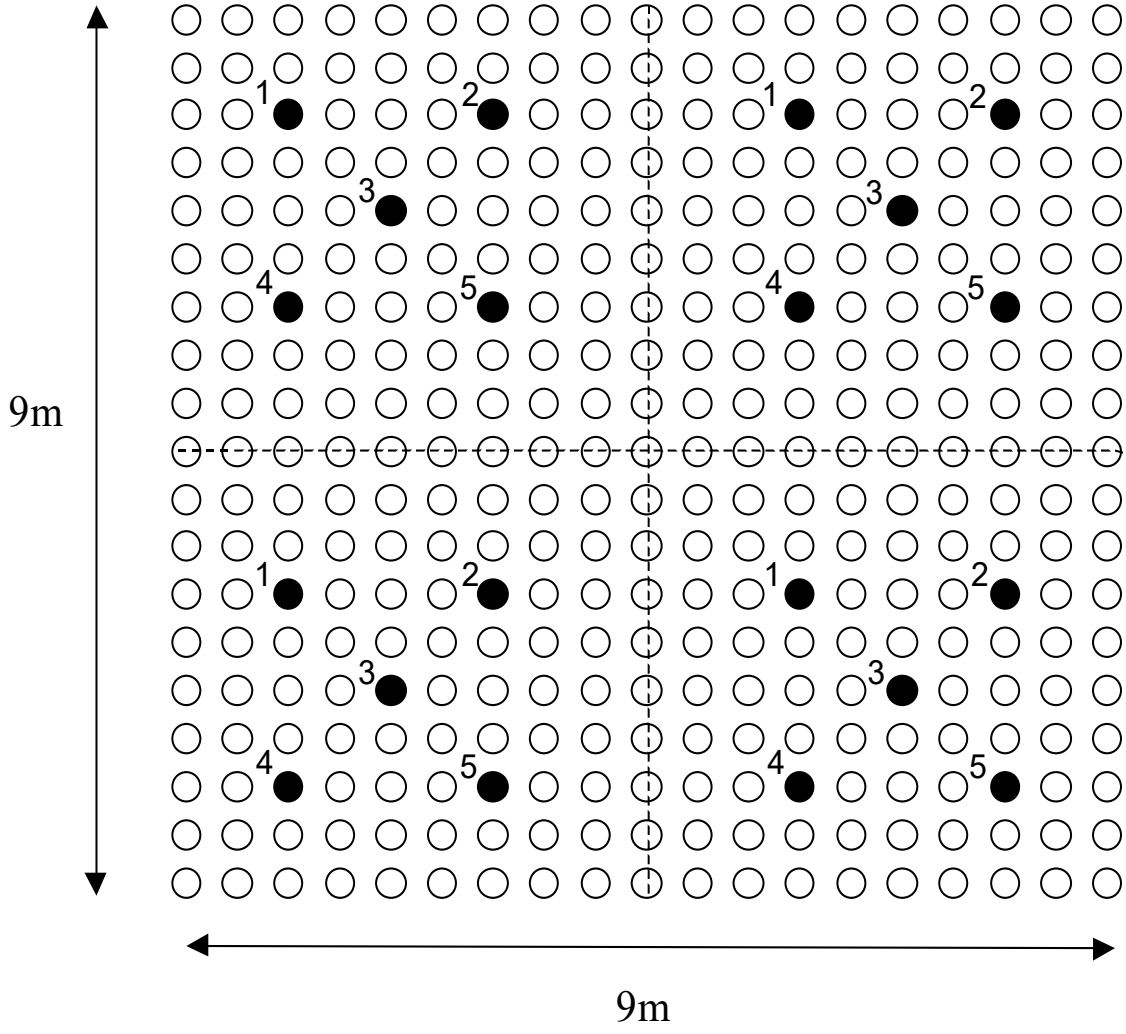


Figure 7. Layout of quadrats in cauliflower plots.



3.4.2.2 Harvest assessments

At harvest approximately 100 plants in total were harvested from each plot (time of harvest depending on curd maturity). Plants from the plots were harvested on three separate occasions (12th April 1999, 15th April 1999 and 20th April 1999) as the plants reached maturity. At each harvest date assessments were taken of disease levels on harvested heads. Harvest plants were taken from the four central rows in each plot (rows 9,10,11,12 see Figure 7). Each cauliflower head was trimmed for market before assessment. The trimmed heads were assessed for the severity of *Mycosphaerella* infection on the wrapper leaves by scoring the disease as described in section 3.2.2.1. The head weight of each individual plant harvested was taken before harvest.

3.4.2.3 Micro-climate measurements

Measurements of temperature, humidity leaf surface wetness and rainfall were collected at 30 min intervals from crop transplanting using a SKYE Datahog II 4 channel logger. Measurements were collected by GSM portable phone Link (Skye Instruments Ltd, Llandrindod Wells, Powys). Environmental data, was used with the cauliflower ringspot disease forecaster, to predict the rate of ringspot inoculum production in the crop.

3.5 Use of ringspot forecasts in commercial cauliflower crops in Cornwall in 1998/99

During the 1998/1999 cropping season a commercial crop of cauliflowers was used to provide start dates for ringspot sporulation production. A cropping area approximately 10 m x 10 m was marked out within a field of over-wintered cauliflowers (cv. Jerome). Leaves of five replicate cauliflower plants within the trial area were marked. The numbers of ringspot lesions occurring on approximately 4 tagged leaves per tagged plant was counted at approximately weekly intervals. Environmental data was collected as above (see section 3.2.2.3). Environmental data on humidity, temperature, leaf surface wetness duration and rainfall was used within the cauliflower ringspot forecaster to predict the occurrence of new ringspot infection within the crop. This was compared to the actual observation taken from leaves of tagged cauliflower plants.

3.6 Grower usage of dark leaf spot forecasts in Commercial Trials in 1999- 2000

3.6.1 Experimental Design (Replicated trials)

Trial sites (3 locations) were established in Lincolnshire in co-operation with Olga (Old Leeke, Boston, Lincs.), Tasco (T. A. Smith & Co, The Elms, Croft, Skegness, Lincs.), Huntapac (Coe House Farm, Marsh Rd, Hesketh Bank, Preston, Lancashire). The cultivars used in trials at each site are listed in Table 11. Natural infection by dark leaf and ringspot occurred at all sites within each trial area. Experimental plots were positioned within commercial fields of Brussels sprouts at randomly selected field positions in each treatment area (see Figure 4, p.27). Trials were conducted at all field sites in 1999 – 2000 as described in section 3.3.1. Chemicals used to control fungal infection on crops are as described in Table 10 (p 25).

3.6.2 Experimental Design (Non-replicated trials)

Additional weather information was obtained at sites supplied by Kettle Produce (Balmalcolm, Cupar, Fife), Farringtons (Anchorage arm, Guide Rd Hesketh Bank Preston, Lancs) with GMS/Technicrop (Ross-on-Wye, Herefordshire). Trials were conducted by the grower/consultant using the PC version of the Brassica$_{spot}$ system provided by HRI. In 1999 - 2000 this contained information on infection risk for *Alternaria brassicae* (dark leaf spot) and spray timing information for *Alternaria brassicae* and *Mycosphaerella brassicicola* (ringspot) and the risk of *Albugo candida* (white blister) infection. Trials were conducted at all field sites in 1999 – 2000 as described in section 3.3.2. Cultivars used in non replicated trials are listed in Table 12.

Table 11 **Site experimental design, cultivar and sprayer operation used in 1999 - 2000 (replicated sample sites)**

Site	Cultivar	Experimental Site Plan Type	Spray Operator Forecast Site
Frieston Shore	Adonis	A	Grower
Skegness	Helimus	A	Grower
Farndon	Adonis	A	Grower

Table 12 Observational sites used in 1999 - 2000 trials (non – replicated samples)

Site	Cultivar	Experimental Site Plan Type	Spray Operator
Hesketh Bank	Ariston	B	Grower
Arbroath	NA	B	Grower
Ross-on–Wye	NA	B	Grower

3.6.3 Micro-climate measurements

Measurements of temperature, humidity, leaf surface wetness and rainfall were collected at 30 min intervals from crop transplanting using a SKYE Datahog II 4 channel logger as described in section 3.1.2.3.

3.6.4 Disease assessments

Methods of disease assessment used in trials in 1999 – 2000 are as described for 1998 – 1999 trials (see sections 3.1.4.1, 3.1.4.2).

3.7 Development and validation of ringspot forecasts in cauliflower crops in 1999 - 2000

3.7.1 Inoculated Cauliflower Trials (Non-Commercial)

3.7.1.1 Experimental Design

In 1999/2000 trials a cropping area of approximately 10 m x 10 m was marked out within a field of over-wintered cauliflowers (cv. Jerome). The numbers of ringspot lesions occurring on approximately 4 tagged leaves of four indicator plants was counted at approximately monthly intervals. Assessment of ringspot lesions on plants are as described in section 3.2.2.1. Environmental data was collected as above (see section 3.1.2.3). Environmental data was used to generate ringspot forecasts for cauliflowers to predict the occurrence of new ringspot infection within the crop.

3.7.1.2 Harvest assessments

At harvest approximately 20 plants in total were harvested from the plot. Plants from the plots were harvested on one occasion () as the plants reached maturity. At each harvest date, assessments were taken of disease levels on harvested heads. Plants were harvested

randomly from the plot. Each cauliflower head was trimmed for market before assessment. The trimmed heads were assessed for the severity of *Mycosphaerella* infection on the wrapper leaves by scoring the disease as described in section 3.2.2.1.

4. RESULTS 1997

4.1 Grower usage of dark leaf spot forecasts in commercial crops

4.1.1 1997 Lincolnshire

4.1.1.1 Initial crop infection by dark leaf spot and other leaf spot pathogens

Disease pressure at all test sites in Lincolnshire was high with early ringspot development observed in many areas. The very wet conditions observed during June 1997 was conducive to rapid disease development by all foliar pathogens which occur on Brussels sprouts (Figure 8ab, 9ab). Infection by a number of foliar pathogens of Brussels sprouts occurred at all sites (Table 13). Consequently, regular applications of fungicides were used, at all sites, to control disease. High levels of ringspot were observed at the Butterwick site were initial infection occurred during early June. Dark leaf spot was also observed at the Butterwick site during the third week of June 1997. At the Holbeach, Donington and Frampton sites dark leaf spot was first observed in the crop at the end of June 1997. Ringspot occurred at all test sites in 1997.

4.1.1.2 Predicted dark leaf spot disease development

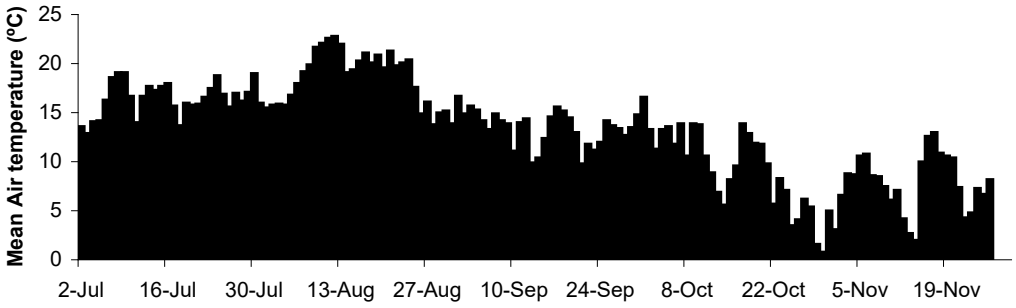
Spray timing predictions differed between sites in Lincolnshire and were for dark leaf spot alone.

Butterwick

Dark leaf spot was first observed at the Butterwick site on the 23 June 1997 at which time predictions of dark leaf spot development commenced. Predicted dark leaf spot development was rapid and the initial disease threshold was reached on the 10 August 1997 (Figure 10). A spray of Folicur (0.75 litres ha^{-1}) was applied to the growers area on the 5 August 1997. Folicur (0.5 litres ha^{-1}) was applied on the 9 August 1997 to the forecast plot using a Knapsack sprayer (Table 14). Folicur has eradicant activity against *Mycosphaerella brassicicola* (ringspot) which was the main disease present at the site. Other diseases present (*Albugo candida*) were not treated.

Figure 8 Air temperature (a) and rainfall (b) at Frampton in 1997

a)



b)

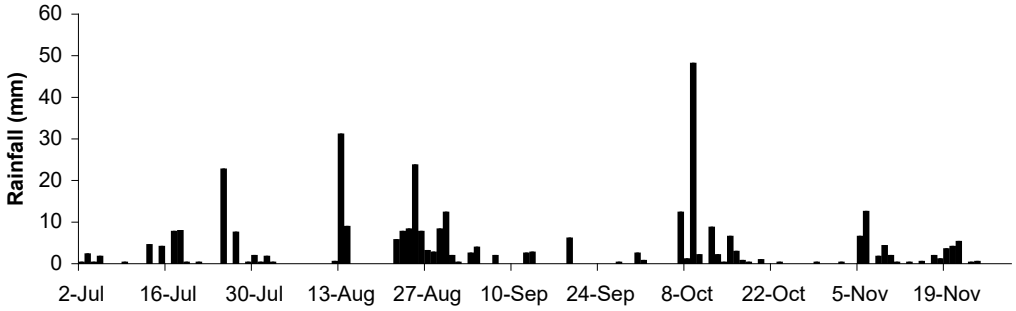
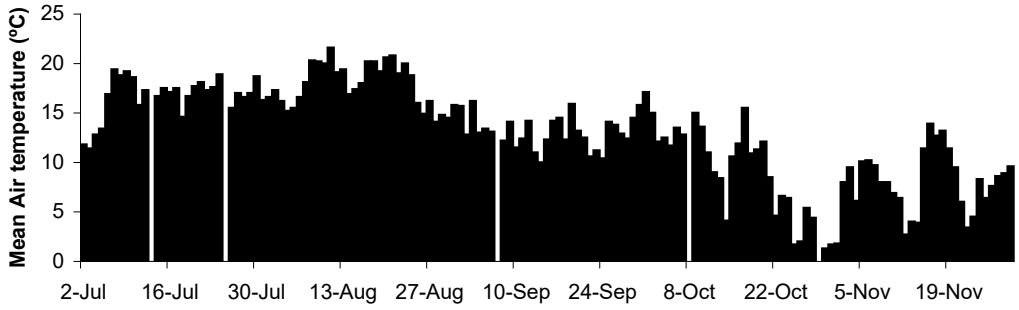


Figure 9 Air temperature (a) and rainfall (b) at Ross-on-Wye in 1997

a)



b)

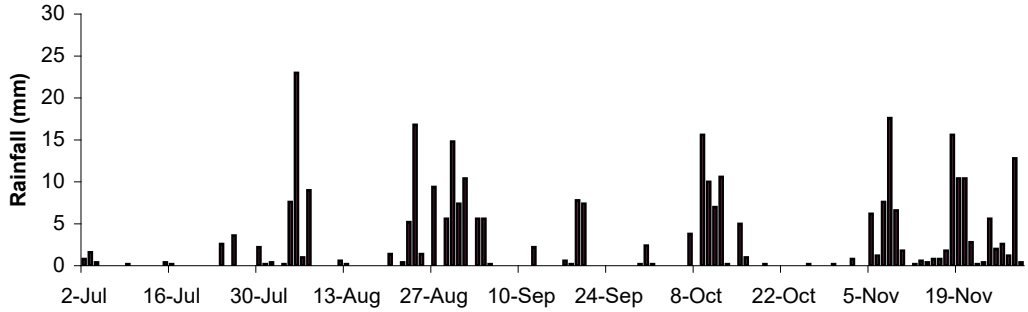


Table 13 **Initial infection by foliar pathogens on Brussel sprouts at each test site**

Site	Planting Date	Albugo (white blister)	Alternaria (dark leaf spot)	Mycosphaerella (Ringspot)
Lincolnshire				
Frampton	23/4	12/6	16/6 23/6	12/6
Holbeach	23/4	19/6	23/6	10/7
Donington	28/4	14/7	26/6	21/7
Butterwick	24/4	16/6	23/6	16/6
Other Areas				
Ross-on-Wye	NA	15/7	22/7	22/7
Scotland	NA	NI	18/8	17/7

NA – Not Available
NI -- Not Infected

Figure 10 Predicted dark leaf spot development at Butterwick 1997

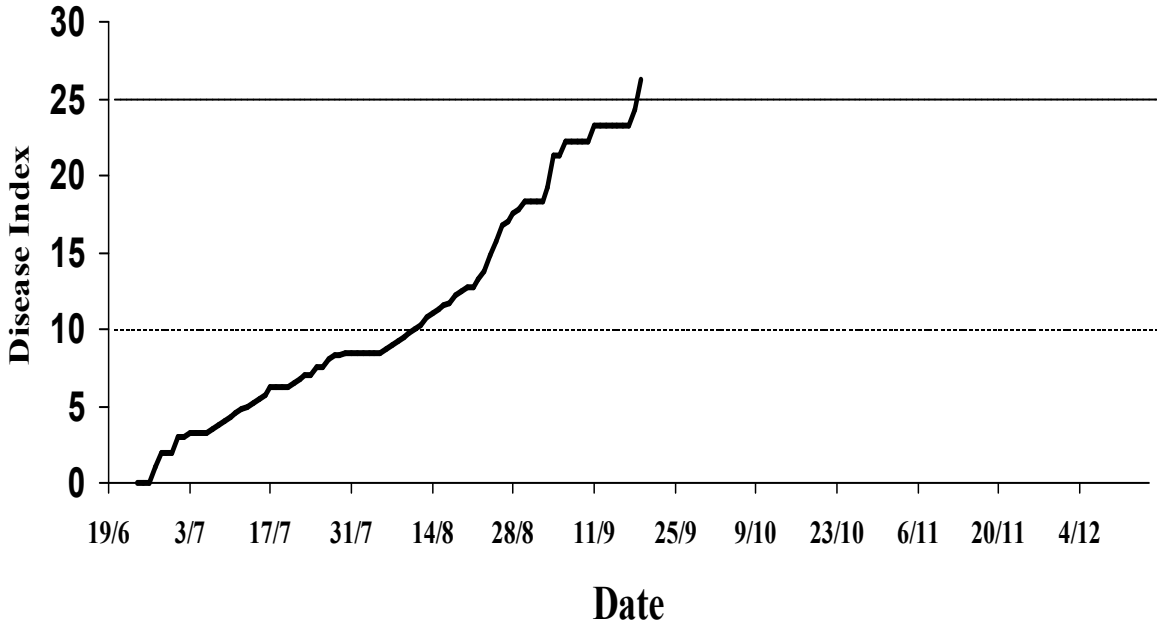


Figure 11 Predicted dark leaf spot development at Donington 1997

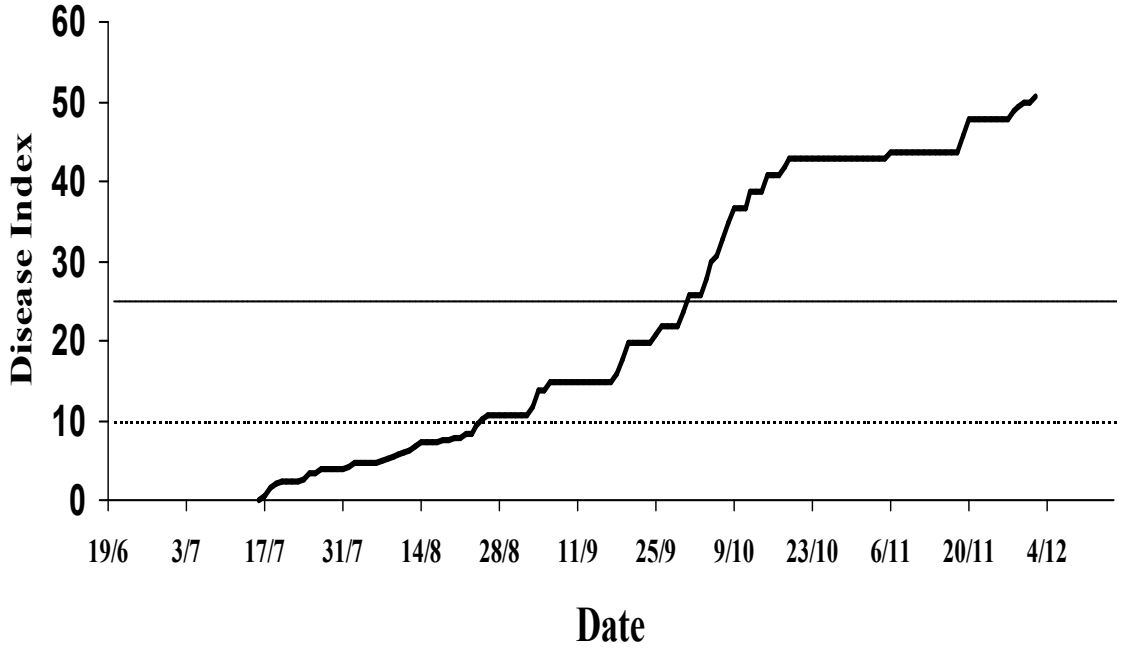


Table 14 Fungicide Treatments at field sites 1997 – Butterwick

Growers Practice	05.08 - Folicur	(0.75 litres ha $^{-1}$)
Dark leaf spot Forecasting system	07.08 - Folicur	(0.5 litres ha $^{-1}$)

Donington

Dark leaf spot was observed at the Donington site on the 15 July 1997 (Figure11). The initial disease threshold (10) was reached on the 24 August 1997. Rovral at 510 g ha^{-1} (forecast plot) and Folicur/ Bravo at 0.5 litres ha^{-1} and 1.5 kg ha^{-1} respectively (growers area) were applied on the 21 August 1997 (Table 15). A further spray application of Folicur (0.5 litres ha^{-1}) was applied to both the growers area and the forecast area on the 10 September 1997. The secondary dark leaf spot forecast criteria (25) was reached on the 29 September 1997 when an additional application of Folicur (0.75 litres ha^{-1}) was applied to both the forecast plot and the growers area. Further forecast disease criteria (dark leaf sporulation) was predicted on the 20 October 1997 at which time Folicur (0.5 litres ha^{-1}) was applied to the forecast plot. Both Folicur and Bravo at 0.5 litres and 1.5 kg ha^{-1} respectively was applied to the growers area on the 25 October 1997 (Table 15).

Frampton

At the Frampton site the growers area was treated with Bravo at 1500 g ha^{-1} on the 8 July 1997 however Bravo at an identical rate was applied to the Forecast plot on the 21 July 1997. Dark leaf spot was observed at the Frampton site on the 15 July 1997 and predictions of dark leaf spot development were then commenced (Figure 12). The initial disease threshold (10) was reached on the 24 August 1997. The initial spray against dark leaf spot of Folicur was applied on the 2 September 1997. A further spray application of Folicur was applied to the growers area on the 10 and 29 September 1997 (Table 16). The second dark leaf spot forecast criteria (25) was passed on the 29 September 1997 however the application of Folicur to the forecast plot was delayed until the 14 October 1997. Further treatments with Folicur Bayfidan and Bravo were applied to the growers area on the 18 October, 28 October and 13 November 1997 respectively. No further fungicide treatments were made to the forecast plot after the 14 October 1997 (Table 16)

Figure 12 Predicted dark leaf spot development at Frampton in 1997

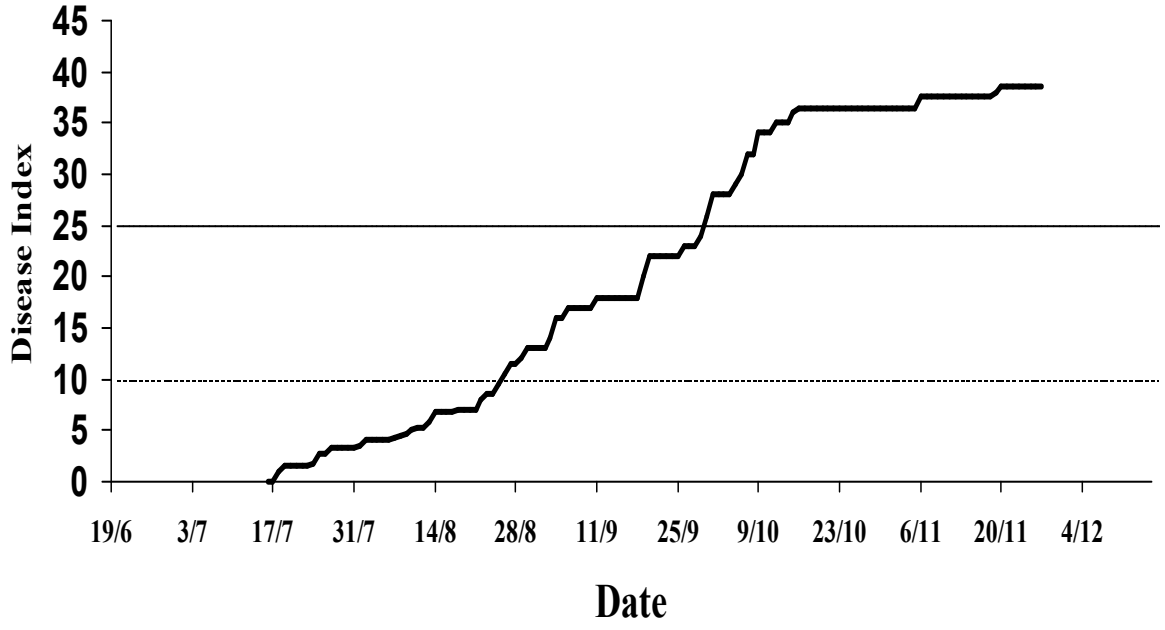


Figure 13 Predicted dark leaf spot development at Holbeach in 1997

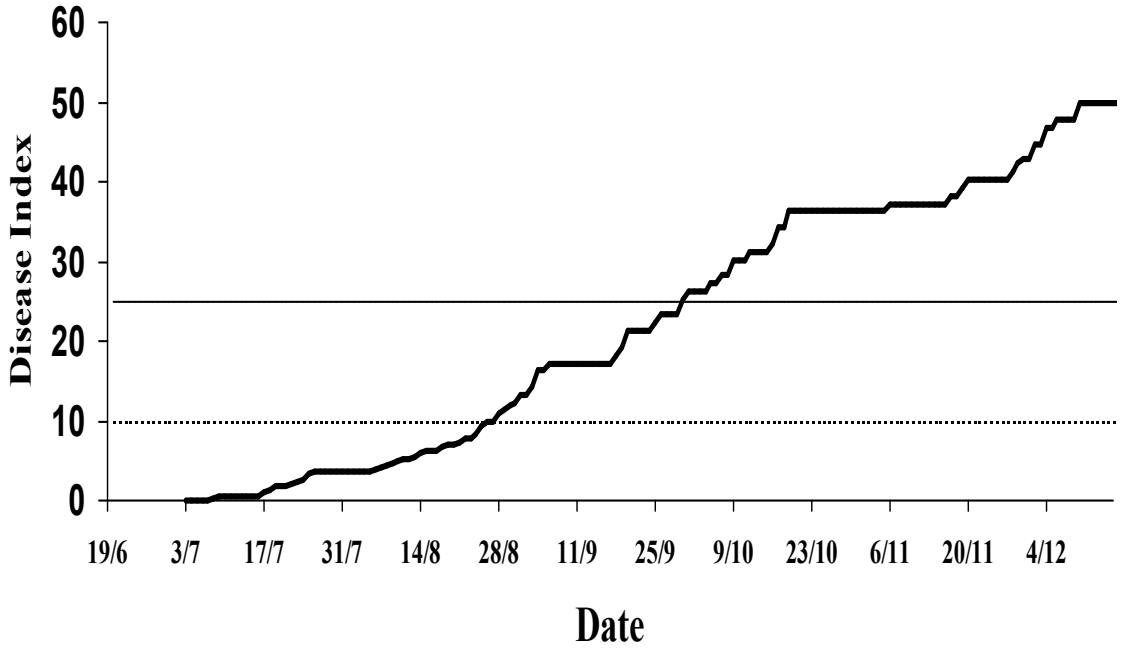


Table 15 Fungicide Treatments at field sites 1997 - Donington

Growers Practice	21.08 – Bravo & Folicur 10.09 - Folicur 04.10 - Folicur 25.10 - Folicur & Bravo
Dark leaf spot Forecasting system	21.08 - Rovral * 10.09 - Folicur 04.10 - Folicur 20.10 - Folicur

* Spray applied to forecast area not requested

Table 16 Fungicide Treatments at field sites 1997 - Frampton

Growers Practice	08.07 - Bravo 10.09 - Folicur 29.09 - Folicur 18.10 - Folicur 28.10 - Bayfidan 13.11 - Bravo
Dark leaf spot Forecasting system	21.07 - Bravo * 02.09 - Folicur 14.10 - Folicur

* Spray applied to forecast area not requested

Holbeach

Dark leaf spot was observed at the Holbeach site on the 23 June 1997 (Table 13). The initial disease threshold was reached on the 25 August 1997 (Figure 13). The growers area was treated with Rovral Flo at 2.0 litres ha^{-1} on the 29 July 1997 however Folicur at 0.75 litres ha^{-1} was applied to the forecast plot on the 7 August 1997. The initial forecast spray against dark leaf spot (Bravo at 3 litres ha^{-1}) was applied to both the forecast plot and the growers area on the 26 August 1997. A further application of Folicur (0.5 litres ha^{-1}) was sprayed on the growers area on the 12 September 1997. The secondary dark leaf spot forecast spray criteria (25) was reached on the 28 September 1997 however the application of Folicur (0.5 litres ha^{-1}) to the forecast plot and the growers area was delayed until the 13 October 1997. No further fungicides were applied to the plots after this date (Table 17).

4.1.1.3 Observed dark leaf spot on buttons at harvest

Butterwick

Buttons were harvested at the Butterwick site on the 16 September 1997 (growers area) and the 19 September 1997 (forecast plot). The incidence and severity of dark leaf spot on buttons harvested in the forecast plot and in the growers area at the Butterwick site is shown in Figures 14 and 15 respectively. There were higher numbers of uninfected buttons harvested at the Butterwick site in the growers area from the middle and top of the plant (Figure 14). There was no difference in the percentage of clean buttons harvested from the bottom of the plant between the forecast plot and the growers plots. There was slightly higher total numbers of lesions on infected buttons harvested from the forecast plot in comparison to the growers area. The largest number of lesions per button were found on the buttons harvested from the bottom of the plant (Figure 15). The numbers of buttons affected by ringspot could not be estimated.

Donington

Buttons were harvested from both the growers area and the forecast plot at Donington on the 2 December 1997. There was no difference between the percentage of uninfected buttons harvested from the top middle and bottom of the plant in the forecast plot and growers area at Donington (Figure16). There were no differences between the dark leaf spot severity score on infected buttons between the forecast and growers areas (Figure 17). Infected buttons had on average only one dark leaf spot lesion. The number of buttons affected by ringspot could not be estimated.

Table 17 Fungicide Treatments at field sites 1997 - Holbeach

Growers Practice	29.07 – Rovral	(2.0 litres ha^{-1})
	26.08 - Bravo	(3.0 litres ha^{-1})
	12.09 - Folicur	(1.0 litres ha^{-1})
	12.09 - Folicur	(0.5 litres ha^{-1})
Dark leaf spot Forecasting system	07.08 - Folicur	(0.75 litres ha^{-1})
	26.08 - Bravo	(3.0 litres ha^{-1}) *
	13.10 - Folicur	(0.5 litres ha^{-1})

* Spray Applied to forecast area not requested

Figure 14 Percentage uninfected buttons harvested from the Growers (□) and Forecast area (▨) at Butterwick 1997

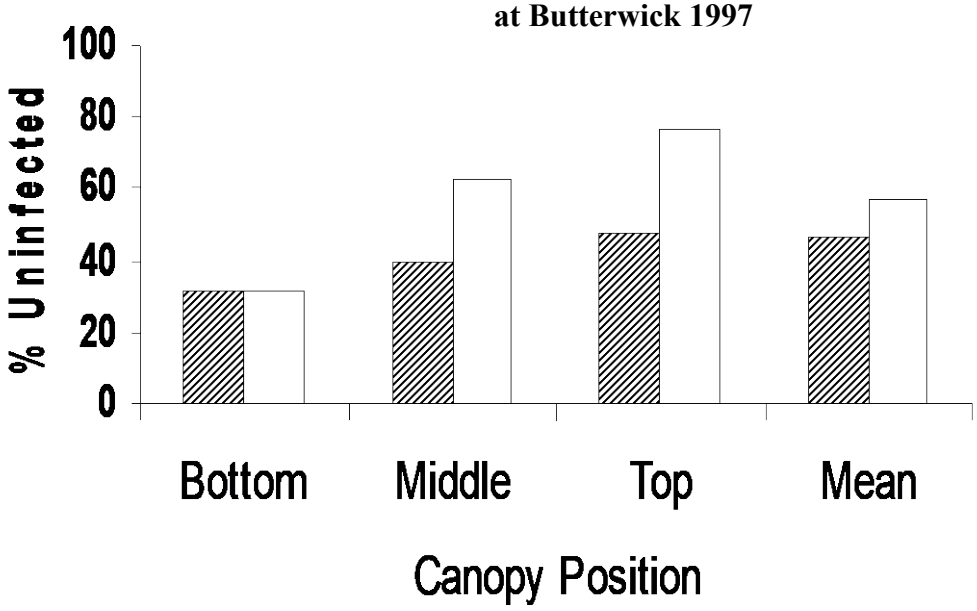


Figure 15 Mean dark spot lesion number on infected buttons from the Growers (□) and Forecast area (▨) at Butterwick 1997

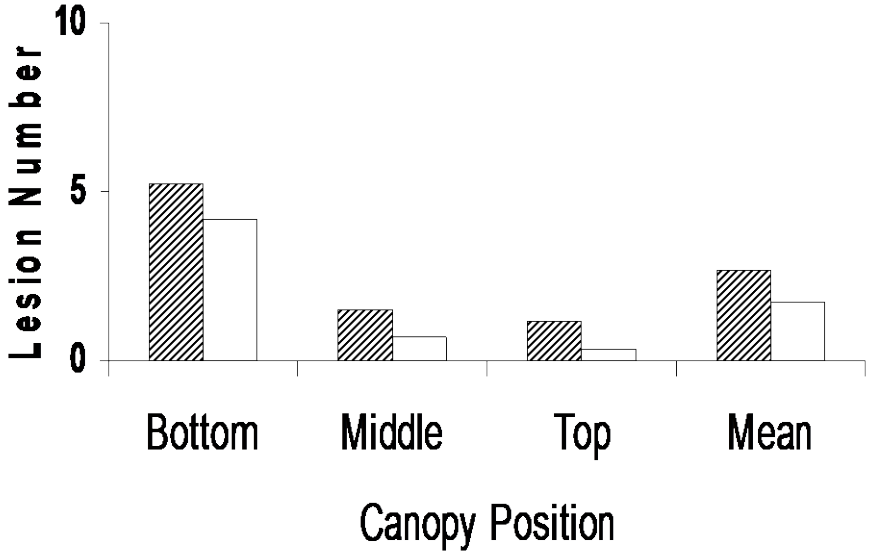


Figure 16 Percentage uninfected buttons harvested from the Growers (□) and Forecast area (▨) at Donington 1997

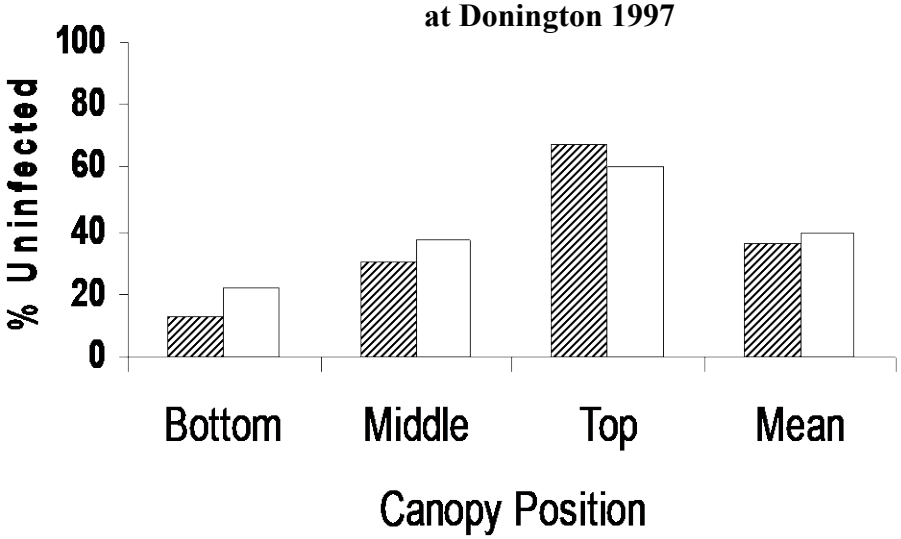
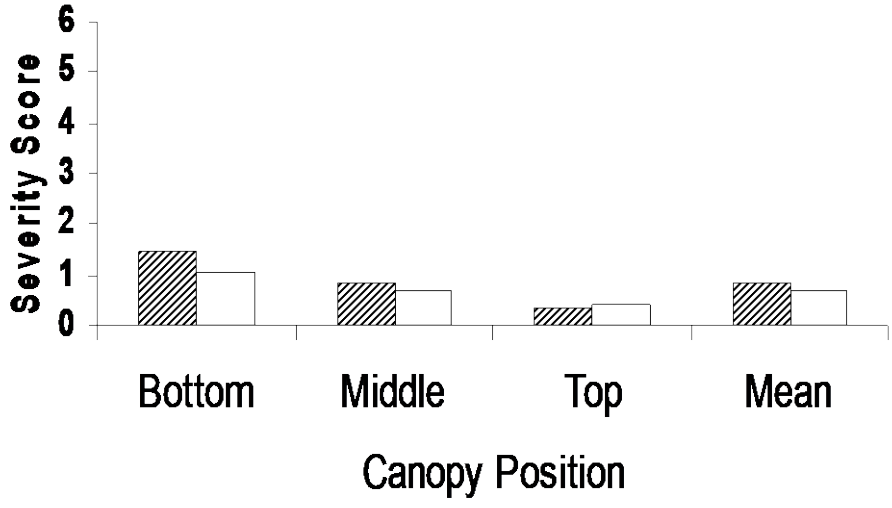


Figure 17 Mean dark spot lesion number on infected buttons from the Growers (□) and Forecast area (▨) at Donington 1997



Holbeach

Buttons were harvested from both the growers area and the forecast plot at Holbeach on the 22 December 1997. There was a higher percentage of uninfected buttons harvested from the bottom and middle of the plant in the growers area in comparison to the forecast plot (Figure18). However the average difference between the two areas on all buttons was approximately 10 %. There were few differences between the dark leaf spot severity scores on infected buttons between the forecast and growers areas (Figure 19). Infected buttons had very few dark leaf spot lesions with a severity score of less than one on buttons from all parts of the plant. This was equivalent to an average of under one lesion per button. No estimation of the number of buttons affected by ringspot could be made.

Frampton

Buttons were harvested from both the growers area and the forecast plot at Frampton on the 26 November 1997. There were significantly higher percentages of uninfected buttons harvested from the bottom and middle and top of of the plant in the growers area in comparison to the forecast area (Figure 20). The average difference between the two areas on all buttons was 40 %. Parts of the forecast plot at Frampton were badly affected by clubroot. Buttons harvested from the forecast area had significantly higher dark leaf spot severity scores in comparison to those from the growers areas (Figure 21). The mean severity score (all buttons) was approximately 1 – 2 in the forecast area in comparison to under one in the growers area. The numbers of buttons affected by ringspot could not be estimated.

4.1.2 1997 Other test sites

4.1.2.1 Initial crop infection by dark leaf spot and other leaf spot pathogens

Disease pressure at other test sites in Scotland and Ross-on-Wye was high with dark leaf spot present at both test sites. Infection by a number of foliar pathogens of Brussels sprouts occurred at both sites (Table 13, p 38). Significant infection by ringspot and white blister was observed at Ross-on-Wye during the middle of July 1997. Dark leaf spot was also observed at the site in St Andrews, Scotland during the second week of August 1997. No *Albugo candida* (white blister) was observed at St. Andrews, however ringspot was present. Dark leaf spot was first observed at the Ross-on-Wye site during mid July.

Figure 18 Percentage uninfected buttons harvested from the Growers (□) and Forecast area (▨) at Holbeach 1997

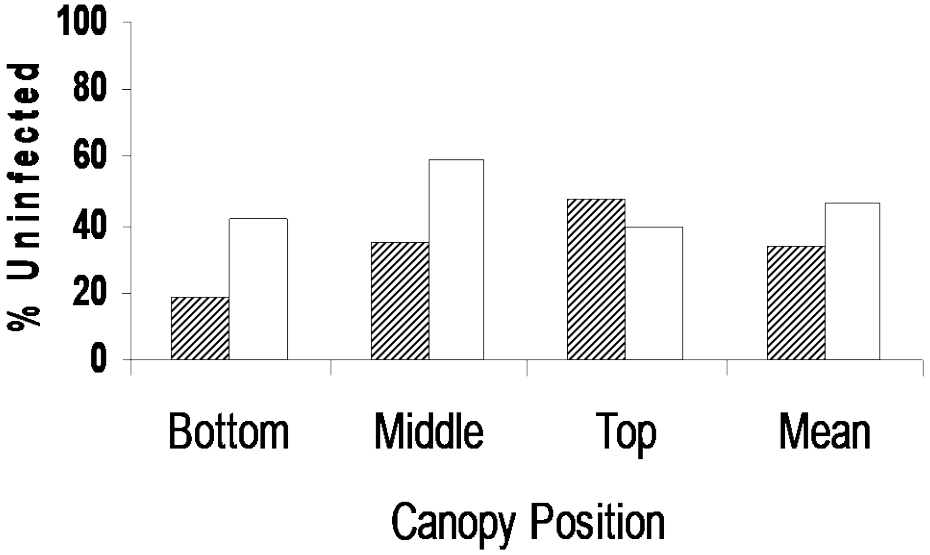


Figure 19 Mean dark spot lesion number on infected buttons from the Growers (□) and Forecast area (▨) at Holbeach 1997

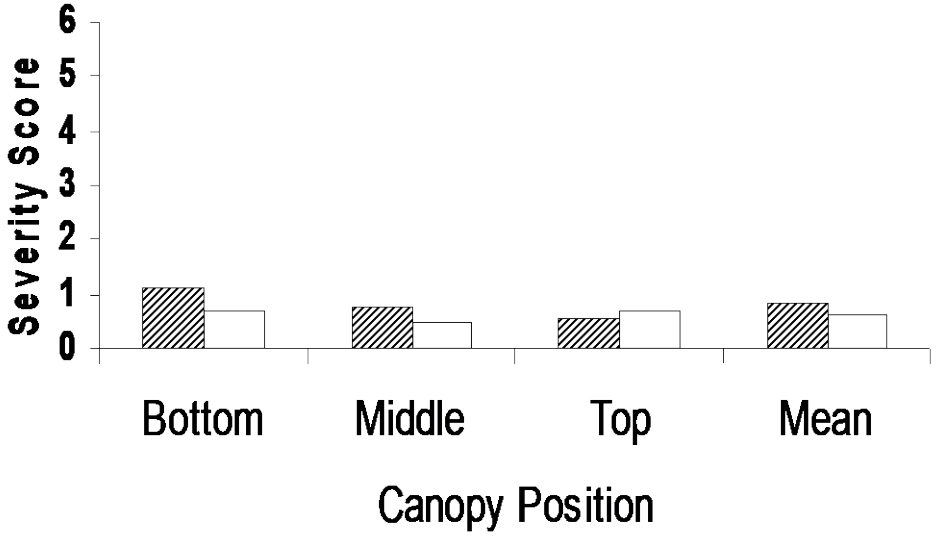


Figure 20 Percentage uninfected buttons harvested from the Growers (□) and Forecast area (▨) at Frampton 1997

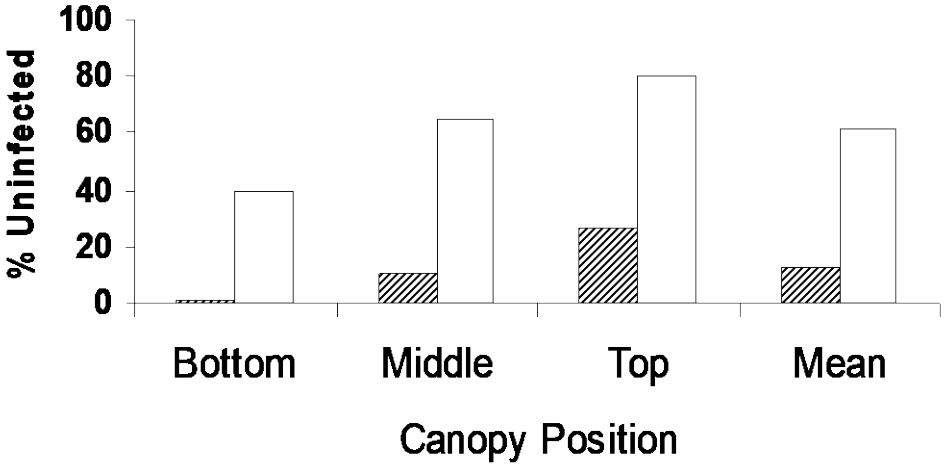
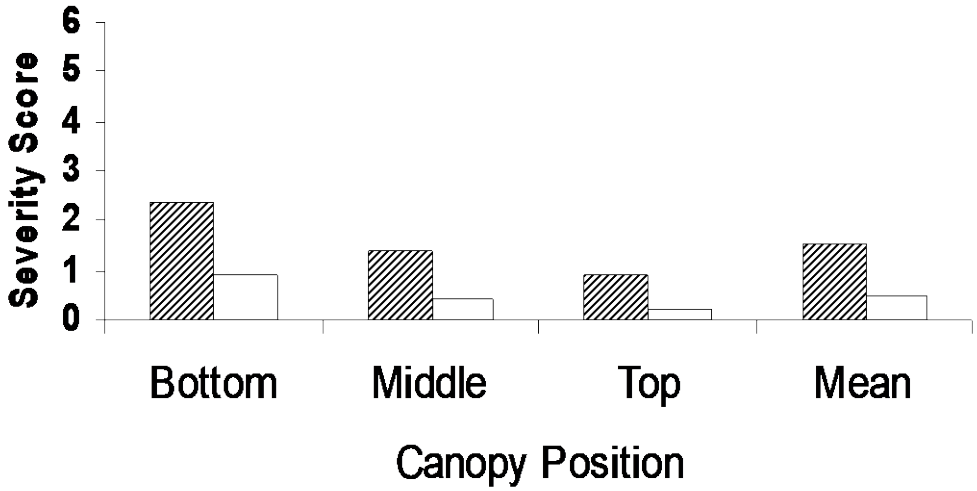


Figure 21 Mean dark spot lesion number on infected buttons from the Growers (□) and Forecast area (▨) at Frampton 1997



4.1.2.2 Predicted dark leaf spot disease development

Ross-on-Wye

Predictions of dark leaf spot in the crop commenced when dark leaf spot was observed on the 22 July 1997. The trial site comprised of one entire field divided equally into two areas (Figure 1c, p 13). An application of Folicur (0.5 litres ha^{-1}) and Bravo (0.75 litres ha^{-1}) was applied to the grower's area on the 25 July 1997 (Table 18). Dark leaf spot development was rapid during late August and the initial disease threshold was reached on the 1 September 1997 (Figure 22) at which time a spray of Folicur (0.3 litres ha^{-1}) was applied to both the growers and the forecast area of the site (4 September 1997). A further spray of Bravo (0.75 litres ha^{-1}) was applied to the grower's area on the 17 September 1997 (Table 18). The second disease theshold (25) was reach on approximately 7 October 1997 (Figure 22). A further spray of Folicur (0.5 litres ha^{-1}) and Bravo (1.0 litres ha^{-1}) was applied to the grower's area on 13 October 1997 however Folicur only (at the same rate) was applied to the forecast area on the same date. No further applications of fungicide were used after the 13 October 1997.

St Andrews, Scotland

An application of Bravo (1.5 litres ha^{-1}) was applied to the grower's area on the 5 August 1997 (Table 19). Dark leaf spot was observed on the 18 August 1997 (Table 13). The trial site comprised of one area (see Figure 1b, p 13). A further spray of Folicur (0.75 litres. ha^{-1}) and Fubol 58 (1.50 kg ha^{-1}) was applied to the grower's area on the 28 August 1997. The initial disease threshold (10) was reach on approximately 28 September 1997 (Figure 23). A spray of Folicur (0.75 litres ha^{-1}) was applied to the both the grower's area and the forecast plot on the 30 September 1997. No further applications of fungicide were made at the site until harvest.

4.1.2.2.1 Observed dark leaf spot on buttons at harvest

Ross-on-Wye

Buttons were harvested from both the growers area and the forecast plot at Ross-on-Wye on the 15 December 1997. Approximately 80 and 60 percent of buttons harvested, regardless of stem position were uninfected by dark leaf spot in the growers area and forecast area

Figure 22 Predicted dark leaf spot development at Ross-on-Wye in 1997

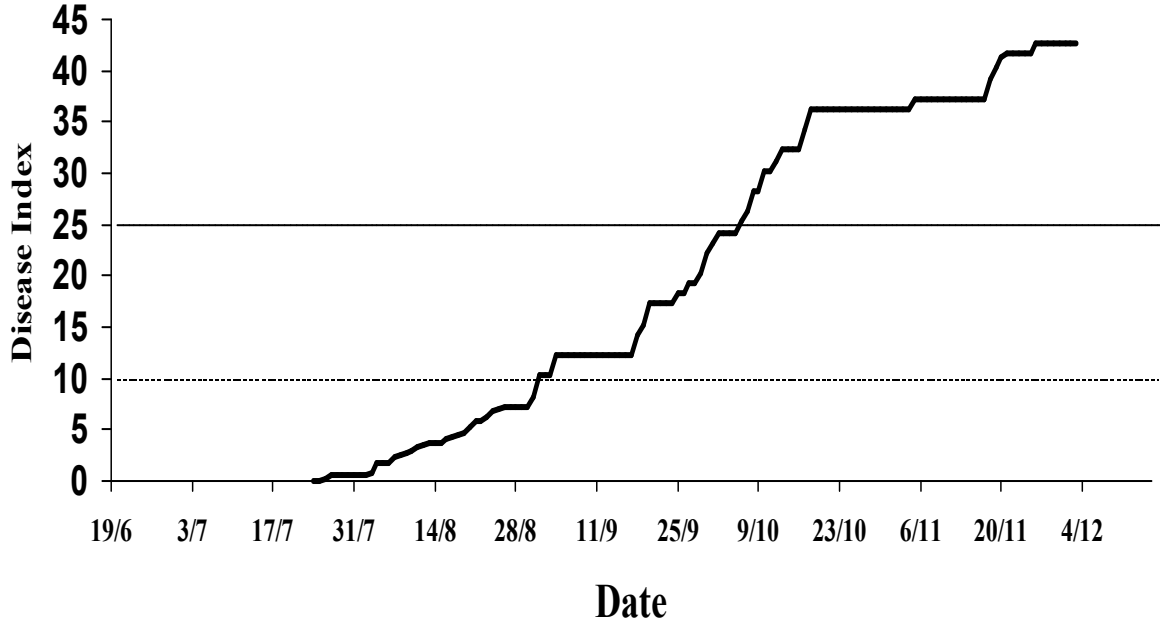


Figure 23 Predicted dark leaf spot development at St Andrews in 1997

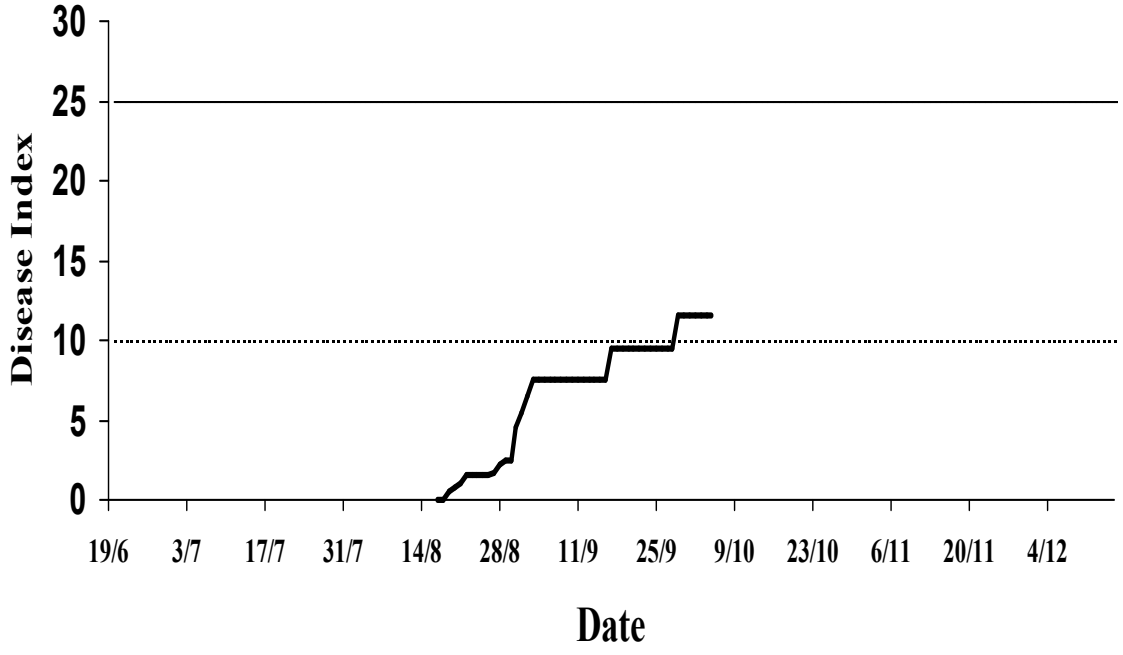


Table 18 Fungicide Treatments at field sites 1997 – Ross-on-Wye

Growers Practice	25.07 - Folicur & Bravo	(0.5/0.75 litres ha $^{-1}$)
	04.09 - Folicur	(0.3 litres ha^{-1})
	17.09 – Bravo	(0.75 litres ha $^{-1}$)
	13.10 - Folicur & Bravo	(0.5/1.0 litres ha $^{-1}$)
Dark leaf spot Forecasting system	04.09 - Folicur	(0.3 litres ha^{-1})
	13.10 - Folicur	(0.5 litres ha^{-1})

Table 19 Fungicide Treatments at field sites 1997 – St Andrews

Growers Practice	05.08 - Bravo	(1.5 litres ha $^{-1}$)
	28.08 - Folicur & Fubol 58	(0.75 / 1.5 litres/ kg ha $^{-1}$)
	30.9 - Folicur	(0.75 litres ha $^{-1}$)
Dark leaf spot Forecasting system	30.09 - Folicur	(0.75 litres ha $^{-1}$)

respectively (Figure 24). There was no significant difference between severity scores in the growers area and the forecast area (Figure 25). Numbers of dark leaf spot lesions per infected buttons from both areas was very low. Infected buttons taken from both areas had on average less than one dark leaf spot lesion per button.

St Andrews

Buttons were harvested from both the growers area and the forecast plot on the 9 December 1997. There was a higher percentage of uninfected buttons harvested from the forecast area in comparison to the growers area (Figure 26). There was higher dark leaf spot severity scores on infected buttons harvested from the growers area in comparison to the forecast area (Figure 27) but the differences in disease severity at all stem heights was small. Numbers of dark leaf spot lesions on infected buttons was observed as 1.5 in the forecast plot and growers area respectively.

4.2 Ringspot forecast usage in replicated trials in commercial crops

4.2.1 Development and validation of ringspot forecasts in cauliflower crops

4.2.1.1 Predicted ringspot development

Ringspot was first observed within the plots on the 9 September 1997. Infection was uniform throughout all plots although dark leaf spot was also present. The early development of ringspot was confirmed by isolating the ringspot pathogen from the infected leaves (as described in Section 3.1.4). Predicted ringspot inoculum production from lesions is shown in Figure 28. Inoculum production from lesions was first predicted on the 8 October 1997 (5 % of lesions producing inoculum). However the secondary spray criteria (50 % of lesions producing inoculum) was predicted to occur on the 12 October 1998.

4.2.1.2 Observed ringspot development on leaves

There were approximately 6 to 25 lesions per leaf (severity score 2) on all treatments when assessments began on the 23 September (Table 20). Folicur (0.5 litres ha^{-1}) was applied to routinely sprayed plots commencing from this time (Table 21) and re-applications were made at approximately 3 week intervals (at the same rate). At the second assessment time (10 October 1998) severity scores of under 2 and approximately 2.5 were recorded in routinely sprayed and in all other plots respectively. A spray of Folicur (0.5 litres ha^{-1}) was applied to the forecast plots (5% threshold) and routinely sprayed plots on the 13 October 1997.

Figure 24 Percentage uninfected buttons harvested from the Growers (□) and Forecast area (▨) at Ross-on-Wye 1997

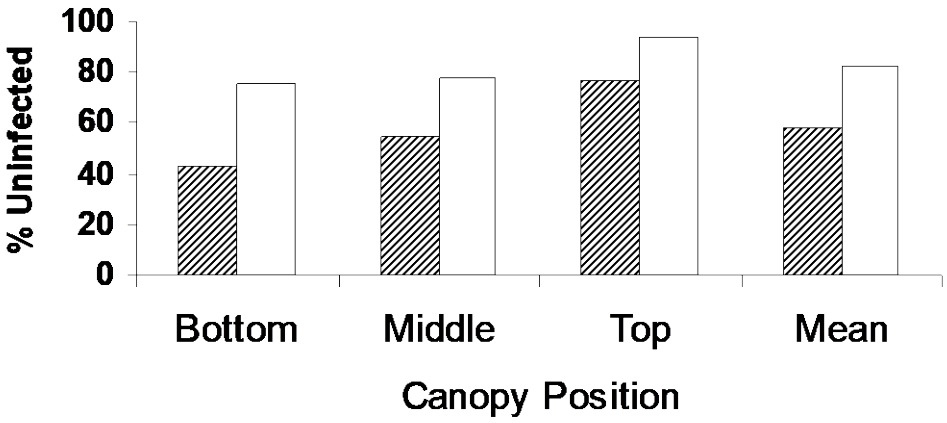


Figure 25 Mean dark spot lesion number on infected buttons from the Growers (□) and Forecast area (▨) at Ross-on-Wye 1997

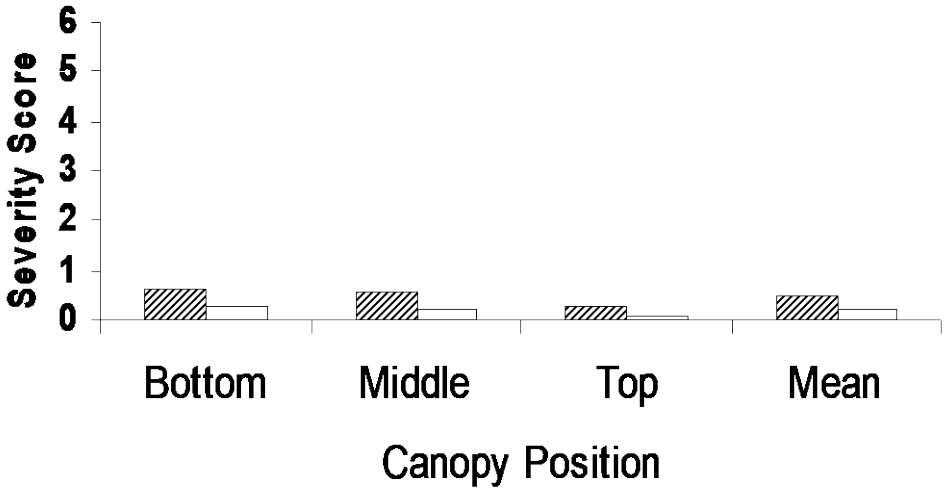


Figure 26 Percentage uninfected buttons harvested from the Growers (□) and Forecast area (▨) at St Andrews 1997

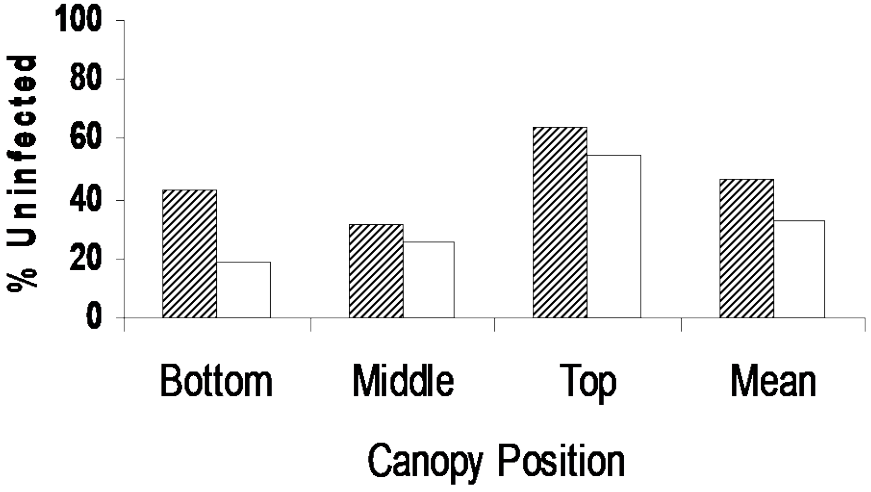


Figure 27 Mean dark spot lesion number on infected buttons from the Growers (□) and Forecast area (▨) at St Andrews 1997

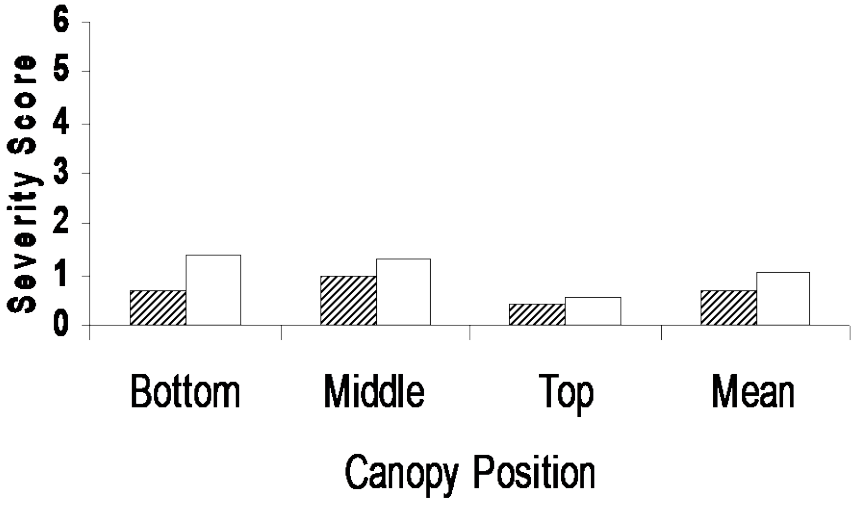
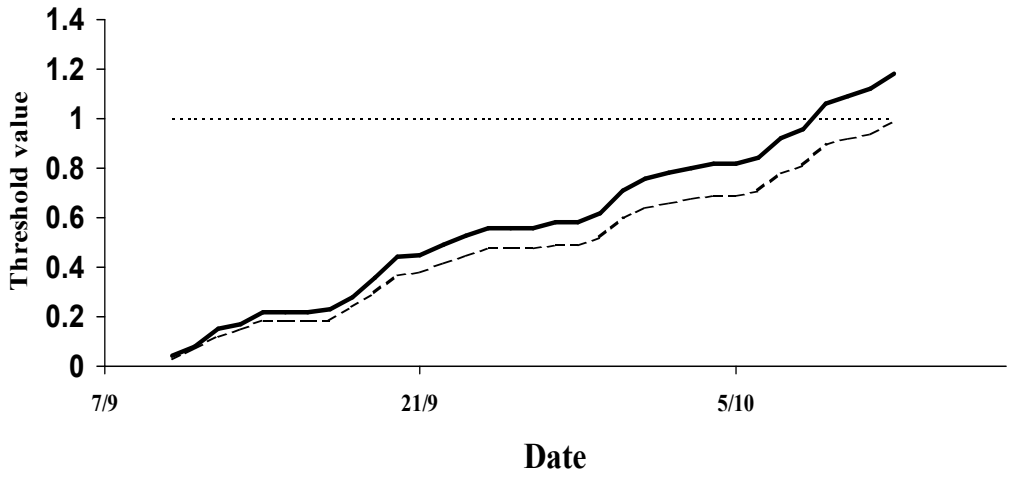


Figure 28 Predicted ringspot development at 5 % threshold ( ) and 50 % threshold (----) at HRI Wellesbourne on cauliflowers



1997. Folicur (1.0 litre ha^{-1}) was applied on the 14 October 1997 to forecast plots treated at the secondary forecast criteria (50 % of lesions producing inoculum). Ringspot severity scores of approximately 2.5 were observed on unsprayed plots on the 20 October 1997 (Table 20). However lower severity scores of approximately 1.8 and 2.0 respectively were recorded on forecast plots (5 % spray threshold) and routinely sprayed sprayed plots respectively. Severity scores of approximately 2.2 were recorded in other forecast treatments (50 % spray threshold). A final spray of Folicur was applied to routinely sprayed plots on the 6 November 1997 (Table 21). At final assessment (20 November 1998) unsprayed plots had a mean ringspot severity score of 1.5. Both forecast treatments and the routine treatment had severity scores of approximately 1 (representing 1 – 5 lesions per leaf) and less than 1 (under one lesion per leaf) respectively.

Table 20 Observed ringspot development on cauliflower leaves at HRI Wellesbourne in 1977

Treatment	Date			
	Severity Score			
	23/9	10/10	20/10	19/11
5 % Threshold	2.25	2.53	1.89	1.12
50 % Threshold	1.84	2.61	2.21	1.11
Routine	2.16	1.82	2.07	0.82
Unsprayed	2.32	2.44	2.42	1.53

Inoculation Date 28/8/98

Table 21 Spray application dates on cauliflower at HRI Wellesbourne in 1997

Treatment	Date			
	Dosage (Folicur litres ha^{-1})			
	21/9	13/10	14/10	06/11
5 % Threshold	-	0.5	-	-
50 % Threshold	-	-	1.0	-
Routine	0.5	0.5	-	0.5
Unsprayed	-	-	-	-

Inoculation Date 28/8/98

4.2.2 Harvest assessments

Cauliflowers were harvested from each replicate plot on the 3 December 1997. The numbers of ringspot lesions on wrapper leaves was generally low however the unsprayed treatment had an average severity score 0.93 (approximately 1 – 5 lesions leaf $^{-1}$) on wrapper leaves around the cauliflower curd (Table 22). Both forecast treatments and the routine treatment had a severity score of approximately half this value. The forecast treatment, which was sprayed at the 5 % spray threshold, had the lowest mean severity score (approximately 0.5). The highest mean head weights were harvested from plots, which had been routinely sprayed with an average weight of approximately 847 g per head (Table 14). However unsprayed plots had a mean harvested head weight of approximately 817 g. Mean head weight harvested from the 5 % and 50 % forecast thresholds were approximately 783g and 796 g respectively. It is unlikely that head weights in each treatment were significantly different from each other.

Table 22 Mean ringspot lesion number and weight of curds harvested from cauliflowers at HRI Wellesbourne in 1997

Treatment	Mean ringspot severity score	Mean curd weight (g)
5 % Threshold	0.53	783
50 % Threshold	0.69	796
Routine	0.60	848
Unsprayed	0.93	816

5. RESULTS 1998

5.1 Grower usage of dark leaf spot and ringspot forecasts in commercial crops

5.1.1 1998 Lincolnshire

5.1.1.1 Initial crop infection by ringspot, dark leaf spot and other leaf spot pathogens

Disease pressure at all test sites in Lincolnshire was moderate and early ringspot development was observed at all sites. Wet conditions recorded during August 1998 was conducive to rapid disease development by all foliar pathogens which occur on Brussels sprouts (Figure 29a, b, c, d). Infection by *Mycosphaerella brassicicola* (ringspot), *Alternaria brassicae* (dark leaf spot) and *Albugo candida* (white blister) occurred at all sites (Table 23). In Lincolnshire both ringspot and dark leaf spot were first observed during early July 1998. Infection by white blister may have occurred at the same time however the disease was not visible until later due to differences in the latency of white blister compared to other diseases. White blister was not observed at the Butterwick site until the third week of August 1998.

5.1.1.2 Predicted ringspot and dark leaf spot disease development

Butterwick

Ringspot and dark leaf spot were first observed at the Butterwick site on the 7 and 20 July 1998 respectively at which time predictions of disease development commenced. Predicted dark leaf spot development was initially slow. However ringspot disease development was rapid and an initial ringspot spray threshold was reached on the 7 August 1998. It was not possible to obtain fungicide spray records applied to the crop. Further ringspot development was observed in the crop on the 21 August 1998. The initial dark leaf spot disease threshold was reached on the 9 September 1998 which coincided with a secondary ringspot spray threshold (Figure 30). The secondary dark leaf spot spray threshold was reached on the 5 October 1998 at Butterwick. Few other air-borne fungal pathogens were present at this trial site. White blister (*Albugo candida*) was first observed in the crop on the 24 August 1998 (Table 23).

Table 23 Initial infection by foliar pathogens on Brussel sprouts at observation test sites in 1998

Site	Planting Date	*Albugo* (White blister)	*Alternaria* (Dark leaf spot)	*Mycosphaerella* (Ringspot)
Lincolnshire				
Holbeach	NA	16/7	10/7	10/7
Donington	NA	16/7	14/7	11/7
Butterwick	NA	24/8	20/7	7/7
Other Areas				
Ross-on-Wye	NA	14/7	14/7	14/7
St Andrews	NA	NI	31/7	31/7

NA – Not Available
NI -- Not Infected

Figure 29 Air temperature (a) and rainfall (b) at Frieston shore 1998 and (c) air temperature (d) rainfall at Hesketh Bank in 1998

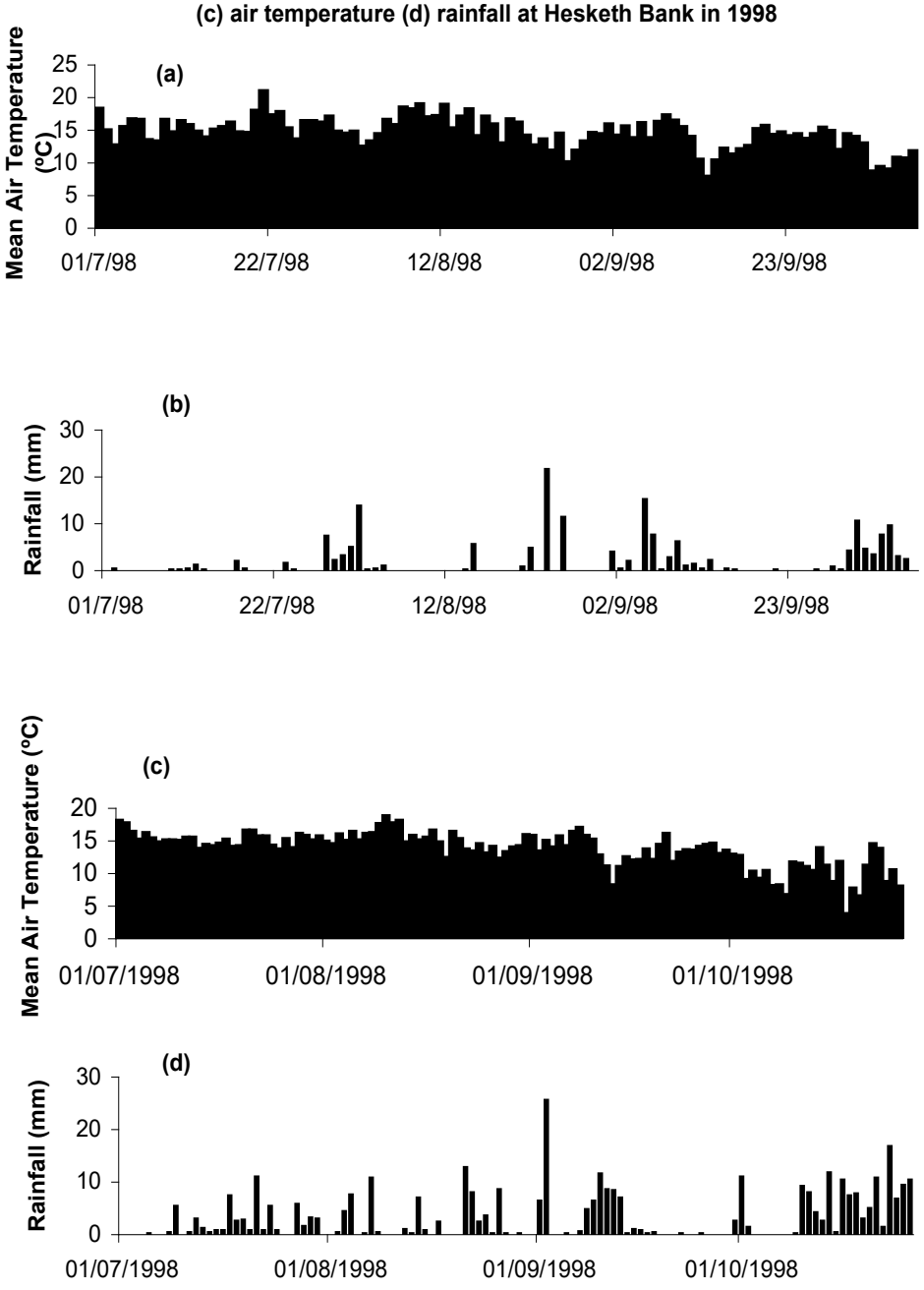
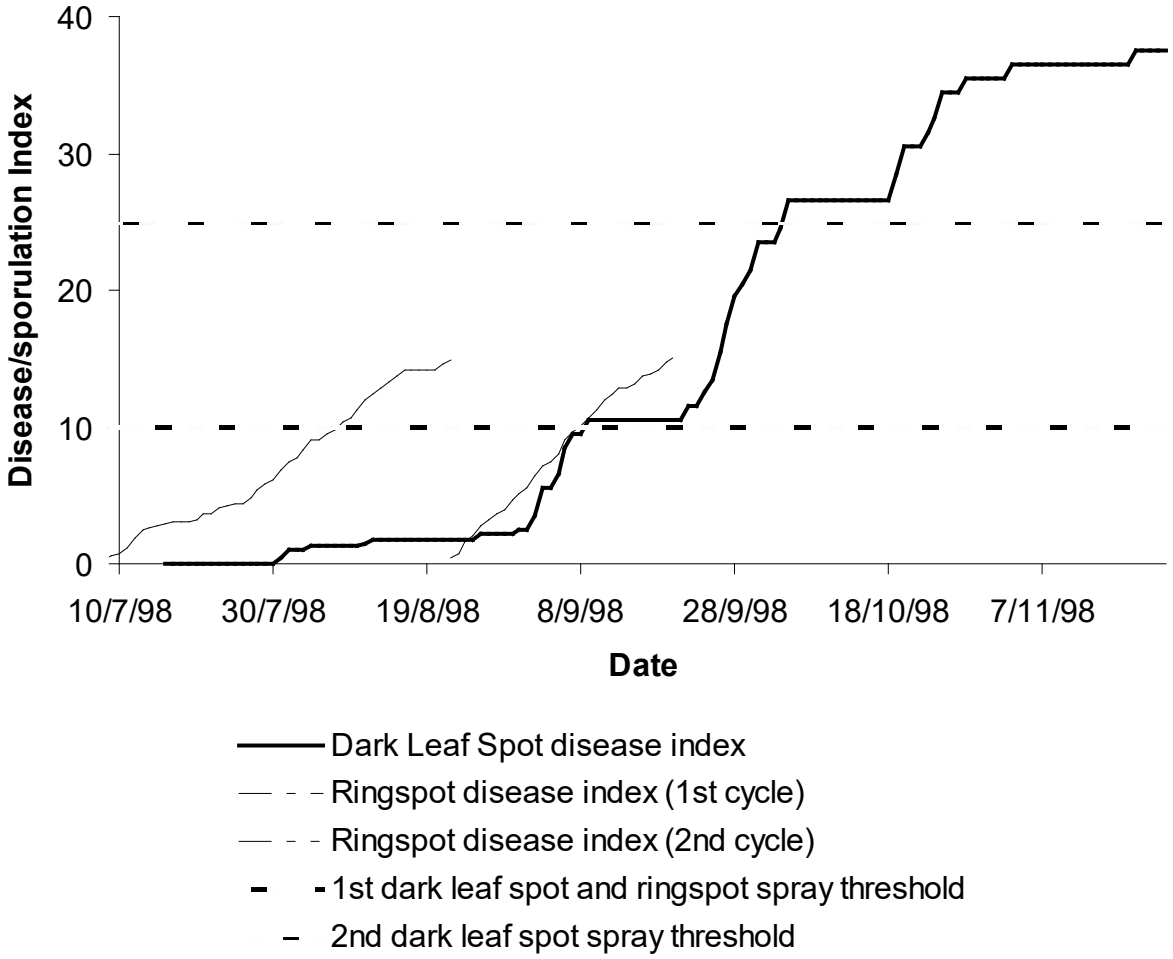


Figure 30 Predicted disease development (Butterwick trial site 1998)



Holbeach

Dark leaf spot and ringspot were initially observed at the Holbeach site on the 10 July 1998 (Table 23). White blister was intially observed in the crop on the 16 July 1998. Small amounts of ringspot were observed on leaves in the crop at the end of September 1998. However at these extremely low levels it was considered that they did not represent a threat to the crop. Low levels of white blister (less than one lesion per plant) were visible within the crop from August 1998 until harvest. The first ringspot disease threshold was reached on the 4 August 1998 however the first dark leaf spot spray threshold was not reached until the 6 September 1998 (Figure 31). The secondary dark leaf spot forecast spray criteria (25) was reached on the 28 September 1998.

Donington

Dark leaf spot was observed at the Donington site on the 14 July 1998 (Table 23). White blister was first observed in the crop on the 16 July 1998. The initial *Alternaria* (dark leaf spot) disease threshold was reached on the 9 September 1998 (Figure 32). However high levels of dark leaf spot were observed on plants in the crop on the 19 August 1998. Most infection was observed on the older leaves of each plant. The secondary dark leaf spot forecast criteria (25) was passed on the 25 September 1998. Ringspot was first observed in the crop on the 11 July 1998 and the sporulation index reached the spray threshold on the 9 Ausust 1998. Secondary ringspot development was observed in the crop on the 24 August 1998. The sporulation index reached the spray threshold for this ringspot outbreak on the 9 September 1998.

Figure 31 Predicted disease development (Holbeach Hurn trial site 1998)

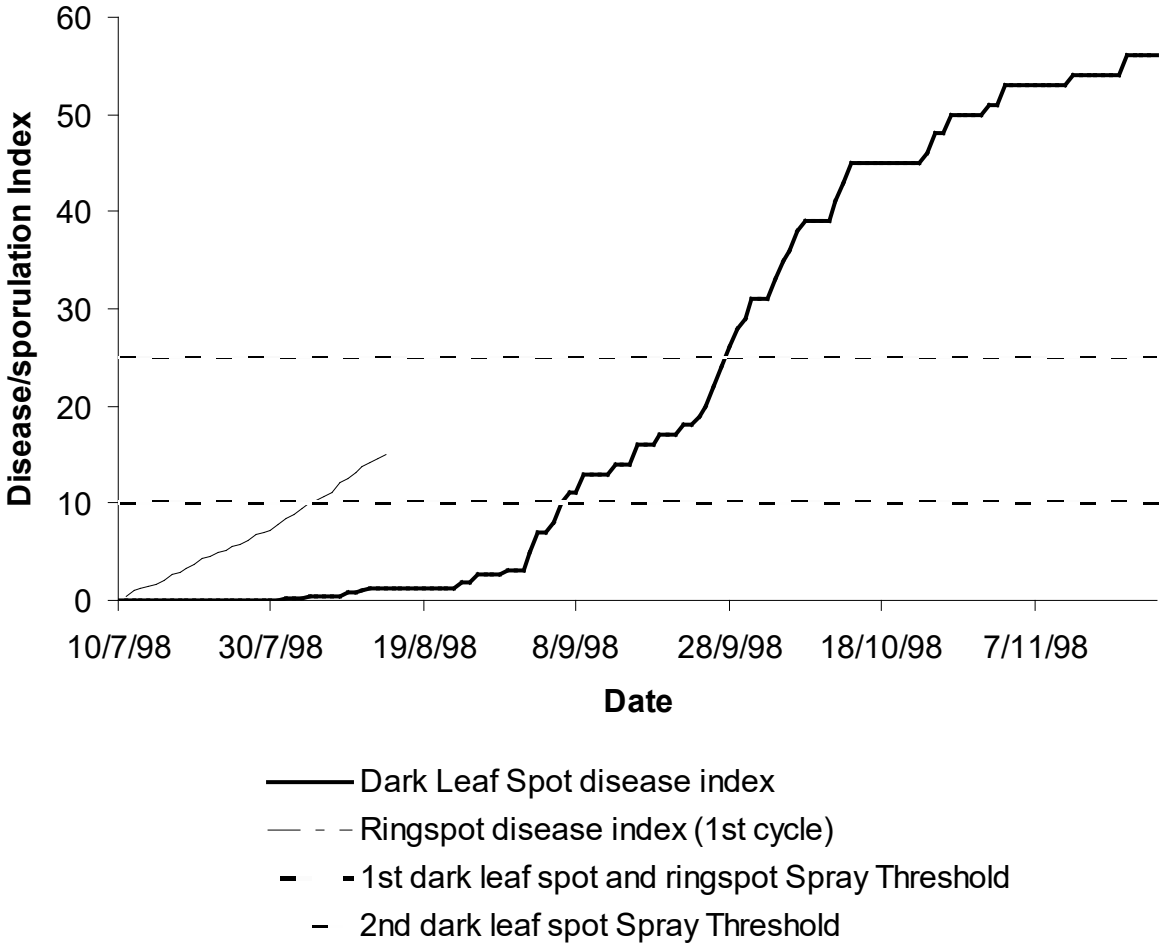
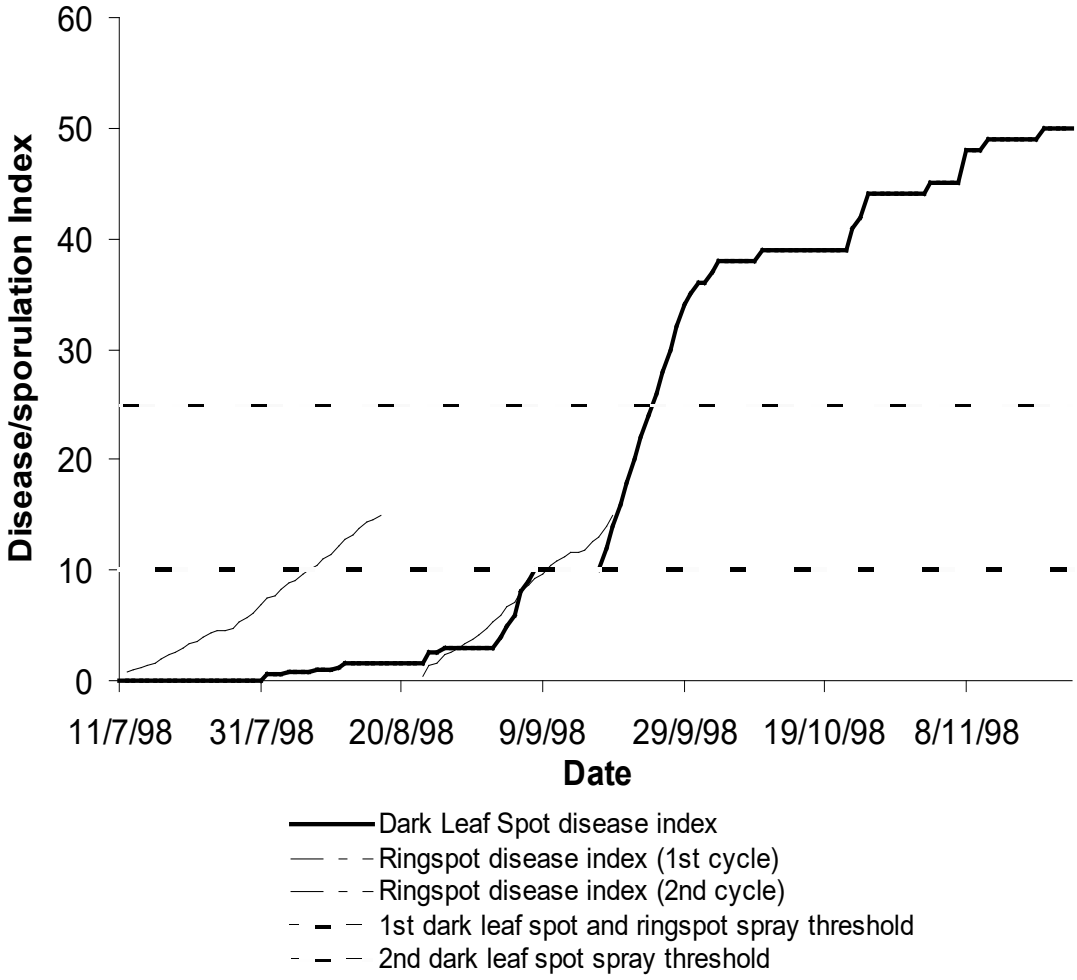


Figure 32 Predicted disease development (Donington trial site 1998)



5.1.1.3 Observed ringspot and dark leaf spot on buttons at harvest (observational sites)

It was not possible to differentiate accurately between lesions caused by *Alternaria brassicae* (dark leaf spot) and *Mycosphaerella brassicicola* (ringspot). However forecasts were provided for both diseases and it was therefore not necessary to differentiate between lesions caused by both diseases on the button. One type of button harvest was taken at these sites as outlined in section 3.1.4.2. A sample of buttons was removed from the top, middle and bottom of the Brussels sprout shank and assessed (as described previously).

Butterwick

Buttons were harvested at the Butterwick site on the 15 January 1999. The incidence and severity of dark leaf spot on buttons harvested in the observation plot at the Butterwick site is shown in Figures 33 and 34. There were higher numbers of uninfected buttons harvested at Butterwick from the middle and top of the plant (Figure 33). There was a lower percentage of clean buttons harvested from the bottom of the plant although this was non-significant. There was higher mean numbers of lesions on infected buttons harvested from the middle of the canopy in comparison to the top and bottom (Figure 34).

Holbeach

Buttons were harvested from the Holbeach site on the 4 December 1998. There was a higher percentage of uninfected buttons harvested from the bottom and top of the plant at the observation site (Figure 35). Approximately 36 % of buttons harvested from the middle position of the Brussels sprouts canopy were uninfected. Infected buttons harvested from the top of the canopy had approximately 1.5 lesions per button (Figure 36). However mean button infection was higher (approximately 2 lesion per button) on infected buttons from the middle and bottom of the canopy.

Donington

Buttons were harvested from the observation site at Donington on the 1 December 1998. There was significantly lower numbers of clean buttons harvested from the bottom of the canopy (Figure 37). Approximately 30-35% of the buttons harvested from the top of the canopy were uninfected. Infected buttons harvested from the bottom of the canopy had approximately 3-4 lesions of either ringspot or dark leaf spot on each button (Figure 38). Infected buttons harvested from other canopy positions had lower numbers of lesions per button.

Figure 33 Percentage (%) clean buttons at Butterwick (1998)

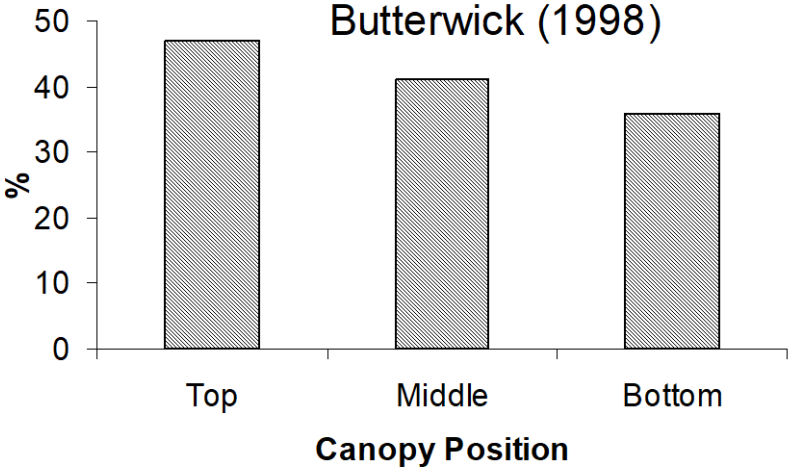


Figure 34 Mean lesion number per infected button at Butterwick (1998)

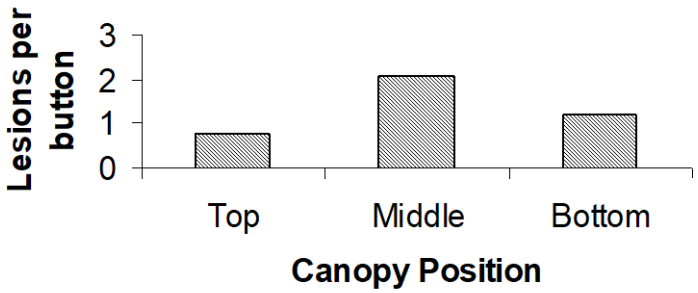


Figure 35 Percentage (%) clean buttons at Holbeach (1998)

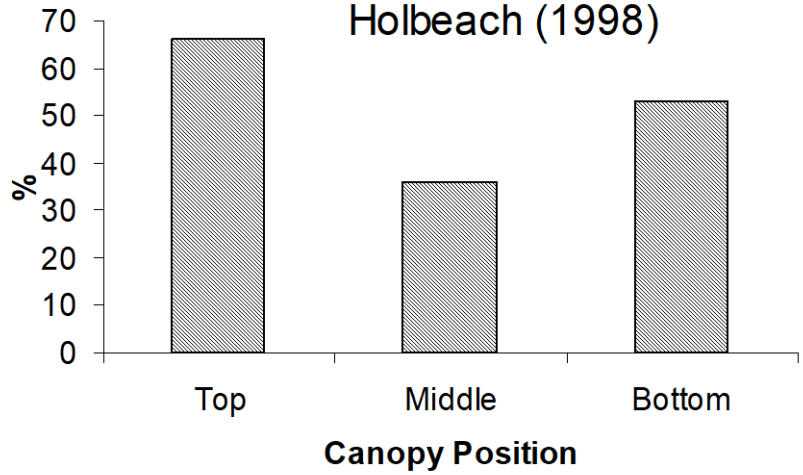


Figure 36 Mean lesion number per infected button at Holbeach (1998)

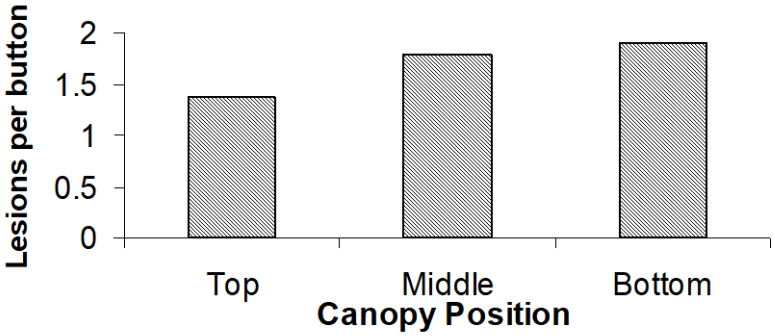


Figure 37 Percentage (%) clean buttons at Donington (1998)

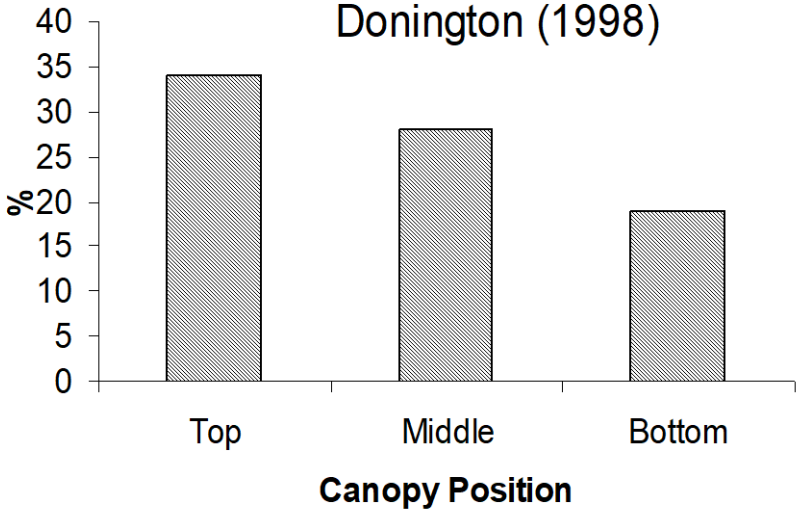
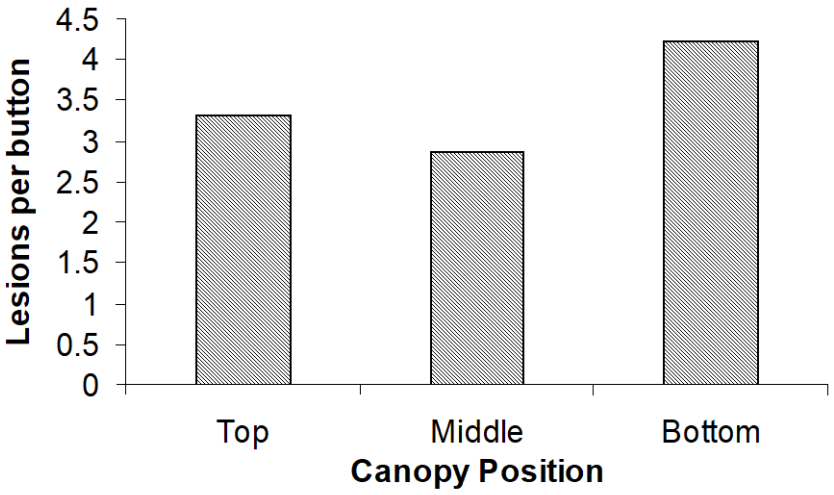


Figure 38 Mean number of lesions per infected buttons at Donington (1998)



5.1.2 1998 Other test sites

5.1.2.1 Initial crop infection by dark leaf spot and other leaf spot pathogens

Disease pressure at St Andrews in Scotland and at Ross-on-Wye was relatively low. However a true picture of the initial infection of the crop could not be gained due to the remoteness of the sites. Both sites experienced wet conditions August 1998 which was conducive to rapid disease development by ringspot and dark leaf spot. Infection by *Mycosphaerella brassicicola* (ringspot), *Alternaria brassicae* (dark leaf spot) and *Albugo candida* (white blister) was first observed at Ross-on-Wye on the 14 July 1998 (Table 23). As the ringspot lesions were small it was assumed the infection had just appeared. At St Andrews both ringspot and dark leaf spot were observed at the trial site on the 31 July 1998. White blister was not observed at the St Andrews trial sites over the duration of the trial.

5.1.2.2 Predicted ringspot and dark leaf spot disease development

St Andrews

Both ringspot and dark leaf spot was observed at St Andrews on the 31 July 1998 (Table 23). The initial dark leaf spot disease threshold was reached on the 4 September 1998 (Figure 39). Infection was observed at the top of the plant. The secondary dark leaf spot forecast criteria (25) was passed on the 29 September 1998. Early ringspot development was first observed in the crop on the 8 August 1998 and sporulation index reached the spray threshold on the 1 September 1998. Lesions were generally less than 5 mm in diameter and were more prevalent on the upper leaves of the crop. It was difficult to visit the crop on a regular basis however secondary ringspot development was observed in the crop on the 7 October 1998. The sporulation index reached the spray threshold for this ringspot outbreak on the 6 November 1998.

Ross-on-Wye

Both ringspot and dark leaf spot were both observed initially at the Ross-on-Wye site aon the 14 July 1998 (Table 23). The ringspot sporulation index reached the spray threshold on the 23 August 1998 (Figure 40). However the initial dark leaf spot disease threshold was reached on the 17 October 1998. The dark leaf spot secondary disease threshold was not reached at this site before harvest. The model output for dark leaf spot indicates that this site was not favourable for dark leaf spot development.

Figure 39 Predicted disease development (St Andrews trial site 1998)

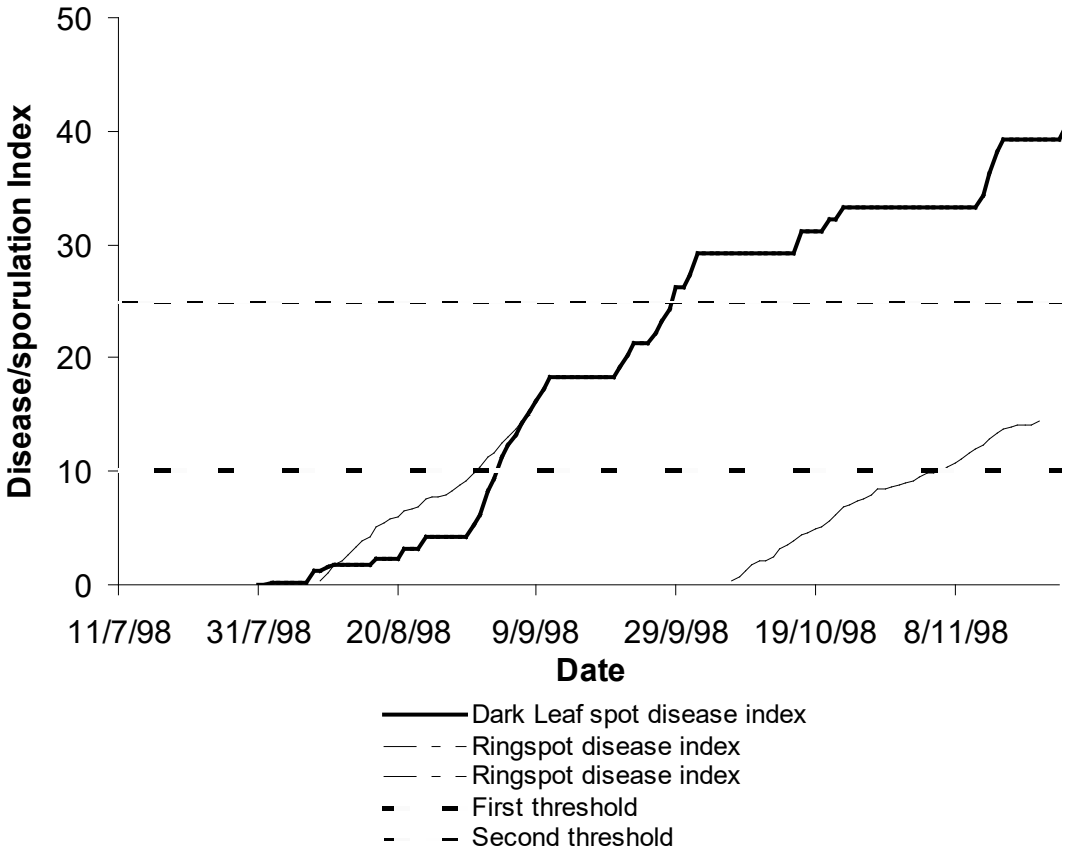
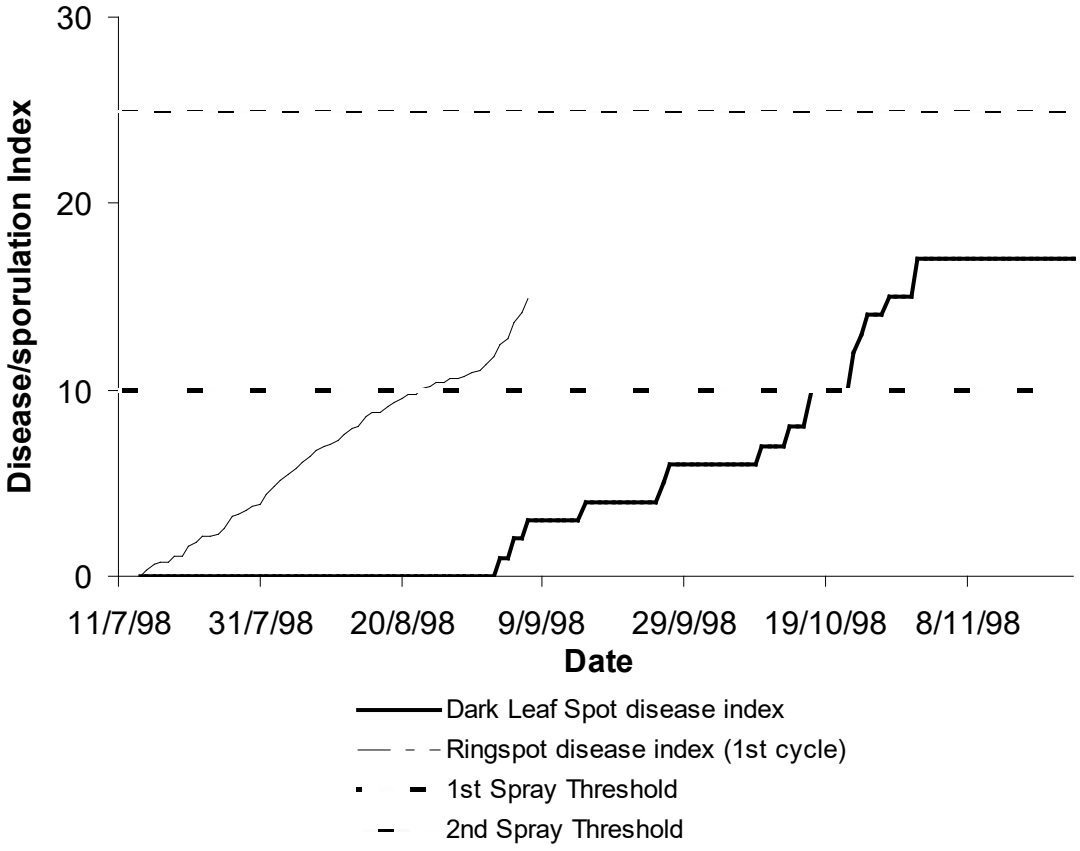


Figure 40 Predicted disease development (Ross-on-Wye) trial site 1998)



5.1.2.3 Observed ringspot and dark leaf spot on buttons at harvest

Both types of button harvests were taken at these sites as outlined in section 3.3.4.2. A sample of buttons was removed from the top, middle and bottom of the Brussels sprout shank and assessed. Additionally whole plant samples of Brussels sprouts shanks were removed from different areas of the field or plots. All the Brussels sprout buttons were removed from the shank and assessed in this type of sample.

St Andrews

Buttons were harvested at the St Andrews site on the 15 December 1998. There was little effect of canopy position on the percentage of infected buttons harvested from the crop (Figure 41). Approximately 60 % of buttons harvested from the crop were uninfected. There was no significant variation in the button infection as assessed by either a sample removed from different positions on the Brussels sprout shank or by harvesting all the buttons from a number of shanks removed from the field. There was little difference in the numbers of dark leaf spot and ringspot lesions per infected button in samples harvested from the top, middle and bottom of the plant (Figure 42). The mean lesion numbers on infected buttons harvested from the shank was low at under two lesions per infected button (Figure 42).

Ross-on-Wye

Button harvests were taken at the Ross-on-Wye site on the 23 December 1998. Due to unexpected plant development, buttons could not be harvested from the top most position of the canopy. Approximately 30 % of buttons sampled from the middle and bottom positions on the canopy remained free of infection (Figure 43). However the percentage uninfected buttons from the whole Brussel sprout shank was approximately 60 %. This may have reflected the absence of buttons taken from the top of the Brussels sprouts canopy in the button sample in comparison to the shank sample where it was included. There were low numbers of lesions per infected button (0.45) in the button sample (Figure 44). The mean number of lesions per button was higher from infected buttons taken from the shank sample (1.5).

Figure 41 Percentage (%) clean buttons at St Andrews (1998)

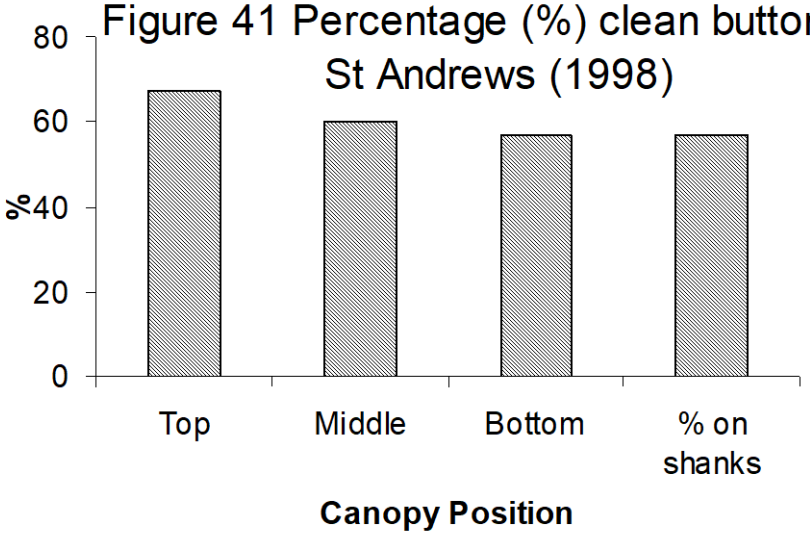


Figure 42 Mean number of lesions per infected buttons at St Andrews (1998)

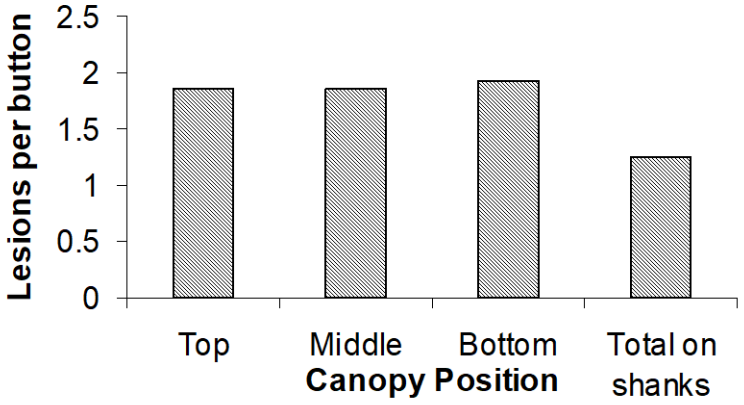


Figure 43 Percentage (%) clean buttons at Ross-on-Wye (1998)

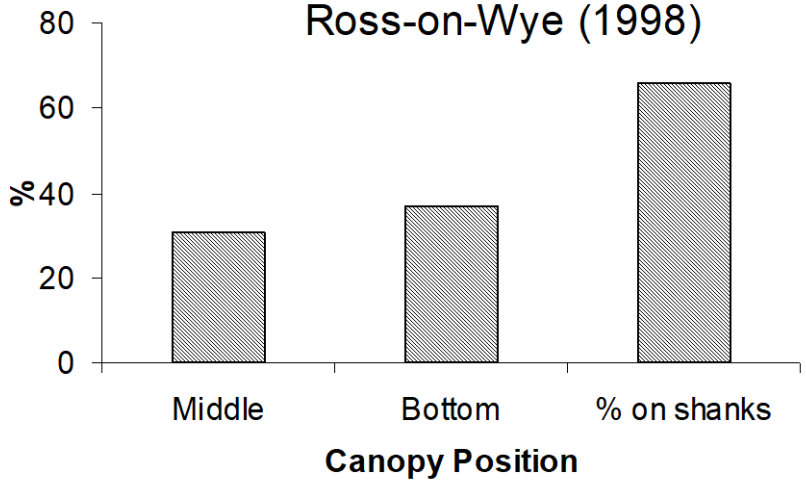
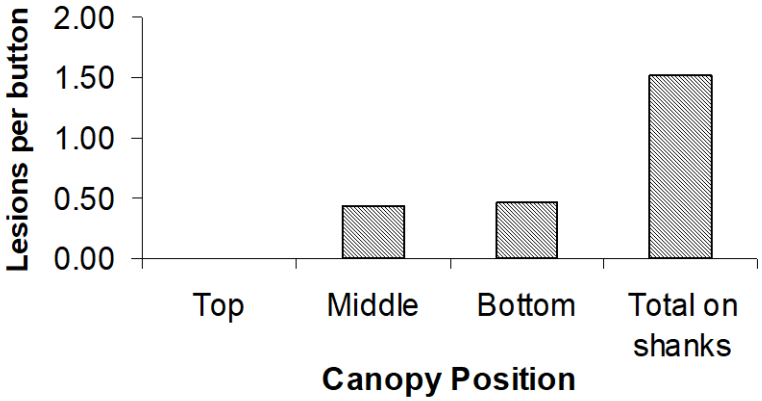


Figure 44 Mean number of lesions per infected buttons at Ross-on-Wye (1998)



5.2 Ringspot and dark leaf spot forecast usage in replicated trials in commercial crops in 1998

5.2.1 Initial crop infection by ringspot, dark leaf spot and other leaf spot pathogens

Three test sites were used in these trials of which two were situated in coastal areas of Lincolnshire with a third located on Hesketh Bank. Infection by *Mycosphaerella brassicicola* (ringspot), *Alternaria brassicae* (dark leaf spot) and *Albugo candida* (white blister) occurred at all sites (Table 24). In Lincolnshire at the Frieston shore site large amounts of ringspot were first observed in the crop on the 29 June 1998. Dark leaf spot was also present in the crop at that time but at very low levels. Development of white blister was not observed at this site until the 19 August 1998. At the Skegness site ringspot and dark leaf spot infection was observed again on the 1 July 1998. There was no observed white blister infection in the crop however high levels of powdery mildew were present in the crop during September 1998 which was associated with the presence of oilseed rape volunteer plants. At Hesketh Bank dark leaf spot and white blister were first observed at low levels on the 23 July 1998. Ringspot infection was first observed in the crop on the 4 August 1998. At this site *Xanthomonas campestris* pv. *campestris* (black rot) and *Peronospora parasitica* (downy mildew) were also present.

Table 24 Initial infection by foliar pathogens on Brussel sprouts at replicated commercial test sites in 1998

Site	Planting Date	*Albugo* (White blister)	*Alternaria* (Dark leaf spot)	*Mycosphaerella* (Ringspot)
Lincolnshire				
Skegness	NA	NI	1/7	1/7
Frieston shore	NA	19/8	29/6	29/6
Other Areas				
Hesketh Bank	NA	23/7	23/7	4/8

NA – Not Available
NI -- Not Infected

5.2.2 Predicted Disease Development Hesketh Bank

Prediction of dark leaf spot and ringspot development commenced at the Hesketh bank site 23 July 1998 (Table 24). Predicted dark leaf spot development was initially slow and the first dark leaf spot spray threshold was not reached until the 5 September 1998 (Figure 45). The second dark leaf spot spray threshold was reached on the 23 September 1998. Ringspot disease development was more rapid even though it had been first observed in the crop on the 4 August 1998. The first ringspot spray threshold was reached on the 26 August 1998. Further fresh ringspot lesions were observed in the crop 7 September 1998. The secondary ringspot spray threshold was reached on the 24 September 1998. Further ringspot disease development was observed at this site on the 26 September 1998. Ringspot development was rapid and the spray threshold was reached on the 16 October 1998 (Figure 45). White blister remained at low levels throughout the cropping period. However this was not surprising as sprays of Fubol were applied to both the growers and forecast areas throughout the trial.

5.2.3 Observed ringspot and dark leaf spot on leaves during the growth season

Higher mean numbers of lesions were observed on counts taken from leaves of plants in the growers plot in comparison to those taken from plants in the forecast plot (Figure 46). There were on average 5 lesions per leaf in counts taken from the growers trial area at Hesketh bank on the 30 September 1998 however this had declined to approximately 1 – 2 lesions per leaf at the second assessment taken on the 21 October 1998. In contrast the mean number of lesions in the forecast plot at the same sampling times dropped from approximately 2 (30/9/98) to 1 lesion per leaf (21/10/98).

5.2.4 Fungicide sprays applied at the Hesketh Bank trial site

Fungicides applied at the Hesketh Bank site are shown in Table 25. Three sprays were applied to both the growers trial area and the forecast area. A spray of Folicur at 0.5 litres ha^{-1} with Fubol at 1.25 kg ha^{-1} was applied on the 25 July 1998 to both the growers trial area and the forecast plots at the Hesketh Bank site. This spray was applied to the forecast plots at first recognition of dark leaf spot in the crop. A further spray of Plover at 0.3 litres ha^{-1} was applied on the 26 August 1998 to both the growers trial area and the forecast plots. This spray was applied to the forecast plots in response to prediction of ringspot inoculum production. Spray applications contained

Figure 45 Predicted Disease Development (Hesketh Bank Trial 1998)

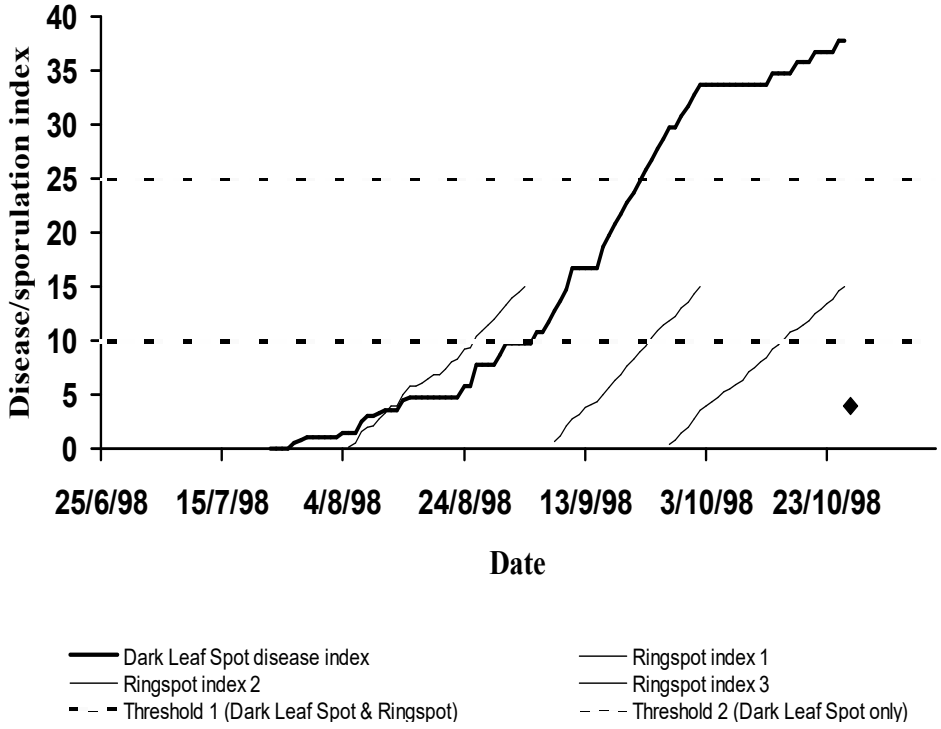
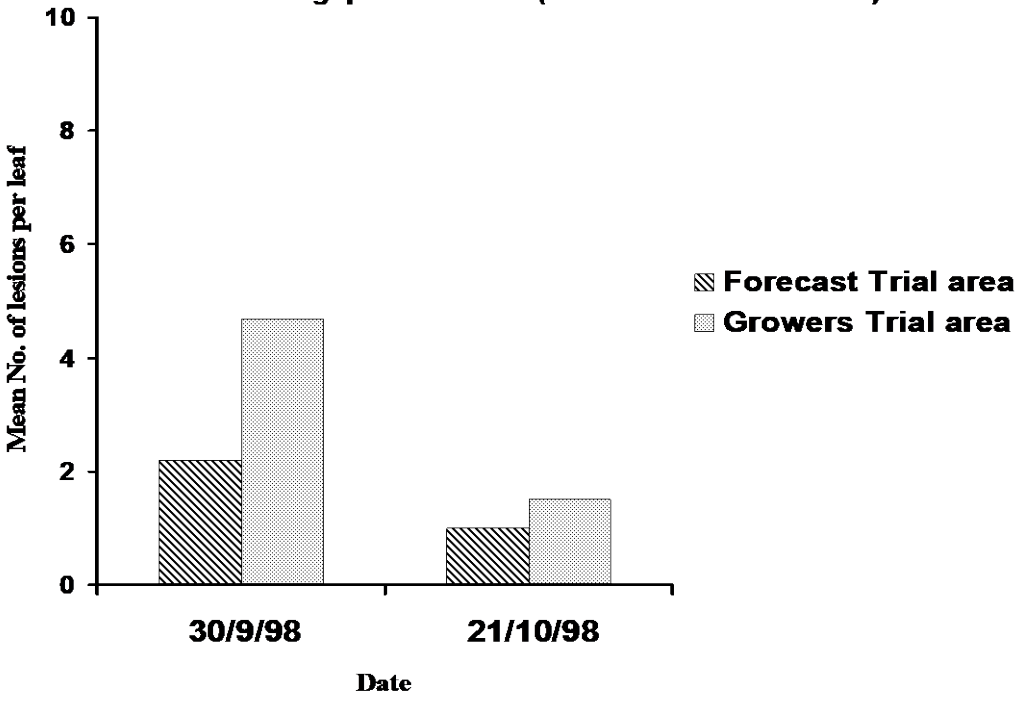


Figure 46 Observed disease development by dark leaf spot and ringspot on leaves (Hesketh Bank Trial 1998)



Fubol in response to perceived risk of crop damage from white blister. A further spray application of Folicur (0.5 litres ha^{-1}) with Fubol (1.25 Kg ha^{-1}) was applied on the 19 September 1998 to the growers trial area. However the forecast plots had Plover (0.3 litres ha^{-1}) applied with Fubol (1.25 Kg ha^{-1}) on the 24 September 1998 in response to further predictions of ringspot inoculum production.

Table 25 Fungicide Treatments at field sites 1998 – Hesketh Bank

Growers Area	25.07 -	Folicur	(0.5 litres ha^{-1})
		Fubol	(1.25 kg ha^{-1})
	26.08 -	Plover	(0.3 litres ha^{-1})
	19.09 -	Folicur	(0.5 litres ha^{-1})
		Fubol	(1.25 kg ha^{-1})
Dark leaf spot/ringspot Forecasting Area	25.07 -	Folicur	(0.5 litres ha^{-1})
		Fubol	(1.25 kg ha^{-1})
	26.08 -	Plover	(0.3 litres ha^{-1})
	24.09 -	Plover	(0.3 litres ha^{-1})
		Fubol	(1.25 kg ha^{-1})

5.2.5 Observed ringspot and dark leaf spot on buttons at harvest at Hesketh Bank

Buttons were harvested at the Hesketh Bank site on the 27 October 1998. The percentage of uninfected buttons harvested from the grower's trial area and the forecast trial area (whole plant shanks samples) are shown in Figure 47. Approximately 60 % of buttons harvested from either area were free of infection by either ringspot or dark leaf spot with no significant difference between areas. The number of lesions per infected Brussels sprout button was under one in both trial areas at Hesketh Bank in 1998 (Figure 48). There was no significant difference between areas when the whole Brussels sprout shank was assessed. However approximately 50-60 % of buttons were uninfected regardless of position on the Brussels sprout shank in the forecast plots when button samples were assessed (Figure 49). There were approximately 60, 30 and 20 % uninfected buttons in the button sample harvested from the top middle and bottom of the Brussels sprout shank in the growers trial area respectively. Mean lesion numbers on infected buttons were higher in the growers trial area than on infected buttons removed from the forecast trial area in button samples taken at the Hesketh bank trial site in 1998 (Figure 50). Higher infection levels were observed on buttons harvested from the bottom of the canopy.

Figure 47 Percentage uninfected buttons at Hesketh Bank 1998 (Whole plant sample)

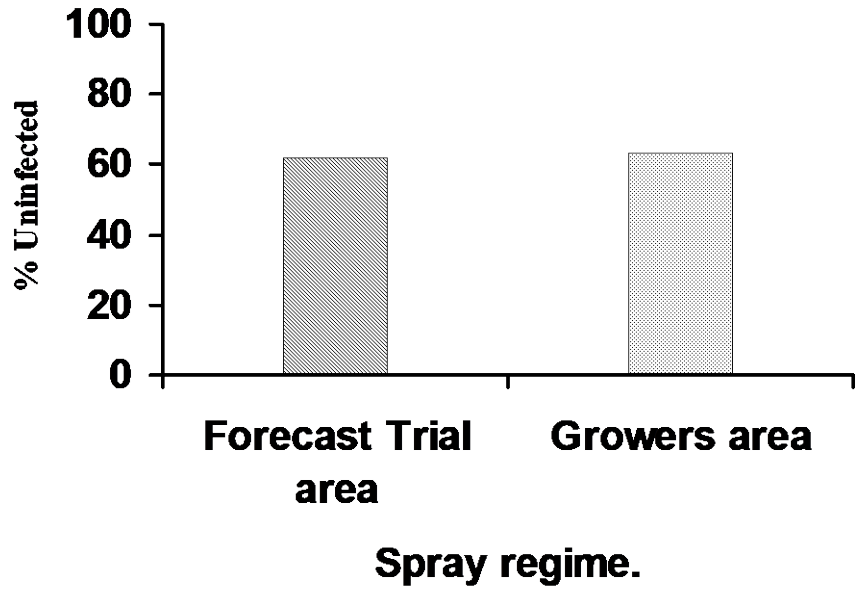


Figure 48 Mean number of lesions per button at Hesketh Bank (Whole plant sample)

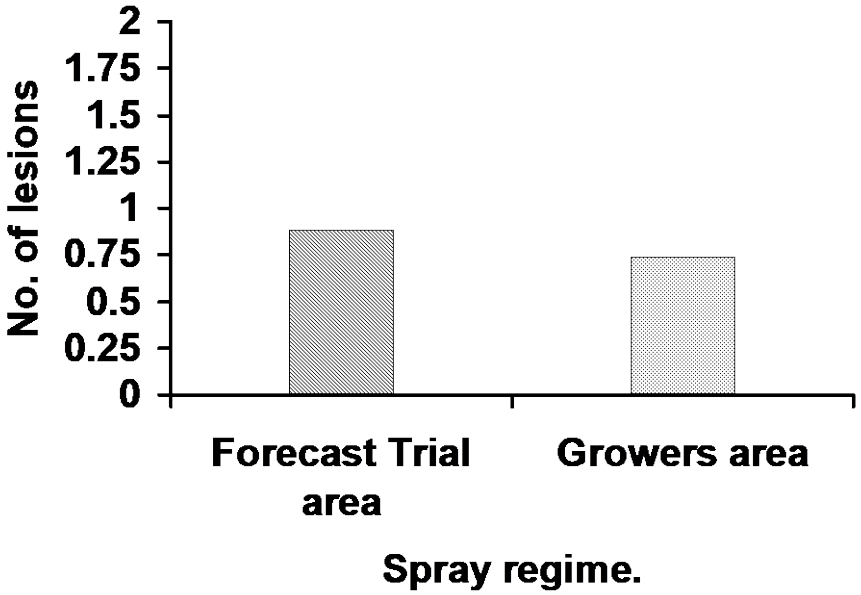


Figure 49 Percentage uninfected buttons at Hesketh Bank 1998 (Button sample)

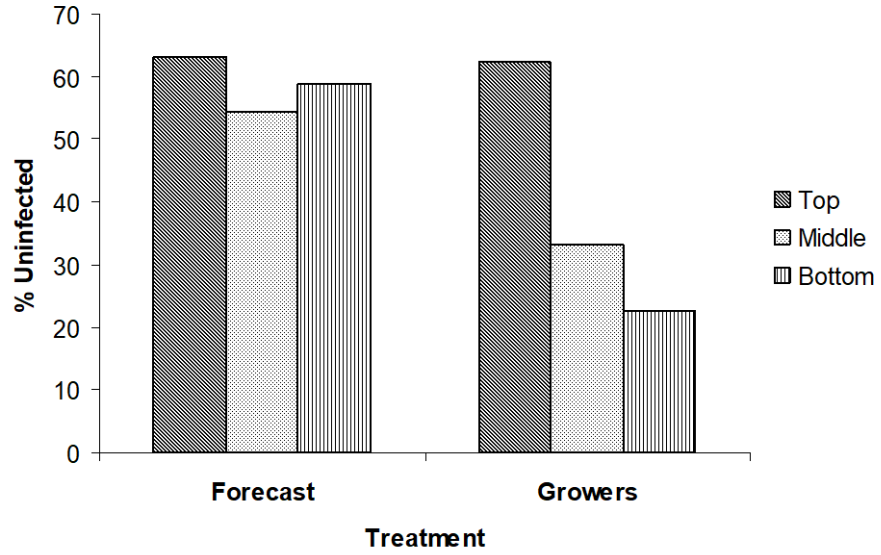
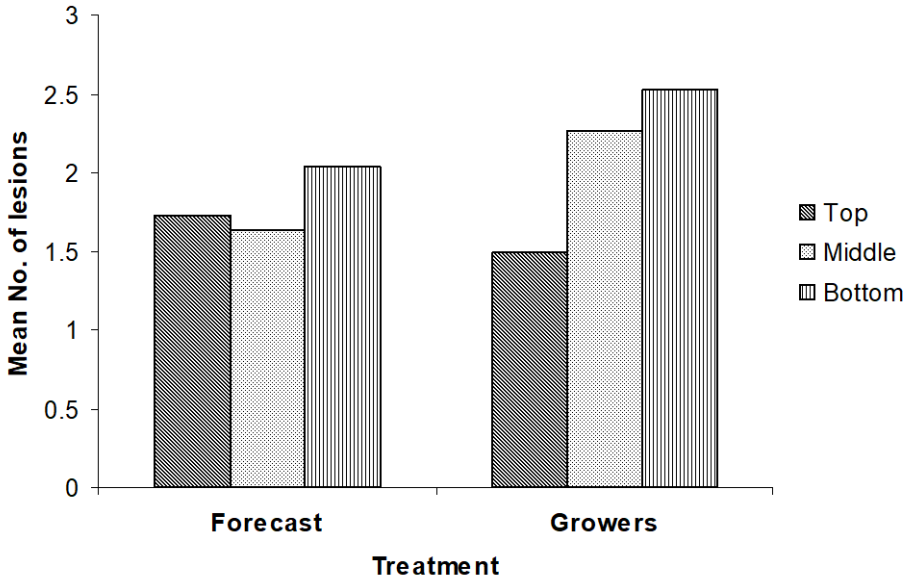


Figure 50 Mean number of lesions per infected button at Hesketh Bank 1998 (Button sample)



5.2.6 Predicted Disease Development Skegness

The predicted disease development at the Skegness trial site is shown in Figure 51. Both dark leaf spot and ringspot were first observed in the crop on the 1 July 1998 at which time forecasts of disease development began (Table 24). The first spray threshold for ringspot in the crop was reached on the 1 August 1998. Secondary ringspot lesions were observed in the crop on the 17 August 1998 and the secondary spray threshold for ringspot development was reached on the 8 September 1998. Dark leaf spot development was not optimal at this site and the initial spray threshold was reached only on the 25 September 1998. Further infection by ringspot was observed in the crop on the 15 September 1998 and a further spray threshold for ringspot was reached on the 7 October 1998. However the secondary spray threshold for dark leaf spot was reached on the 15 October 1998 (Figure 51).

5.2.7 Observed ringspot and dark leaf spot on leaves during the growth season at the Skegness trial site

The mean number of ringspot and dark leaf spot lesions on Brussels sprout leaves at Skegness was assessed on the 22 September 1998 and the 14 October 1998. There were significantly higher numbers of lesions per leaf, on plants in the grower's trial area than in the forecast plots on the 22 September 1998 (Figure 52). However at the second assessment date there was little difference between treatments in the number of lesions numbers with on average only one lesion of either ringspot or dark leaf spot per leaf.

5.2.8 Fungicide sprays applied at the Skegness trial site

Fungicides applied at the Skegness site are shown in Table 26. There were considerable differences in the spray regime between the growers trial area and the forecast trial plots. A spray of Bravo at 1.5 kg ha^{-1} was applied to the growers trial area on the 15 July 1998. Further sprays of Plover (0.3 litres ha^{-1}) were applied on the 8 August, 2 September and 21 September 1998 to the growers trial area. A spray of Plover (0.3 litres ha^{-1}) was applied to the forecast plots on the 4 August and 10 September 1998. Due to the presence powdery mildew at potentially damaging levels a spray of Bayfidan (0.5 litres ha^{-1}) was applied to both the forecast area and the growers area on the 24 September 1998. A further spray of Plover (0.3 litres ha^{-1}) or Bravo (1.5 kg ha^{-1}) was applied to the on the 13 October and the 21 October 1998 to the forecast and growers areas respectively.

Figure 51 Predicted Disease Development (Skegness trial site 1998)

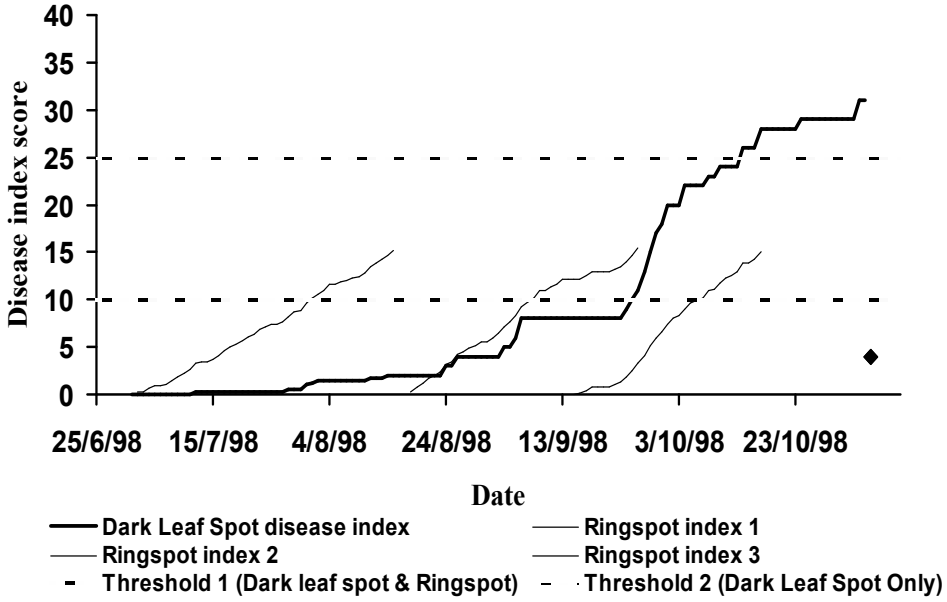


Figure 52 Observed disease development by dark leaf spot and ringspot on leaves (Skegness trial site)

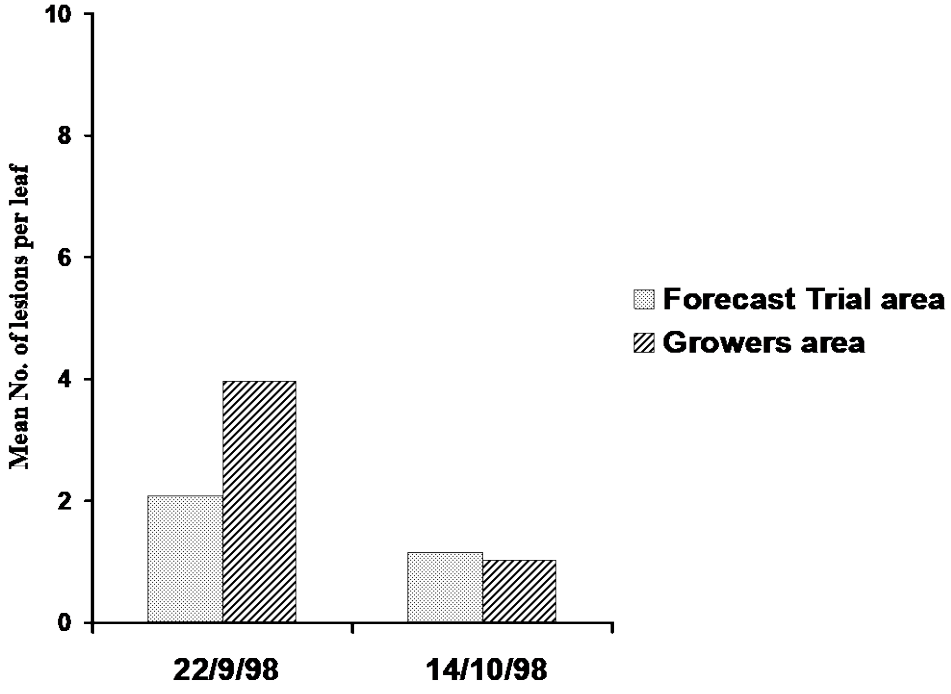


Table 26 Fungicide Treatments at field sites 1998 – Skegness site

Growers Area	15.07 - Bravo	(1.5 kg ha $^{-1}$)
	08.08 - Plover	(0.3 litres ha^{-1})
	02.09 - Plover	(0.3 litres ha^{-1})
	21.09 - Plover	(0.3 litres ha^{-1})
	24.09 - Bayfidan	(0.5 litres ha^{-1})
	21.10 - Bravo	(1.5 kg ha $^{-1}$)
Dark leaf spot/ringspot Forecasting Area	04.08 - Plover	(0.3 litres ha^{-1})
	10.09 - Plover	(0.3 litres ha^{-1})
	24.09 - Bayfidan	(0.5 litres ha^{-1})
	13.10 - Plover	(0.3 litres ha^{-1})

5.2.9 Observed ringspot and dark leaf spot on buttons at harvest at the Skegness trial site

Buttons were harvested at the Skegness site on the 5 November 1998. In harvests of whole plants from the two trial areas approximately 60 % of buttons were uninfected regardless of spray regime (Figure 53). There was lower mean numbers of lesions per infected button in the forecast area compared to the grower's trial area although the differences were not significant (Figure 54). When buttons were randomly harvested from the top middle and bottom of the plant and assessed for infection some differences were observed between treatments. The percentage of uninfected buttons harvested from the top of the canopy was approximately 75 % from both the forecast and growers trial areas (Figure 55). Slightly higher numbers of uninfected buttons were harvested from the middle part of the canopy in the growers trial area (58 %) in comparison to the forecast area (53%). Approximately 20 % of buttons harvested from the bottom of the canopy regardless of regime remained uninfected (Figure 55). There were higher mean numbers of lesions per button harvested from the middle and bottom part of the canopy in the growers trial area in comparison to the forecast trial plots. (Figure 56). Approximately 2.5 lesions were found on infected buttons harvested from the bottom of the canopy in the grower's treatment, which was the highest level recorded.

Figure 53 Percentage uninfected buttons at Skegness site 1998 (Whole plant sample)

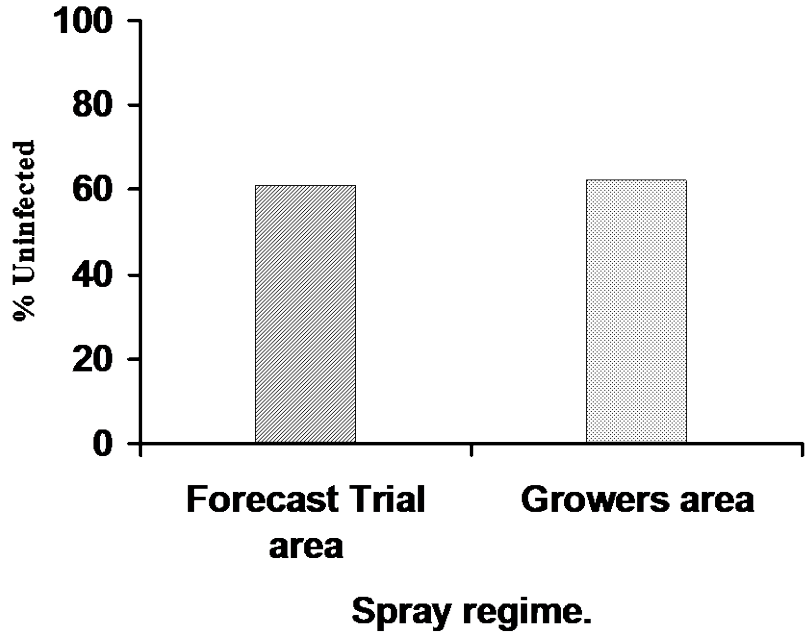


Figure 54 Mean number of lesions per button at the Skegness site (Whole plant sample)

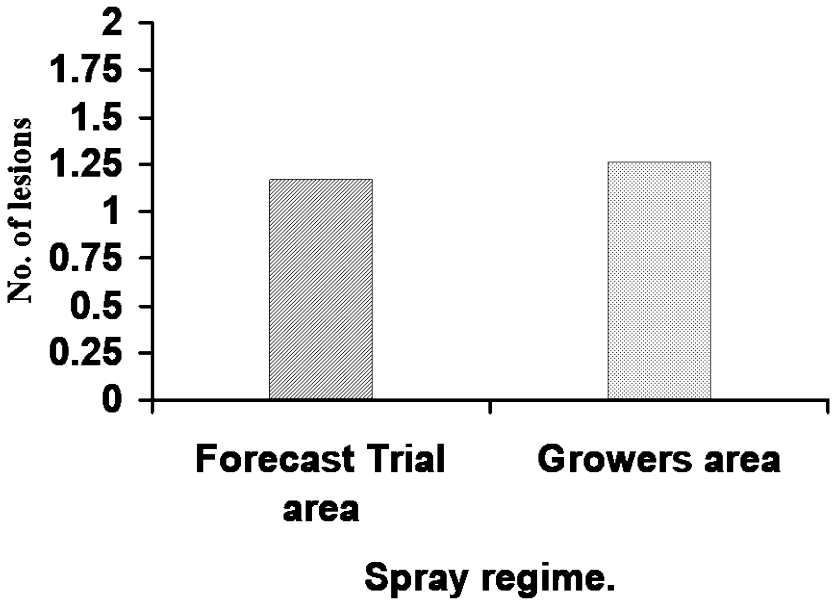


Figure 55 Percentage uninfected buttons at Skegness 1998 (Button sample)

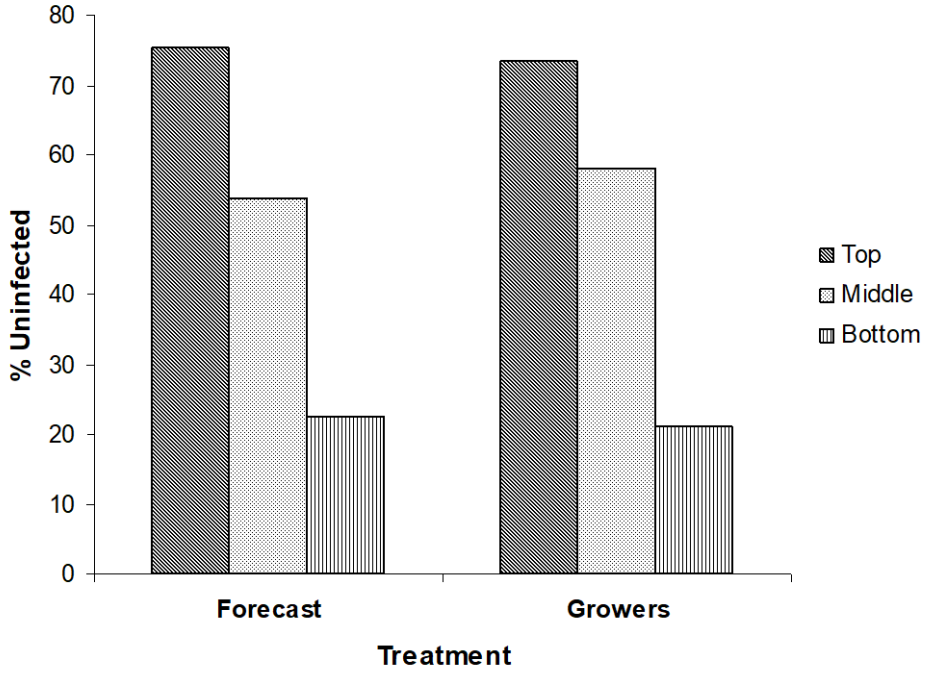
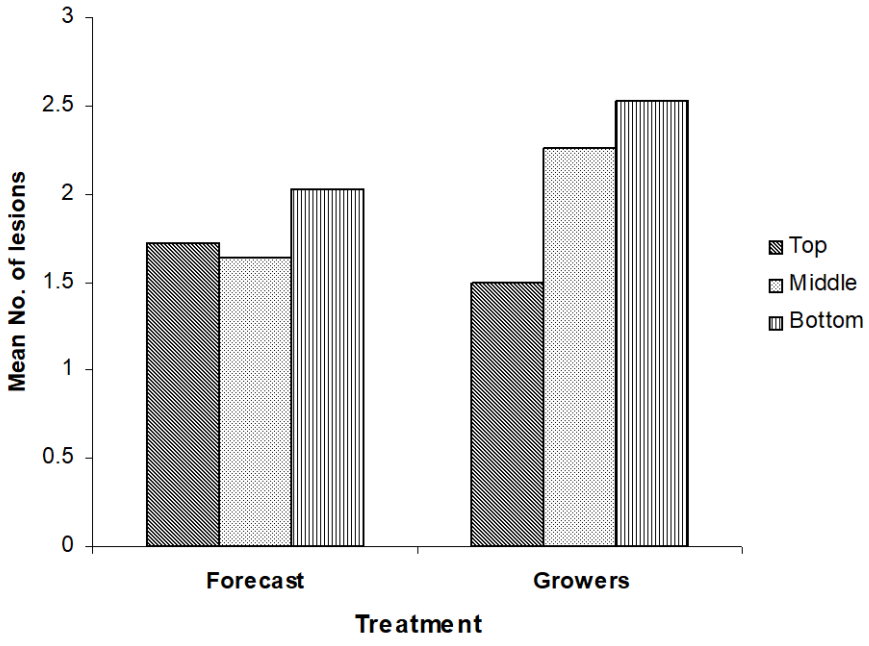


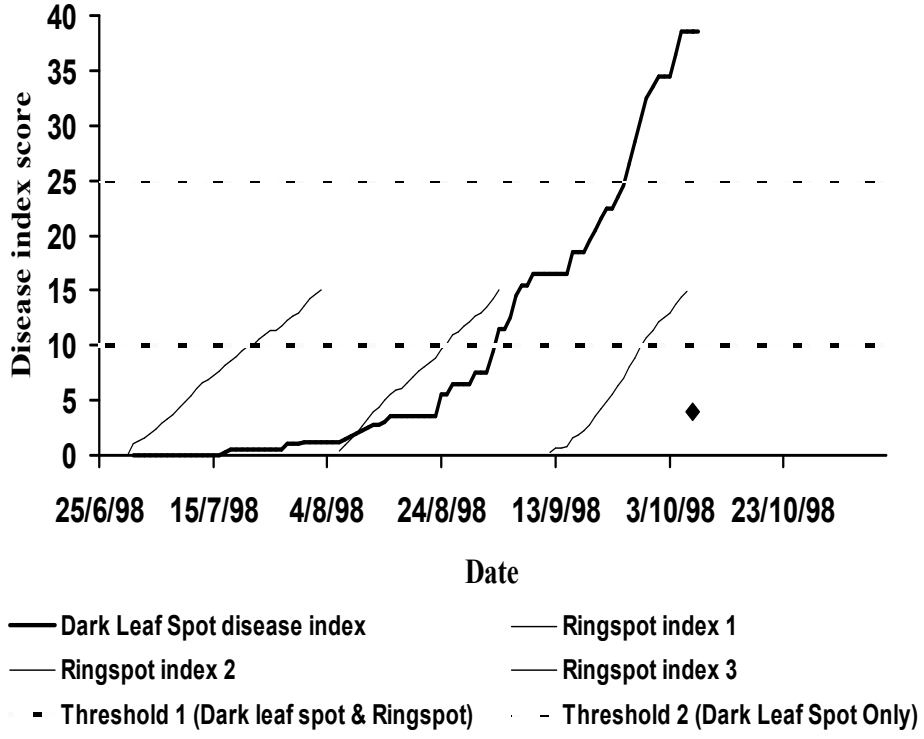
Figure 56 Mean number of lesions per infected button at Skegness 1998 (Button sample)



5.2.10 Predicted Disease Development Frieston Shore

The predicted disease development at the Frieston Shore trial site is shown in Figure 57. Dark leaf spot and ringspot were observed in the crop on the 29 June 1998 (Table 24). The first spray threshold for ringspot in the crop was reached on the 22 July 1998. Secondary ringspot lesions were observed in the crop on the 5 August 1998 suggesting that this outbreak had resulted from inoculum produced within the crop. The secondary spray threshold for ringspot development was reached on the 25 August 1998. Dark leaf spot development, as indicated by the disease index score, was not initially rapid at this site. The initial spray threshold was reached only on the 3 September 1998. However further infection by ringspot was observed in the crop on the 11 September 1998 and a further spray threshold for ringspot was reached on the 29 September 1998. The secondary spray threshold for dark leaf spot was reached rapidly on the 26 September 1998 only 3 weeks after the first threshold (Figure 57).

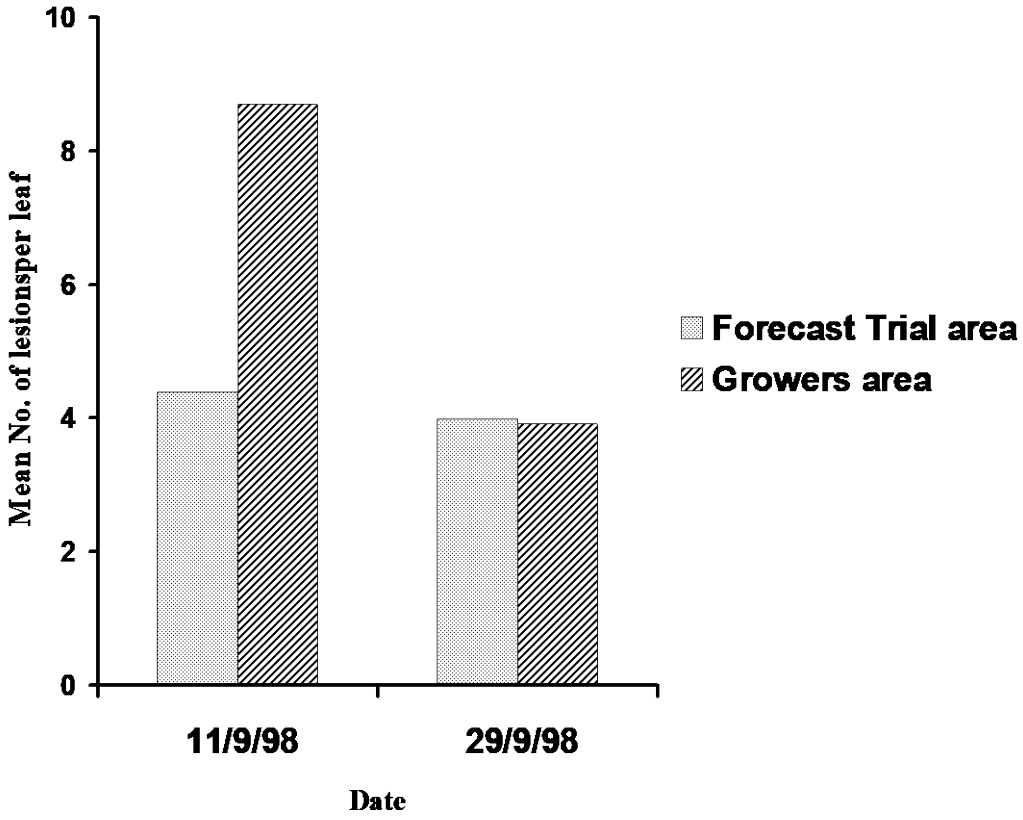
Figure 57 Predicted Disease Development (Frieston shore trial site 1998)



5.2.11 Observed ringspot and dark leaf spot on leaves during the growth season

Observed ringspot and dark leaf spot on leaves of Brussels sprouts at Frieston shore is shown in Figure 58. Assessments of leaves were taken on the 11 and 29 September 1998. There were approximately 9 lesions per leaf on plants assessed in the growers trial area on the 11 September 1998. However in the forecast area only 4 – 5 lesions per leaf were observed at the same sampling period. At the second sampling time there was approximately the same level of disease in both trial areas (4 lesions per leaf).

Figure 58 Observed disease development by dark leaf spot and ringspot on leaves (Frieston shore trial site)



5.2.12 Fungicide sprays applied at the Frieston Shore trial site

Fungicides applied at the Frieston Shore site are shown in Table 27. There were differences in the spray regimes applied to the growers area and the forecast trial plots. A spray of Bayfidan (0.5 litres ha^{-1}) was applied to both the growers area and the forecast trial area on the 30 June 1998. Further sprays of Folicur (0.5 litres ha^{-1}) were applied on the 21 July 1998 to the forecast trial area however Bayfidan (0.5 litres ha^{-1}) was applied to the growers trial area on the same date. The grower applied a further spray of Folicur to his part of the trial on the 4 August 1998 but no sprays were applied to the forecast area at that time. Further sprays of Plover (0.3 litres ha^{-1}) were applied to both the grower's area and the forecast plots on the 24 August, and the 11 September 1998. An additional spray of Bravo (1.5 kg ha^{-1}) was applied to both the grower's area and the forecast plots on the 1 October 1998.

Table 27 Fungicide Treatments at field sites 1998 – Frieston shore site

Growers Area	30.06 - Bayfidan	(0.5 litres ha^{-1})
	21.07 - Bayfidan	(0.5 litres ha^{-1})
	04.08 - Folicur	(0.5 litres ha^{-1})
	24.08 - Plover	(0.3 litres ha^{-1})
	11.09 - Plover	(0.3 litres ha^{-1})
	01.10 - Bravo	(1.5 kg ha^{-1})
Dark leaf spot/ringspot Forecasting Area	30.06 - Bayfidan	(0.5 litres ha^{-1})
	21.07 - Folicur	(0.5 litres ha^{-1})
	24.08 - Plover	(0.3 litres ha^{-1})
	11.09 - Plover	(0.3 litres ha^{-1})
	01.10 - Bravo	(1.5 kg ha^{-1})

5.2.13 Observed ringspot and dark leaf spot on buttons at harvest at the Frieston shore trial site

Buttons were harvested at the Frieston shore site on the 7 October 1998. In harvests of whole plants from the two trial areas approximately 50 % of buttons were uninfected in the forecast plots in comparison to 40 % in the plots sprayed according to the grower's regime (Figure 59). There was lower mean numbers of lesions per infected button in the forecast area compared to the grower's trial area although the differences were small (Figure 60). Infected buttons harvested in the forecast plots had approximately 1 lesion per button. However buttons harvested from the grower's plots had 1.25 lesions per infected button. Similar results were obtained in button

Figure 59 Percentage uninfected buttons at the Frieston shore site (Whole plant sample)

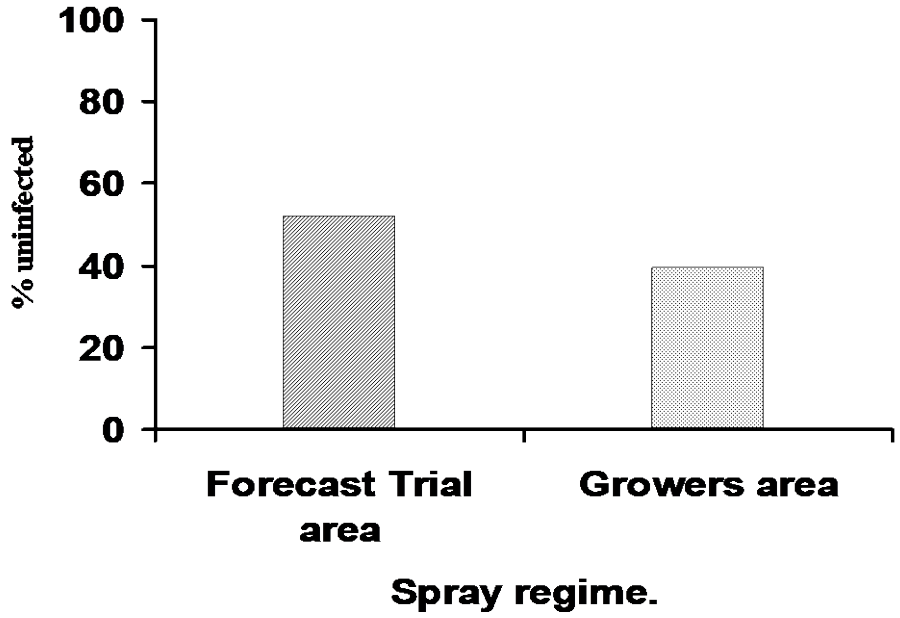


Figure 60 Mean number of lesions per button at the Frieston shore site (Whole plant sample)

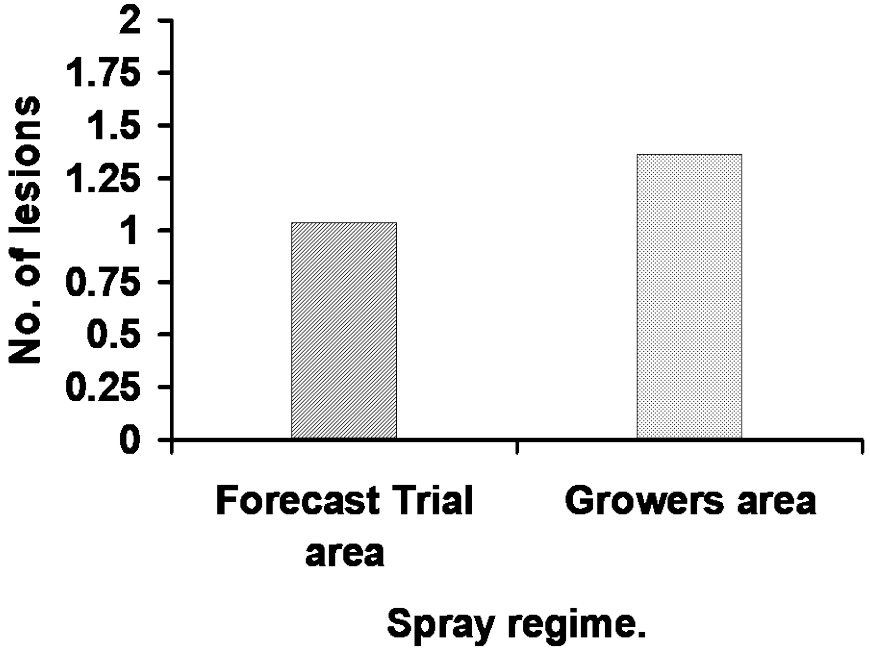
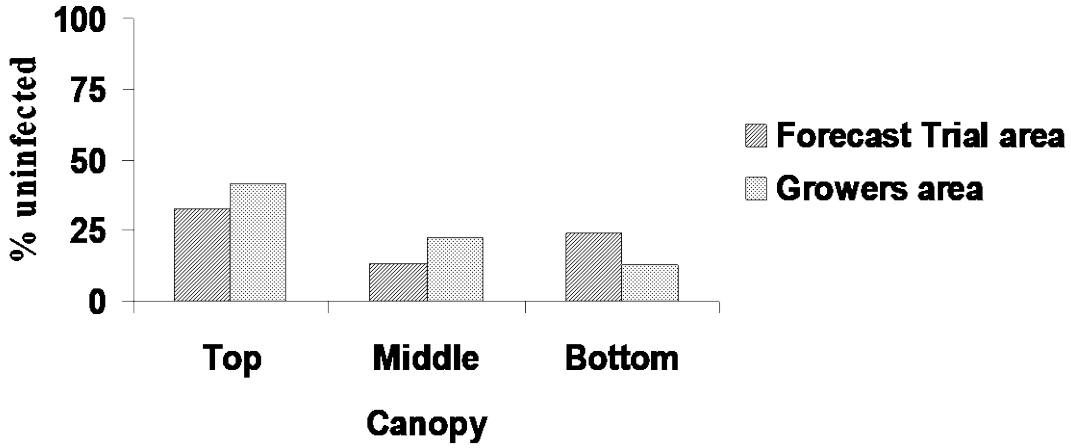


Figure 61 Percentage uninfected buttons at Frieston shore (Button sample)



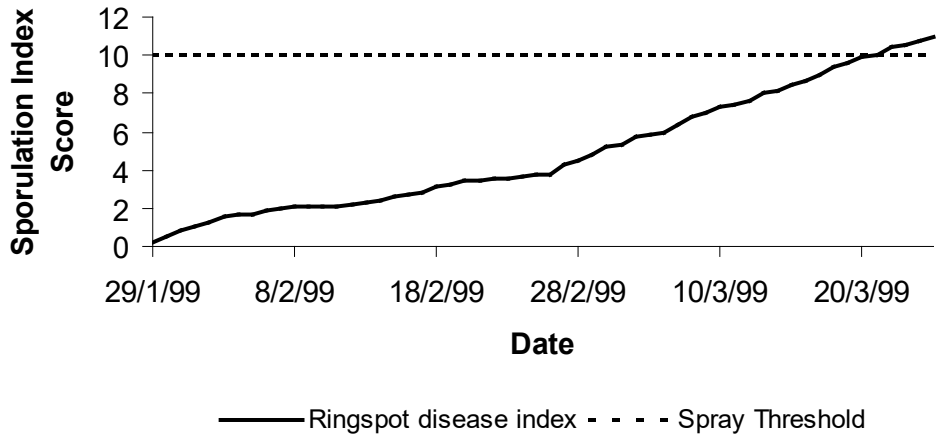
samples taken from the top middle and bottom of the canopy (Figure 61). Approximately 41 % of buttons harvested from the top of the canopy were uninfected in the grower's trial area. However 33 % of buttons sampled from the top of the canopy were uninfected in the forecast trial plots. Approximately 13 % of buttons removed from the bottom of the Brussels sprouts canopy from the growers area were uninfected. Twenty four percent of buttons removed from the bottom of the Brussels sprouts canopy were uninfected with ringspot or dark leaf spot in the forecast area of the trial at Frieston shore (Figure 61).

5.3 Development and validation of ringspot forecasts in cauliflower crops

5.3.1 Predicted ringspot development

An over-wintered cauliflower crop (cv. Jerome) was used in the 1998 trials to test ringspot forecasts on cauliflower. Plots were inoculated with infected ringspot trash on the 17 September 1998. Fresh ringspot infection was observed during mid-October 1998. Infection was uniform throughout all plots and the presence of ringspot was confirmed by isolating the ringspot pathogen from the infected leaves (as described in Section 3.1.4.2). However as only ringspot inoculum produced during curd formation would potentially cause yield losses the sprays were based on the prediction of inoculum production close to harvest. A substantial amount of fresh ringspot infection was observed on plants on the 28 January 1999 and predictions of ringspot inoculum production within the crop commenced from this time (Figure 62). Predicted ringspot inoculum production from lesions is shown in Figure 62. Inoculum production from these lesions was predicted on the 21 March 1999 (5 % of lesions producing inoculum). The secondary spray criteria (50 % of lesions producing inoculum) was not used in the trial.

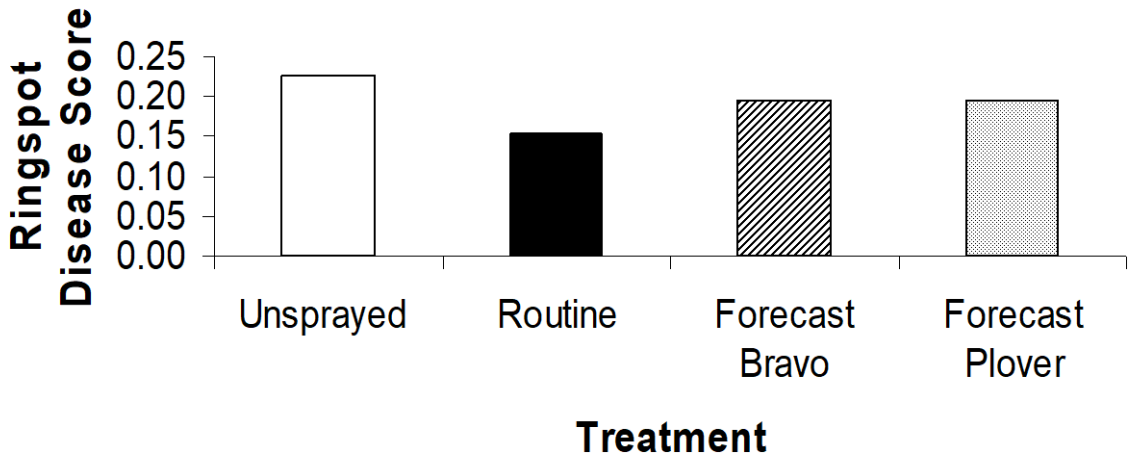
Figure 62 Predicted ringspot inoculum production (Over-wintered cauliflowers HRI Kirton)



5.3.2 Observed ringspot on cauliflower heads at harvest

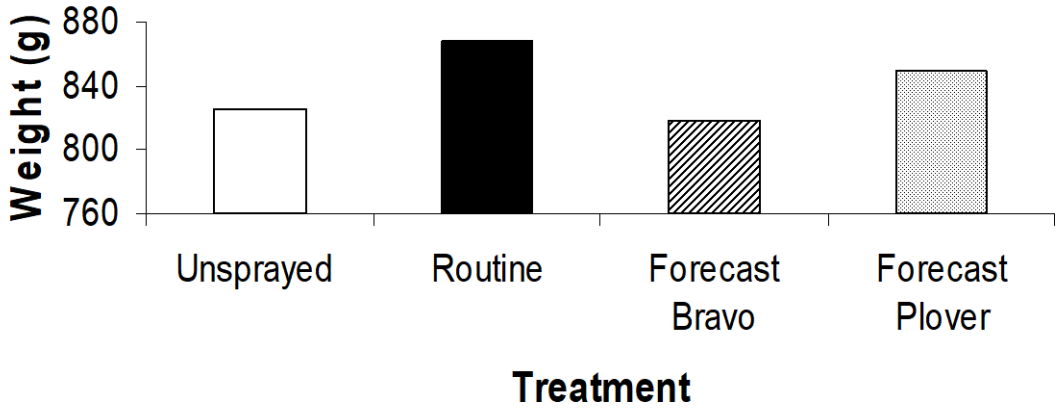
The treatments used in the cauliflower trial are stated in section 3.2.1.3. A spray of Folio (2 litres ha^{-1}) was applied to all treatment plots on the 28 August 1998 to control white blister infection which had occurred within the plots. Three applications of Plover (0.3 litres ha^{-1}) were applied to the routine treatment on the 1 February 1999, 24 February 1999 and the 17 March 1999. A spray of either Plover (0.15 litres ha^{-1}) or Bravo (3 kg ha^{-1}) was applied in the forecast treatments (5% threshold) on the 26 March 1999. Ringspot incidence was low at harvest and all harvested cauliflower heads had severity scores of below 1 (Figure 63). Mean ringspot severity scores of approximately 0.22 were observed on heads harvested from unsprayed plots on the 15 April 1999 (Figure 63). Lower severity scores of approximately 0.19 were recorded on heads harvested from forecast plots sprayed with either Plover or Bravo. The lowest mean ringspot severity score (0.15) was observed on cauliflowers harvested from the routine treatment. There was no significant difference in the level of ringspot on harvested heads regardless of treatment.

Figure 63 Ringspot disease scores on harvested cauliflower heads 1998 (HRI Kirton)



The weight of cauliflower curds at harvest is shown in Figure 64. The highest mean head weight (869 g) was harvested from the routinely spayed treatment. However the mean cauliflower head weight harvested in the unsprayed plot was 825 g. A single application of Plover applied according to the ringspot forecast produced mean head weights of 849 g (Figure 64). The results suggest that there was little effect of ringspot on cauliflower yield in this trial.

Figure 64 Mean head weight of cauliflowers heads in 1998 (HRI Kirton)



5.3.3 Ringspot development on cauliflower leaves pre harvest

Very low levels of ringspot were observed in all treatments due to the predominantly to dry conditions which occurred in January 1999. There were few differences between treatment in the numbers of lesions per leaf. Mean numbers of ringspot lesions per leaf were approximately 1 (data not presented).

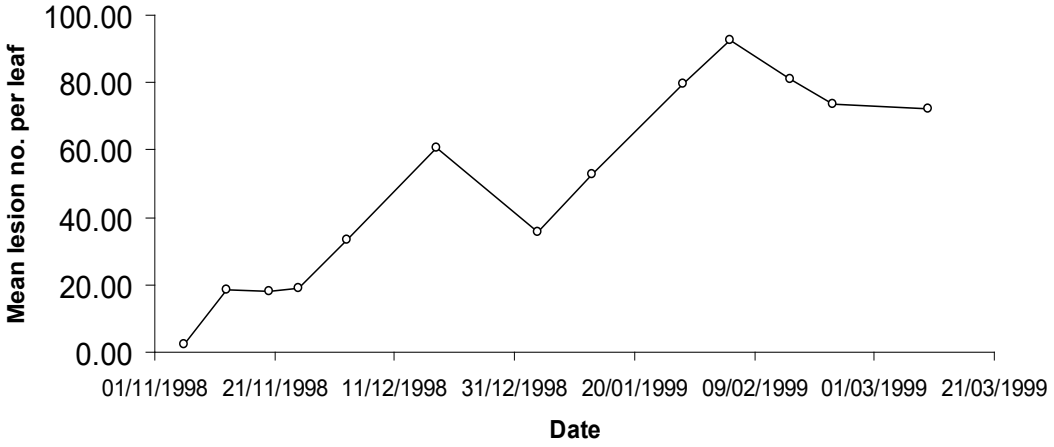
5.4 Use of the ringspot forecaster in commercial cauliflower crops

5.4.1 Observed disease development in a commercial crop of cauliflowers

In an over-wintered cauliflower crop in Cornwall in 1998/1999 there was an increase in the numbers of ringspot lesions per leaf from first sampling on the 6 November 1998 until the 13 November 1998 (Figure 65). A second period of disease increase occurred

between the 3 December 1998 and the 18 December 1998. Further disease development was observed in the plot between the 13 January 1999 and the 18 February 1999.

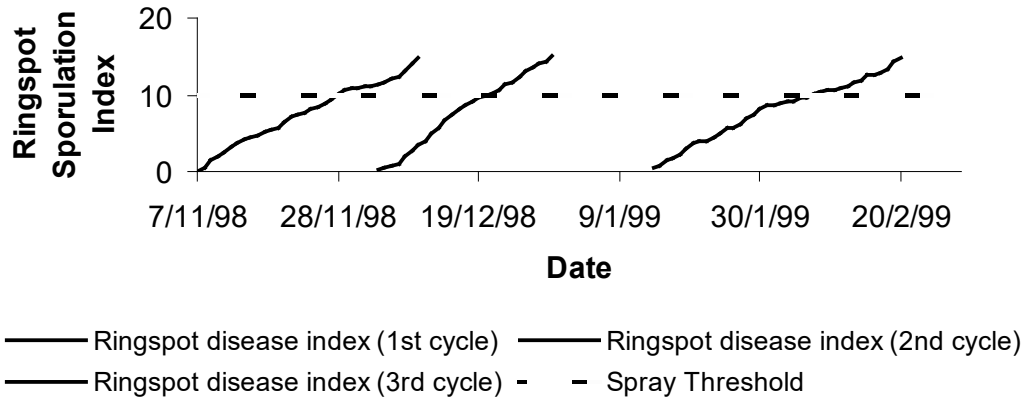
Figure 65 Mean number of lesions per leaf on commercial cauliflower plants in Cornwall 1998/99



5.4.2 Predicted inoculum production at the field site in Cornwall

The predicted inoculum production, based on observations taken in the crop, are shown in Figure 66. Three periods of increased disease development were observed from leaf observations in the crop. Based on these observations fungicides could have been applied to the crop on the 28 November 1998 (1st cycle), 20 December 1998 (2nd cycle), and the 7 February 1999 (3rd cycle). Application of fungicides at any one of these timings would have slowed disease development. However due to very wet conditions fungicide sprays were applied on the 18 January 1999 as this period was the only one suitable for field spays operations to be carried out. At harvest observations taken from the crop showed that ringspot was present only at very low levels. On many cauliflowers plants ringspot was undetectable. There was no significant effect of ringspot on cauliflower yield. Harvested heads had on average 0.12 lesions per plant.

Figure 66 Predicted ringspot disease development in a commercial cauliflower crop in 1998 (Camborne, Cornwall)



6. RESULTS 1999

6.1 Non replicated observational trials in 1999

6.1.1 Initial crop infection by ringspot, dark leaf spot and other leaf spot pathogens at non-replicated trial sites in 1999

Disease pressure at all test sites in Lincolnshire was high and early ringspot infection was detected at all test sites. Conditions were conducive for rapid disease development by foliar pathogens of Brussels sprouts and cauliflowers. Very wet conditions were observed during mid August, late September and early October 1999 which were conducive to rapid disease development by all foliar pathogens which occur on Brussels sprouts (Figure 67ab, 68ab). On many days during this period 20 – 30 mm of rainfall was recorded. However time at which first infection by *Mycosphaerella brassicicola* (ringspot), *Alternaria brassicae* (dark leaf spot) and *Albugo candida* (white blister) occurred at all test sites was variable (Table 28). Ringspot, dark leaf spot and white blister were observed at Hesketh Bank during mid July 1999. In Scotland (Arbroath) only dark leaf spot was observed at the observation site. No white blister or ringspot infection was detected however the site did become infected by light leaf spot (*Pryenopeziza brassicae*) during mid October 1999. Ringspot, white blister and dark leaf spot were first observed at Ross-on-Wye during July 1999 (Table 28).

Figure 67 Air temperature (a) and rainfall (b) Farndon, Cheshire 1999

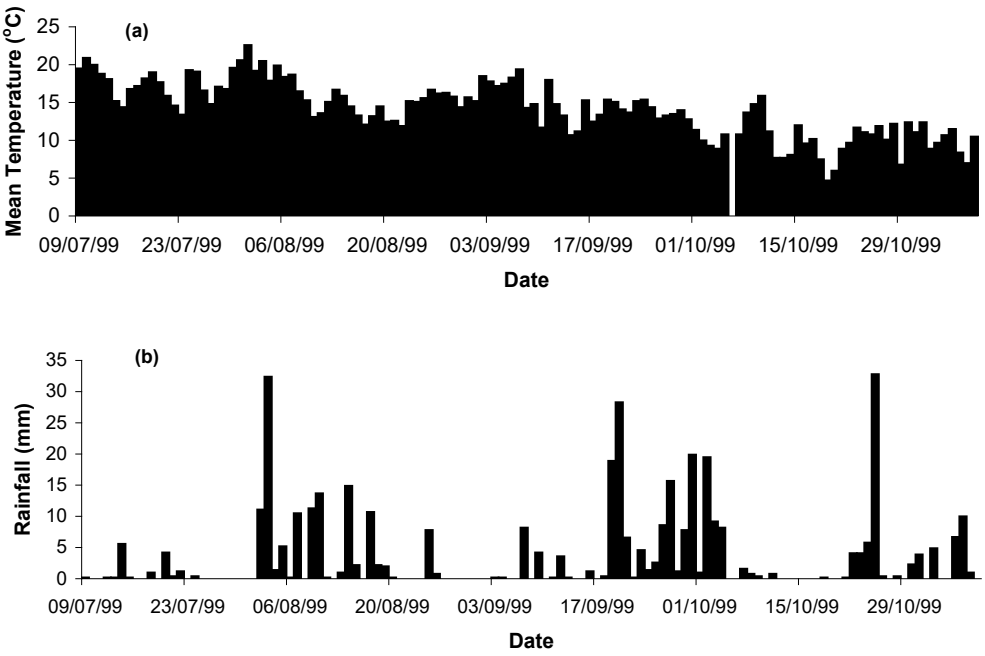


Figure 68 Air temperature (a) and rainfall (b) Frieston Shore 1999

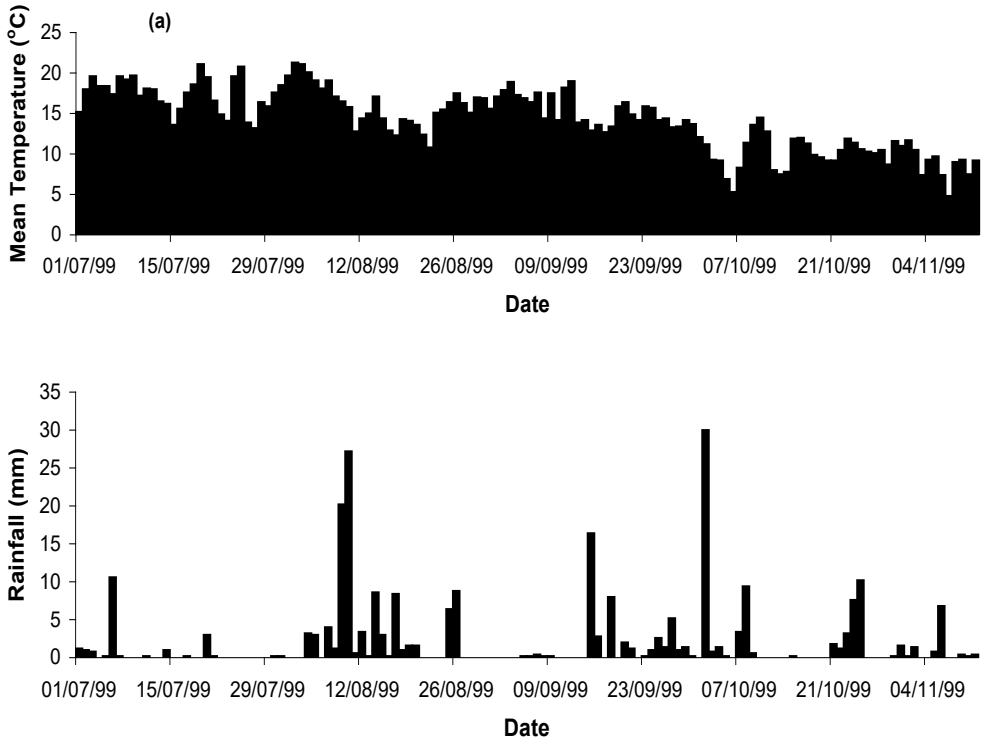


Table 28 Initial infection by foliar pathogens on Brussel sprouts at all test sites in 1999

Site	Planting Date	*Albugo* (White blister)	*Alternaria* (Dark leaf spot)	*Mycosphaerella* (Ringspot)
Grower/Forecast Treatments				
Farndon	20/5	23/7	23/7	16/7
Skegness	NA	26/7	3/8	1/7
Frieston Shore	NA	26/6	1/7	1/6
Grower Treaments only				
Hesketh Bank	7/5	12/7	19/7	13/7
Ross-on-Wye	NA	2/7	26/7	26/7
Arbroath	NA	NI	10/8	NI

NA – Not Available

NI -- Not Infected

6.1.2 Predicted ringspot and dark leaf spot disease development

Hesketh Bank

Ringspot and dark leaf spot were first observed at the Hesketh Bank site in 1999 on the 13 and 19 July 1999 respectively at which time predictions of disease development commenced (Figure 69). The first predicted spray timing threshold was reached for ringspot alone on the 4 August 1999. A spray of Plover (0.3 litres ha^{-1}) was applied to the crop on the 17 August 1999 (Table 29). Further ringspot was observed in the crop on the 16 August 1999 indicating that it was most likely linked to the initial ringspot outbreak. Predicted dark leaf spot development was initially slow. However the first dark leaf spot spray threshold was reached on the 5 September 1999 and this coincided with a secondary ringspot spray threshold on the 7 September 1999. A further spray of Plover was applied on the 16 September (0.3 litres ha^{-1}). The secondary dark leaf spot spray threshold was reached on the 26 September 1999 however a further spray of Plover (0.3 litres ha^{-1}) was applied to the crop on the 29 September 1999. Few other air-borne fungal pathogens were present at this trial site. Further sprays of Folicur (0.75 litres ha^{-1}) were applied to the crop on the 20 October and 13 November 1999. White blister (*Albugo candida*) was first observed in the crop on the 12 July 1999 (Table 28). The predicted occurrence of white blister in the crop is shown in Figure 70. A spray of Folio (2.0 Kg ha^{-1})was applied to the crop on the 9 July 1999. Maximum activity by

Albugo candida at the Hesketh Bank site was predicted to occur between the 19 and 30 September 1999 (Figure 70).

Table 29 Fungicide Treatments at field sites 1999 – Hesketh Bank

Growers Area	09.07 - Folio	(2 kg ha^{-1})
	17.08 - Plover	(0.3 litres ha^{-1})
	16.09 - Plover	(0.3 litres ha^{-1})
	29.09 - Plover	(0.3 litres ha^{-1})
	20.10 - Folicur	(0.75 litres ha^{-1})
	13.11 - Folicur	(0.75 litres ha^{-1})

Figure 69 Predicted disease development (Hesketh Bank trial site 1999)

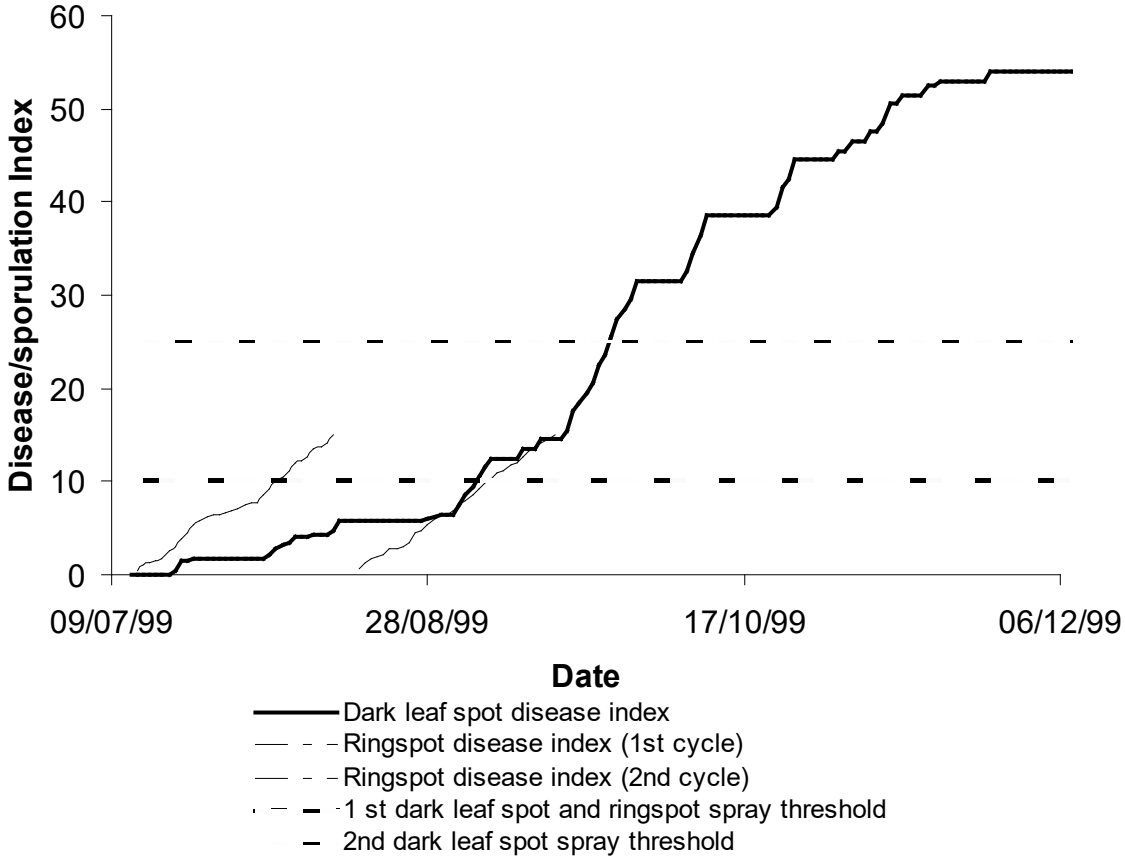
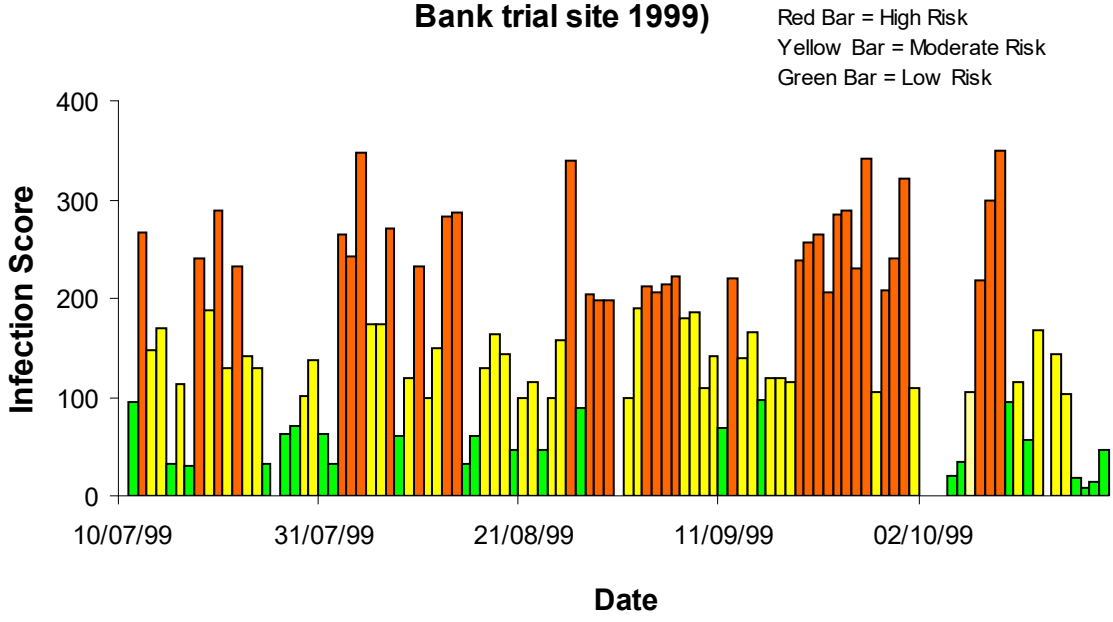


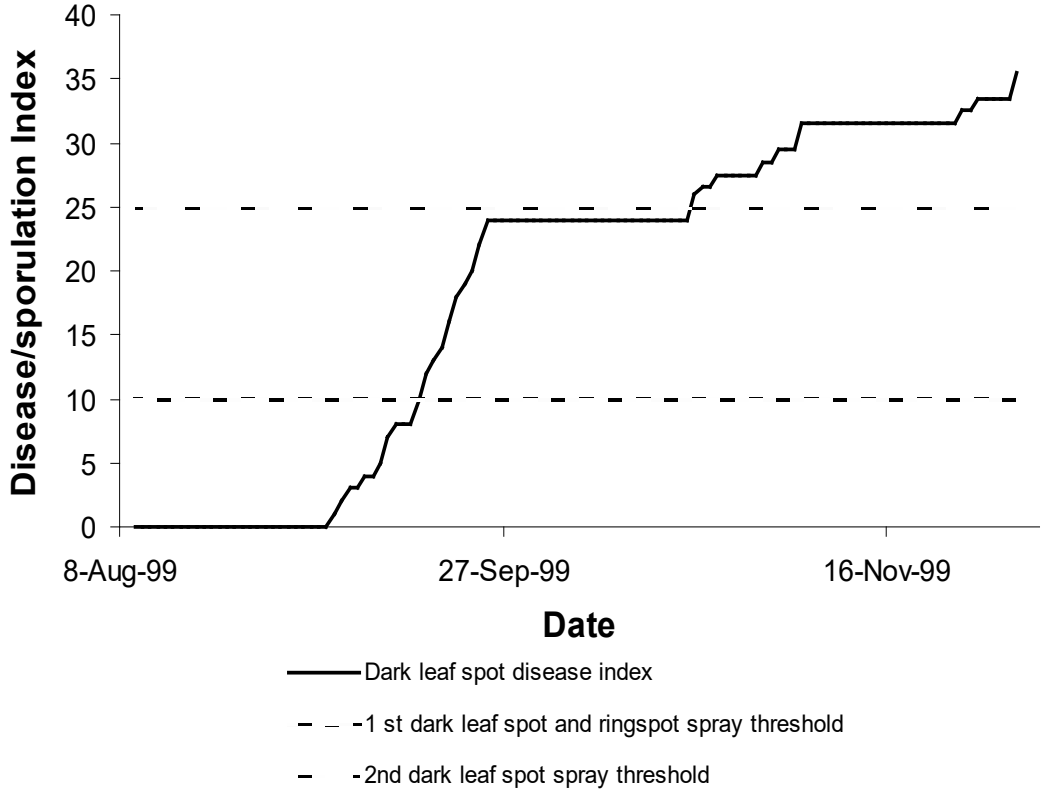
Figure 70 Predicted Occurrance of *Albugo candida* (Hesketh Bank trial site 1999)



Arbroath

Only dark leaf spot was observed at this trial site. First observations were made on the 10 August 1999 (Table 28). The initial dark leaf spot threshold was reached on the 16 September 1999 (Figure 71). The secondary dark leaf spot spray threshold was reached on the 22 October 1999. Brussels sprouts plants within the observation site were infected with light leaf spot, which had originated from an adjacent field of oilseed rape. No infection by white blister was observed in the crop at this site (Table 28).

Figure 71 Predicted disease development (Arbroath trial site 1999)



Ross-on-Wye

Both ringspot and dark leaf spot were both observed initially at the Ross-on-Wye site on the 26 July 1999 (Table 28). White blister was observed in the crop during early July 1999. However due to technical difficulties with the weather station on site no weather information could be collected and model predictions were therefore not produced by HRI for this site. Only maximum and minimum temperatures were available to HRI during the growing season. It is possible that these can still be used to generate model prediction. However this work is outside the remit of this technical report.

6.1.3 Observed ringspot and dark leaf spot on buttons at harvest

Samples of Brussels sprouts shanks were removed from different areas of the field or plots as described in section 3.3.4.2. At observational sites in 1999 only whole plant assessments were taken on plants removed from one area of the site. Each trial area consisted of the growers treatment only with the exception of the Arbroath site where one plot was used to test forecast disease predictions in comparison to the rest of the field (where the growers practice was followed). All Brussels sprout buttons were removed from all harvested plant shanks and assessed as described in section 3.3.4.2.

Hesketh Bank

Approximately 68 % of buttons harvested from the crop were uninfected by either ringspot or dark leaf spot (Figure 72a). Buttons were harvested at the Hesketh Bank site on the 20 December 1999 and all harvested buttons were grade I marketable. The mean lesion numbers on infected buttons harvested from the shank was low at under one lesion per infected button (Figure 72b).

Arbroath

Buttons were harvested at the Arbroath site on the 22 December 1999. Approximately 40 % of buttons were uninfected by dark leaf spot or ringspot in the forecast trial area (Figure 73a). In comparison 44 % of buttons were infected with dark leaf spot in the remaining area of the field. There was approximately 1.73 lesions per infected button harvested from the forecast trial area in contrast each infected button harvested from the growers area had on average 1.59 lesions (Figure 73b). At this site the majority of buttons (90 – 100 %) were infected with light leaf spot and it proved difficult to differentiate light leaf spot, early ringspot or dark leaf spot symptoms on the button.

Ross-on-Wye

Button harvests were taken at the Ross-on-Wye site on the 1 February 2000. Only whole Brussels sprout shanks were harvested and assessed at this site. Approximately 80 % of buttons sampled were uninfected (Figure 74a).. There were low numbers of lesions per infected button (approximately 0.25) in the button sample (Figure 74b). Other diseases were also present at very low levels.

Figure 72 The percentage uninfected buttons (a) and mean number of lesions per infected button (b) harvested at Hesketh Bank 1999

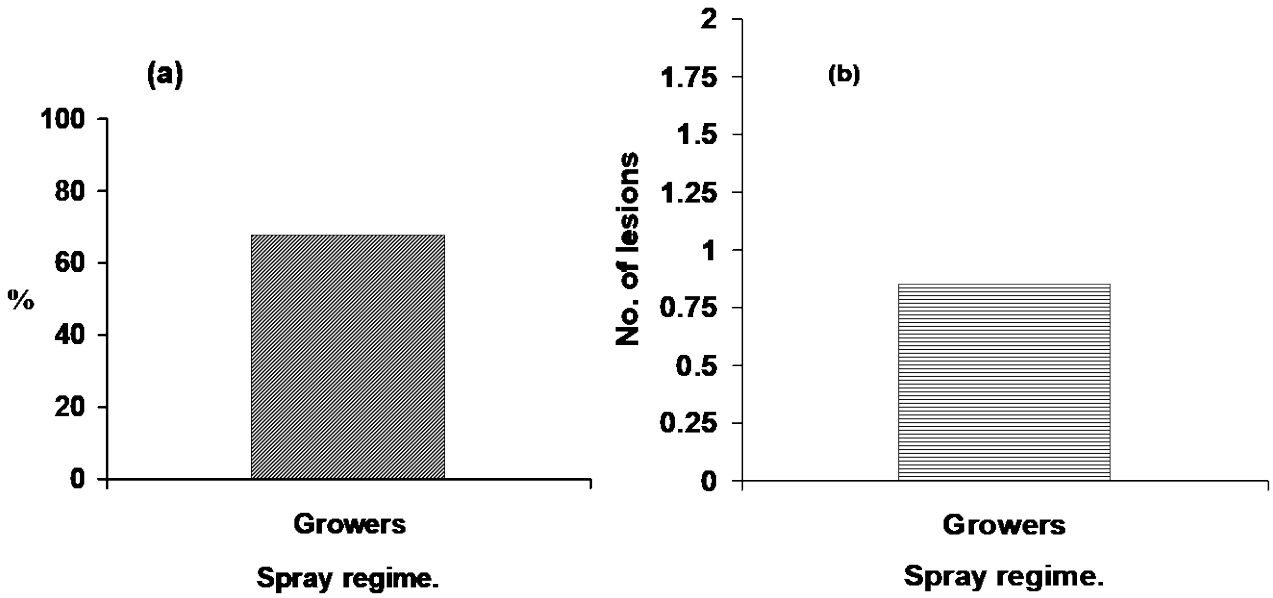


Figure 73 The percentage uninfected buttons (a) and mean number of lesions per infected button (b) harvested at Arbroath in 1999

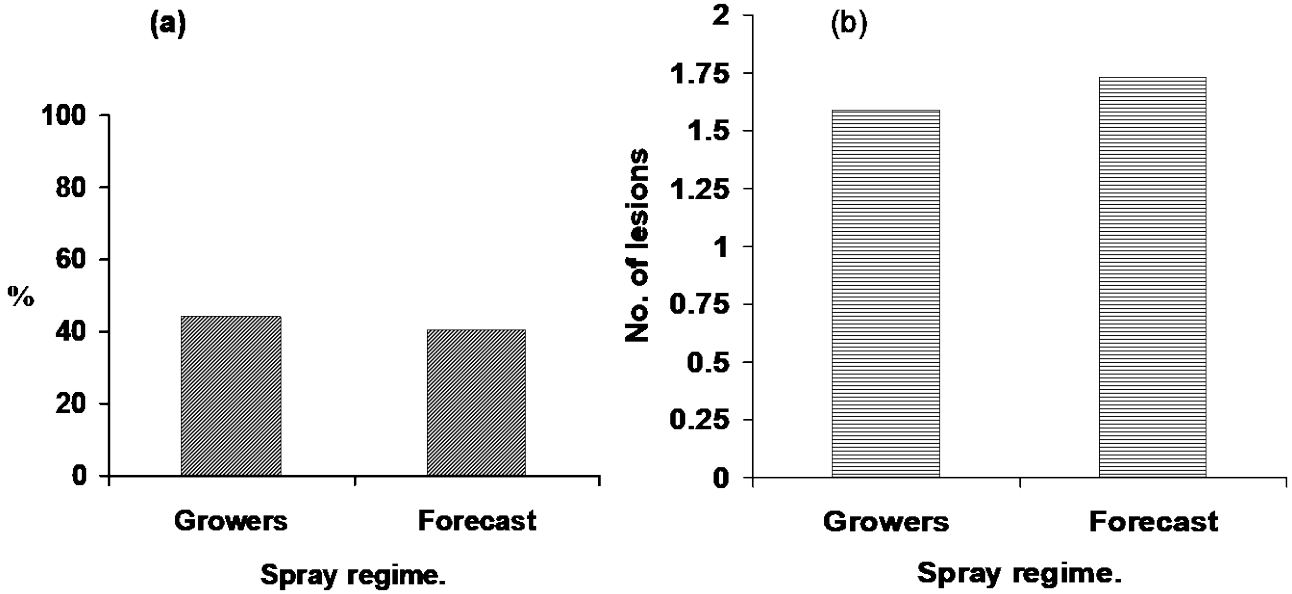
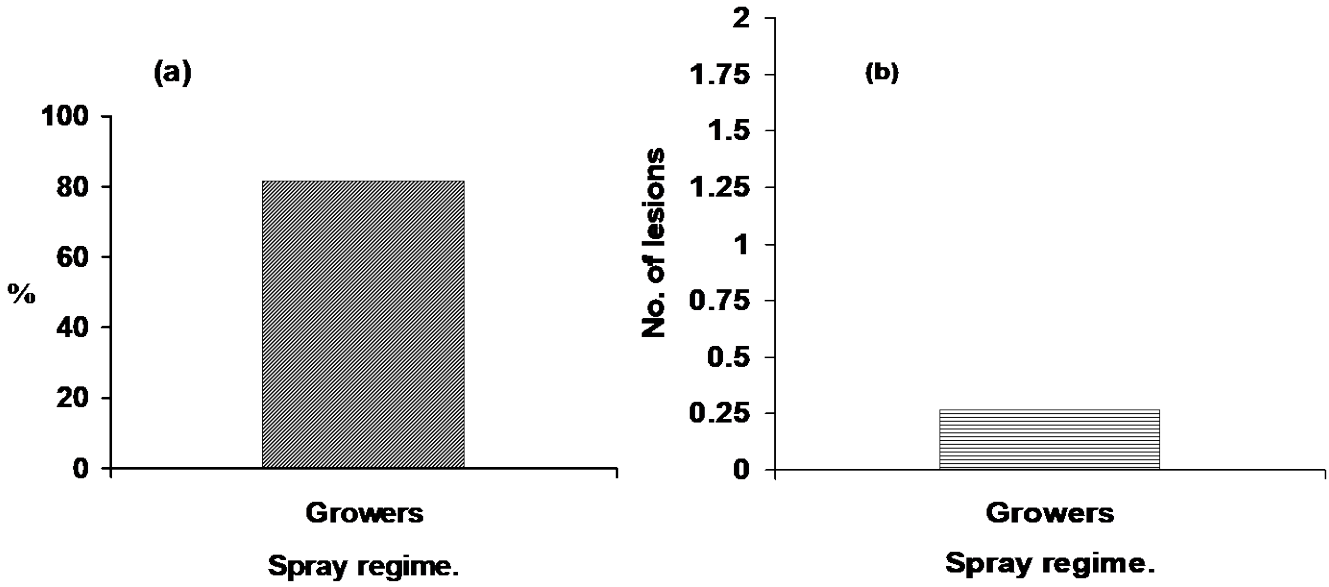


Figure 74 The percentage uninfected buttons (a) and mean number of lesions per infected button (b) harvested at Ross-on-Wye 1999



6.2 Ringspot and dark leaf spot forecast usage in replicated trials in commercial crops in 1999 - 2000

6.2.1 Initial crop infection by ringspot, dark leaf spot and other leaf spot pathogens

Three replicated trials were conducted at commercial sites in 1999 – 2000. Two sites were situated in coastal areas of Lincolnshire with a third located on Farndon in Cheshire. Ringspot, dark leaf spot and white blister was present at all sites (Table 28). In Lincolnshire at the Frieston shore site high levels of ringspot were first observed in the crop on the 1 June 1999. Dark leaf spot and white blister were not detected at this site until the 26 June and the 1 July 1999 respectively. At the Skegness ringspot was observed at low levels on the 1 July 1999 however, white blister and dark leaf spot infection were not observed until the 26 July and the 3 August 1999 respectively. Both diseases occurred at low levels in the crop. At Farndon all diseases occurred at very low levels especially ringspot. Dark leaf spot and white blister were first observed on the 23 July 1999 (Table 28). Ringspot infection was first observed at Farndon on the 16 July 1999. Both *Erysiphe cruciferarum* and *Peronospora parasitica* (downy mildew) were also present at all sites especially at Frieston shore.

6.2.2 Predicted disease development Farndon, Cheshire

Prediction of dark leaf spot development commenced at the Hesketh bank site 23 July 1999 (Table 28). Predicted dark leaf spot development was rapid and the first dark leaf spot spray threshold was not reached until the 5 September 1999 (Figure 75). The second dark leaf spot spray threshold was reached on the 29 September 1999. Ringspot disease levels in the crop were very low. However the initial ringspot sporulation index was reached on 5 August 1999 (Figure 75). Early high-risk white blister infection periods were recorded in the crop on the 9 and 11 July 1999 (Figure 76). There was a significant period of potential high-risk infection from the 2 August 1999 until the 7 August 1999 and from the 2 September 1999 until the 6 September 1999. Risk of white blister infection remained high from the 18 September until the 30 September 1999 and from the 21 October to the 5 November 1999 (Figure 76).

Figure 75 Predicted disease development (Farndon trial site 1999)

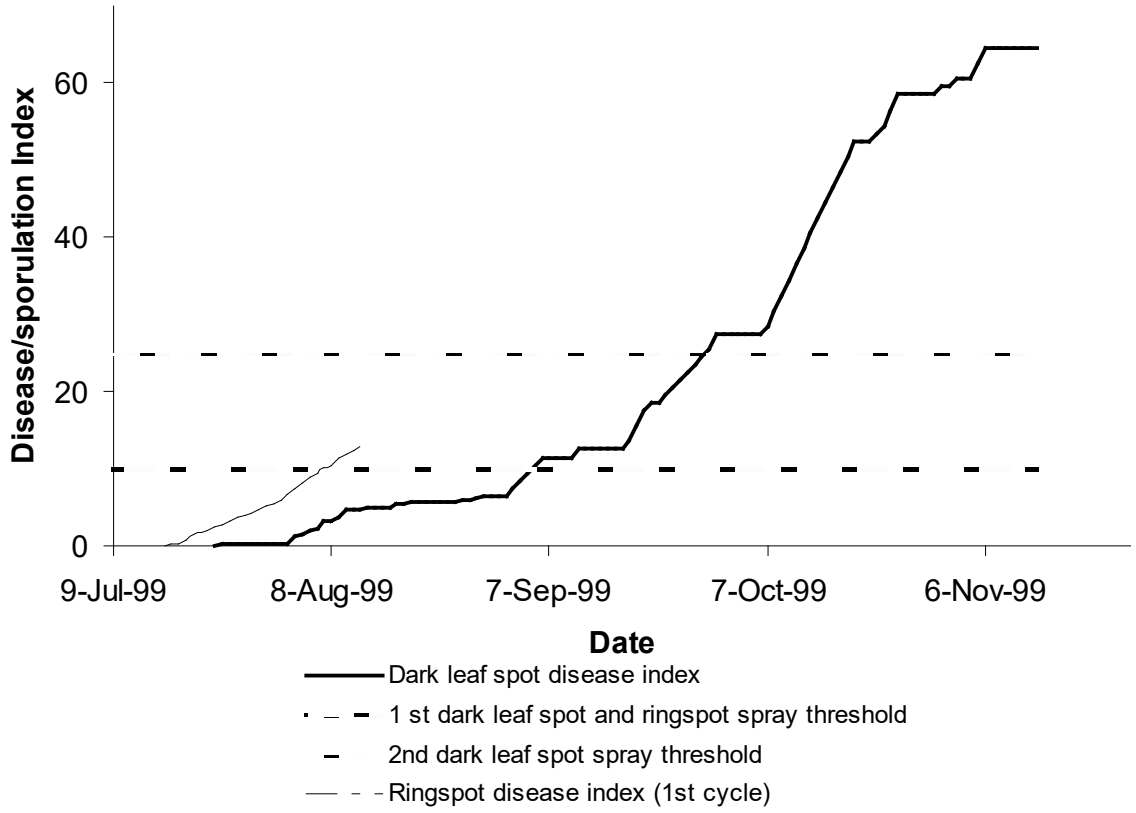
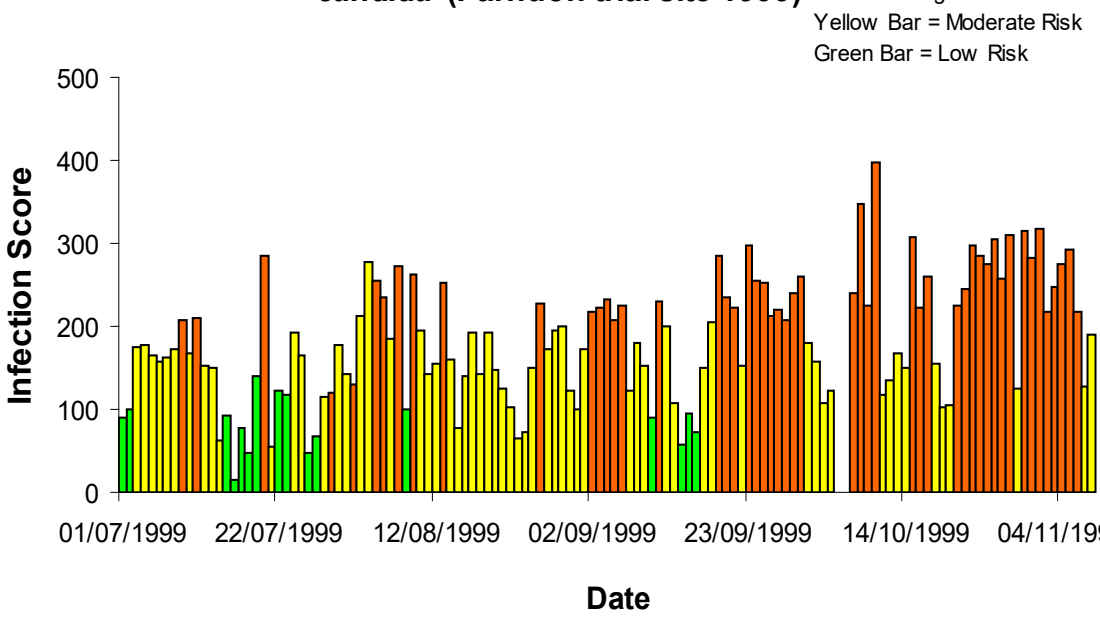


Figure 76 Predicted infection (50 % threshold) by *Albugo candida* (Farndon trial site 1999)



6.2.3 Observed ringspot and dark leaf spot on leaves during the growth season at Farndon in 1999

There were few differences in the mean numbers of lesions on leaves assessed in the forecast and growers trial areas (Figure 77). There were on average approximately 2 lesions per leaf in counts taken from both the forecast and the growers trial area at Farndon on the 23 July 1999 however this had declined to approximately 1 lesions per leaf at the second assessment taken on the 2 September 1999 in both trial areas.

6.2.4 Fungicide sprays applied at the Farndon trial site in 1999

Fungicides applied at the Farndon site are shown in Table 30. A spray of Plover at 0.3 litres ha^{-1} with Folio at 2.0 kg ha^{-1} was applied on the 29 July 1999 to both the growers trial area and the forecast plots at Farndon. This spray was applied to the forecast plots at first recognition of dark leaf spot and in response to a prediction of ringspot inoculum production in the crop. A further spray of Plover at 0.3 litres ha^{-1} was applied on the 11 and 22 September 1999 to the forecast and growers area respectively. This spray was applied to the forecast plots in response to the initial dark leaf spot disease threshold predictions. Due to the presence of powdery mildew at the site Bayfidan was applied to both the growers and the forecast trial areas on the 24 September 1999. A further spray application of Plover (0.3 litres ha^{-1}) was applied, on the 14 October 1999, in response to the predictions of the secondary dark leaf spot disease threshold at Farndon (Table 30).

Figure 77 Observed disease development by dark leaf spot and ringspot on leaves (Farndon Trial 1999)

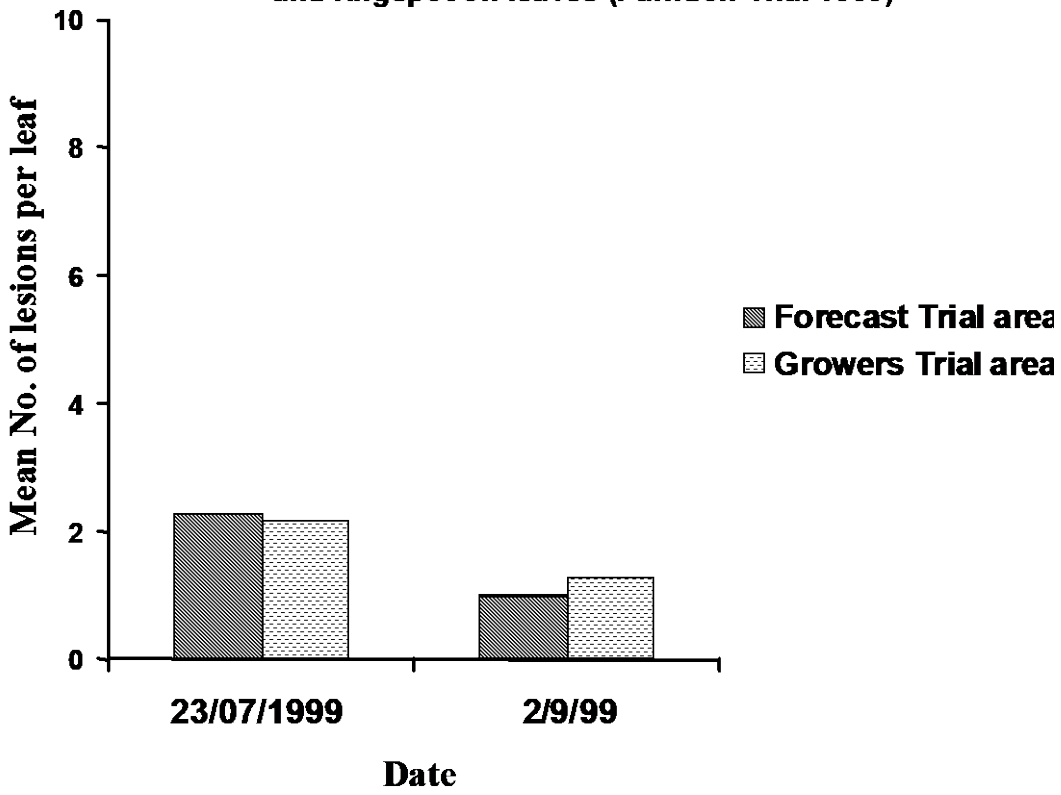


Table 30 Fungicide Treatments at field sites 1999 – Farndon

Growers Area	29.07 -	Plover	(0.3 litres ha^{-1})
		Folio	(2.0 kg ha^{-1})
	11.09 -	Plover	(0.3 litres ha^{-1})
	24.09 -	Bayfidan	(0.5 litres ha^{-1})
	14.10	Plover	(0.3 litres ha^{-1})
Dark leaf spot/ringspot Forecasting Area	29.07 -	Plover	(0.3 litres ha^{-1})
		Folio	(2.0 kg ha^{-1})
	22.09 -	Plover	(0.3 litres ha^{-1})
	24.09 -	Bayfidan	(0.5 litres ha^{-1})
	14.10	Plover	(0.3 litres ha^{-1})

6.2.5 Observed ringspot and dark leaf spot on buttons at harvest at Farndon 1999

Buttons were harvested at Farndon on the 17 December 1999. The percentage of uninfected buttons harvested from the grower's trial area and the forecast trial area (whole plant shanks samples) are shown in Figure 78. Approximately 86 % of buttons harvested from the forecast area of the trial were uninfected by either ringspot or dark leaf spot. However 72 % of buttons were uninfected of those harvested from the growers area at the trial site. The mean number of lesions per infected Brussels sprout button was 0.25 and 0.56 in the forecast and grower areas of the trial respectively at Farndon in 1999 (Figure 79). There was no significant difference between areas when the whole Brussels sprout shank was assessed. There were approximately 90, 60 and 60 % uninfected buttons in the button sample harvested from the top middle and bottom of the Brussels sprout shanks in the forecast trial area respectively (Figure 80). Few differences were observed between the top middle and bottom of the Brussels sprout shank in the button sample removed from the growers trial area (Figure 81). Mean lesion numbers on infected buttons were higher in the forecast trial area (middle and bottom) than on infected buttons removed from all areas of the grower trial area in button samples taken at the Farndon trial site in 1999 (Figure 81). Higher infection levels were observed on buttons harvested from the bottom of the canopy in both forecast and grower trial areas.

Figure 78 Percentage uninfected buttons at Farndon 1999 (whole plant sample).

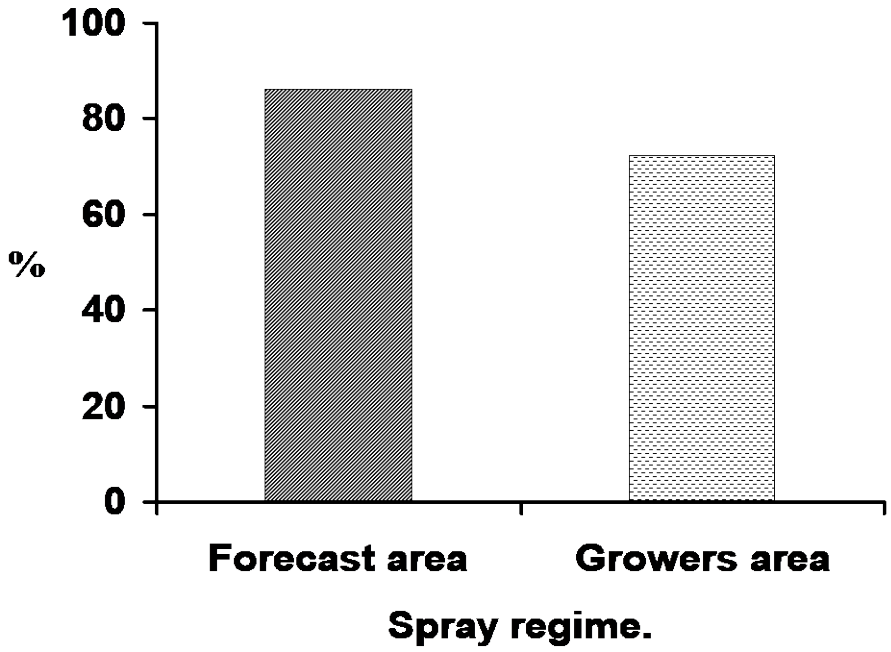


Figure 79 Mean number of lesions per button at Farndon 1999 (whole plant sample).

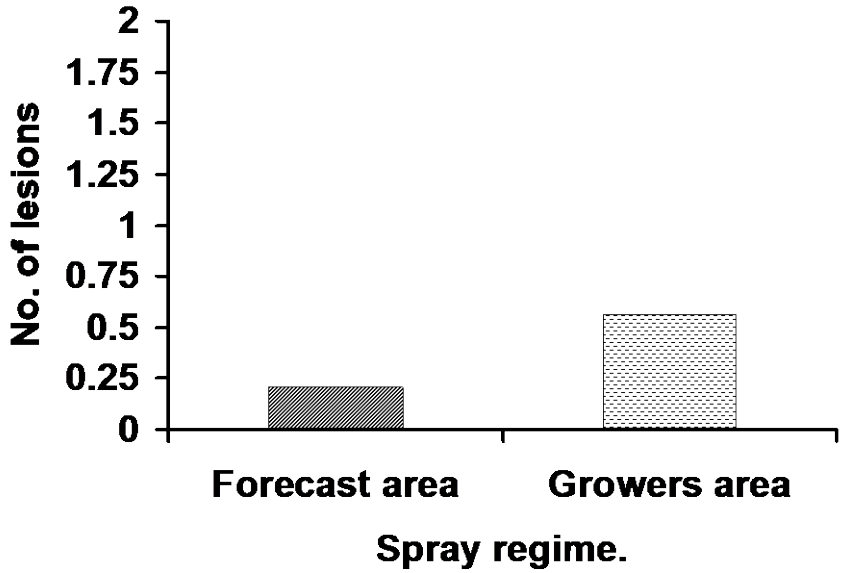


Figure 80 Percentage uninfected buttons at Farndon 1999 (Button sample)

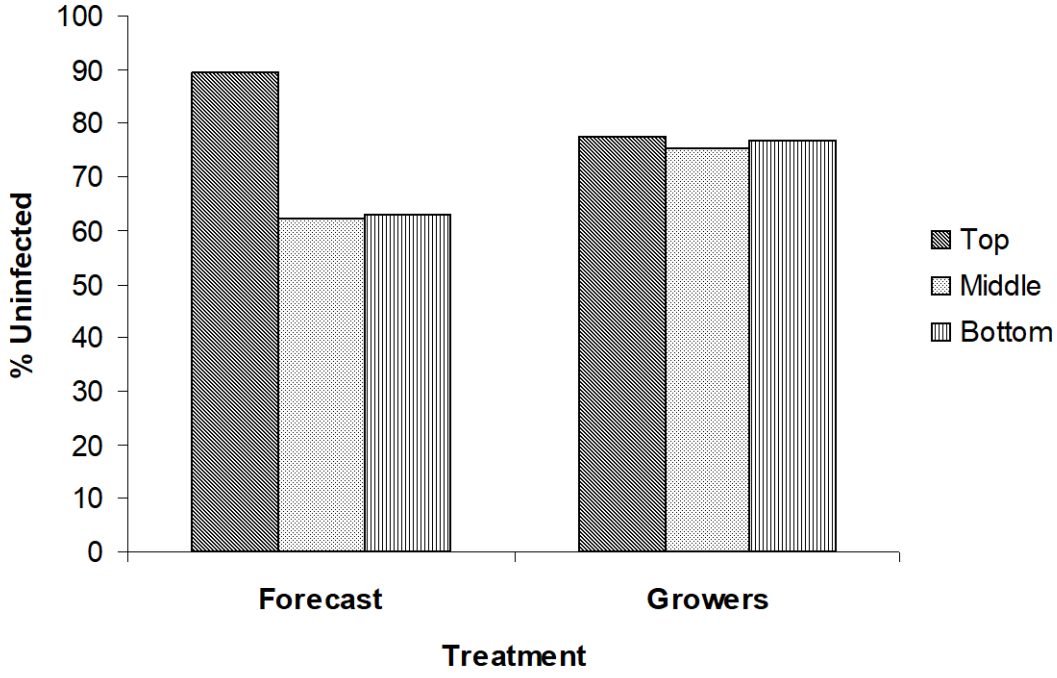
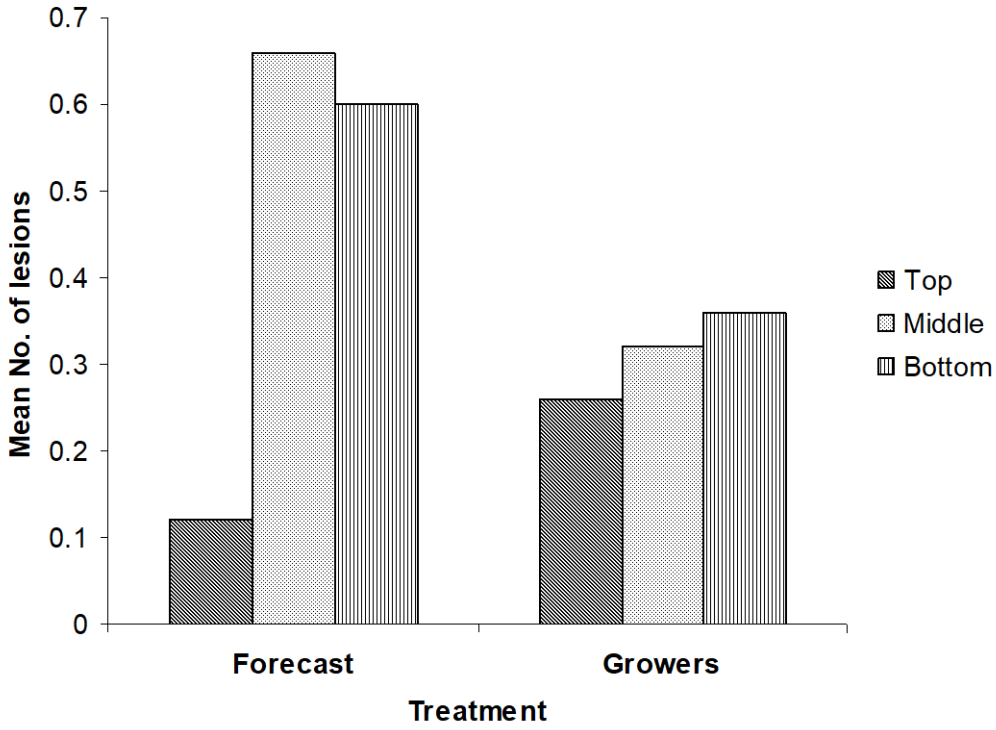


Figure 81 Mean number of lesions per infected button at Farndon1999 (Button sample)



6.2.6 Predicted disease development Skegness, Lincolnshire

Prediction of dark leaf spot development commenced at the Skegness site 3 August 1999 (Table 28). Predicted dark leaf spot development was rapid and the first dark leaf spot spray threshold was not reached until the 6 September 1999 (Figure 82). The second dark leaf spot spray threshold was reached on the 21 September 1999. Ringspot was observed in the crop on the 1 July 1999 (Figure 82). The ringspot spoulation index was reached on the 20 July 1999. No further ringspot lesions were observed in the crop after this time period. Early high-risk white blister infection periods were recorded in the crop on the 9 and 11 July 1999 (Figure 83). There were significant periods of high-risk infection occurred during the period 28 June 1999 until the 20 July 1999 and from the 4 August 1999 until the 14 August 1999. The highest white blister risk period occurred during the period 20 September until the 4 October 1999 however there was also a number of significant risk periods from the 21 October 1999 until the 14 November 1999.

Figure 82 Predicted disease development (Skegness trial site 1999)

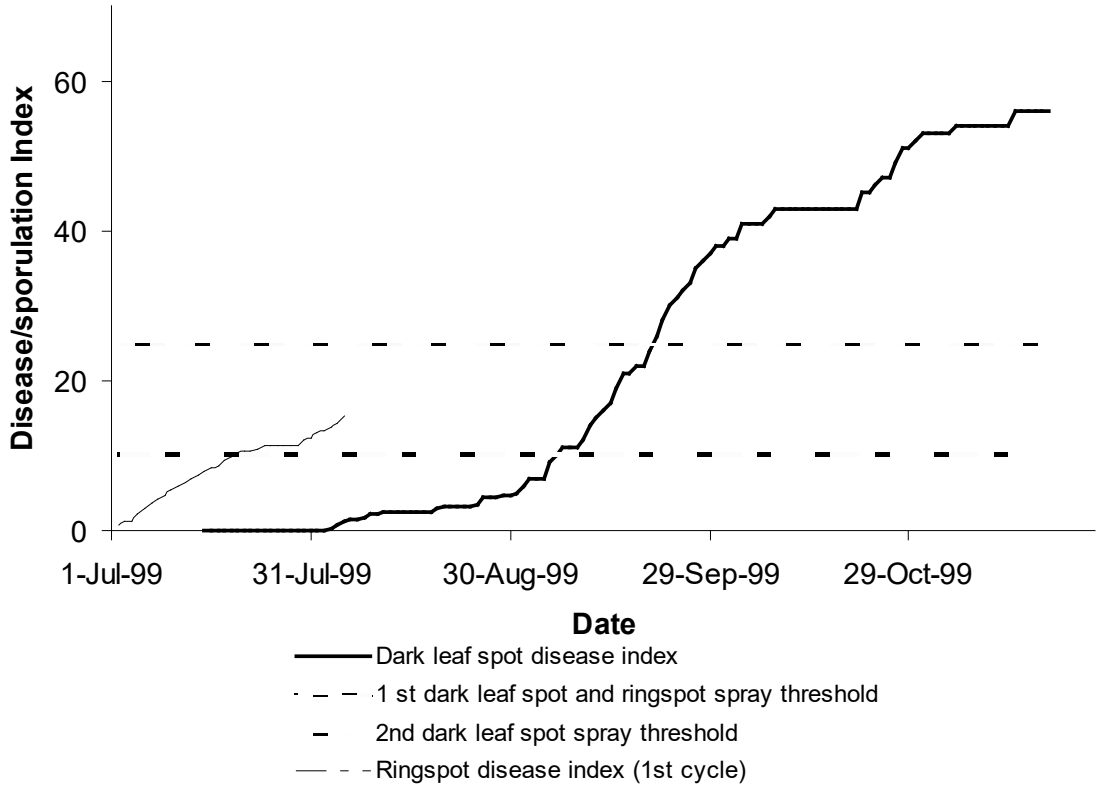
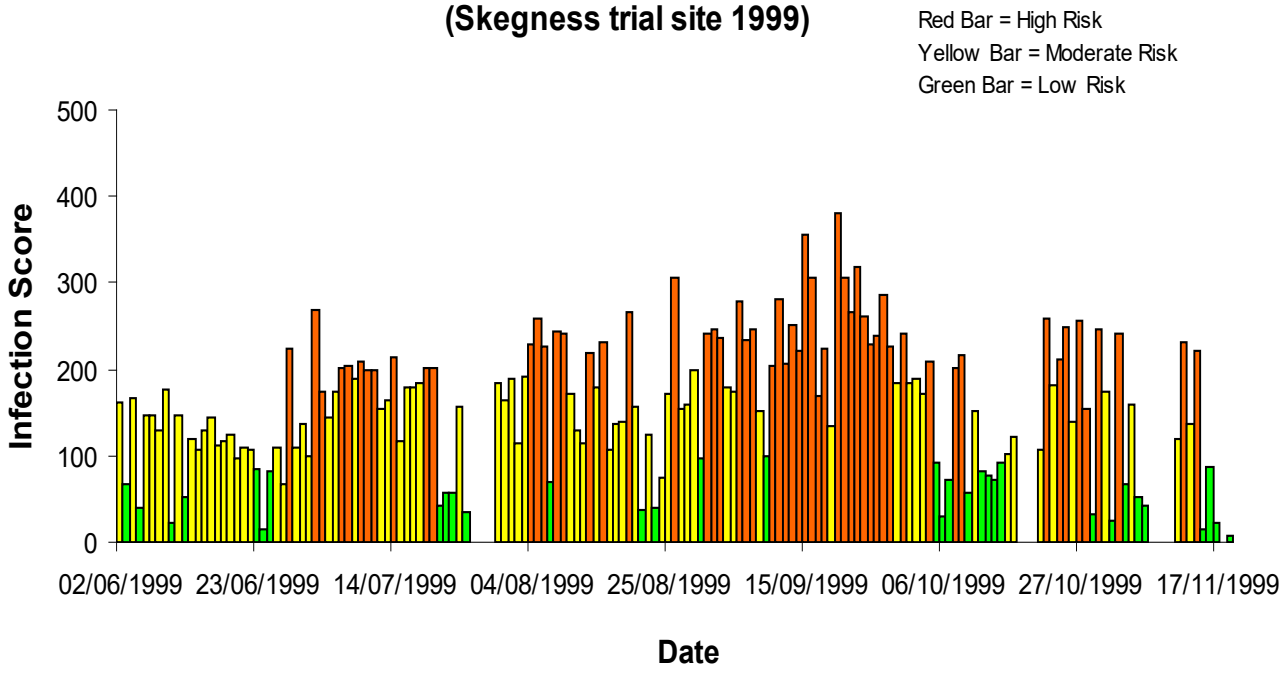


Figure 83 Predicted infection (50 % threshold) by *Albugo candida* (Skegness trial site 1999)



6.2.7 Observed ringspot and dark leaf spot on leaves during the growth season at Skegness in 1999

The mean numbers of lesions on leaves assessed in the forecast and growers trial areas at Skegness are shown in Figure 84. There were on average approximately 2 lesions per leaf on leaves assessed in the growers trial area at Skegness during August 1999. The number of lesions per leaf increased to 2.34 when the same leaves were assessed on 9 September 1999. However the numbers of lesions per leaf on leaves assessed in the forecast trial area on the 10 August 1999 was 1.66 but this value declined to 1.29 in assessments taken on the 9 Serptember 1999 (Figure 84).

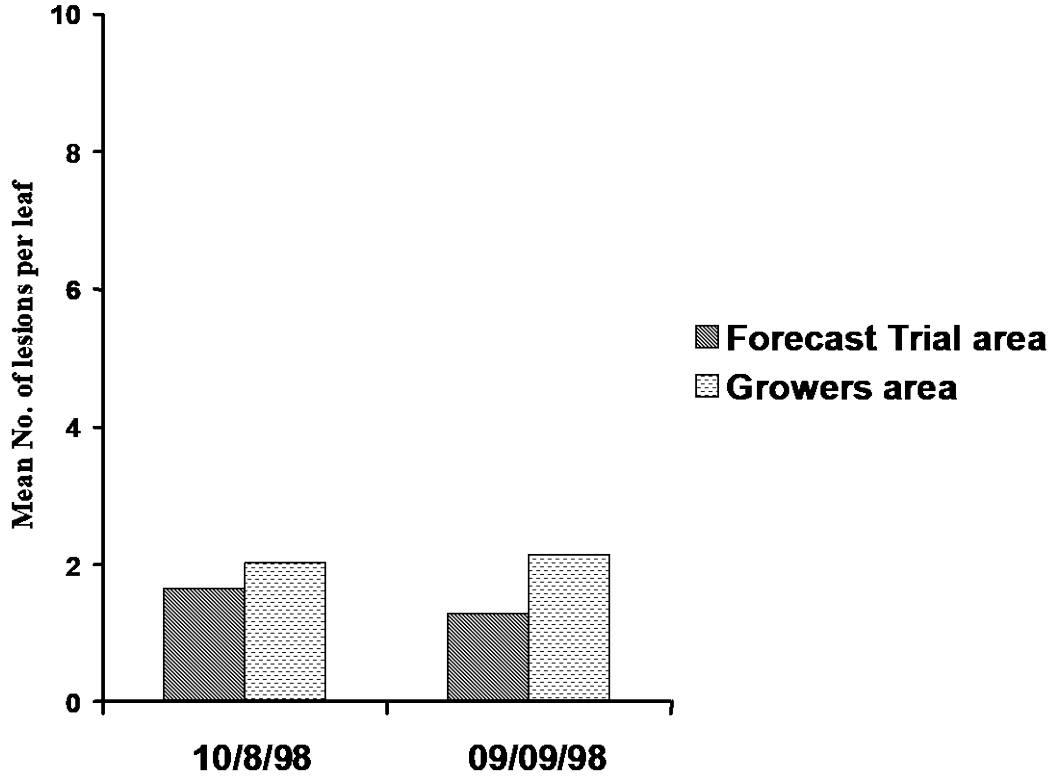
6.2.8 Fungicide sprays applied at the Skegness trial site in 1999

Fungicides applied at the Skegness trial site are shown in Table 31. A spray of Bravo was applied at 1.5 kg ha^{-1} on the 12 July 1999 to the growers trial area. A further spay of Folio at 2.0 kg ha^{-1} was applied to the same area on the 4 August 1999. A spray of Plover (0.3 litres ha^{-1}) with Folio (2.0 kg ha^{-1}) was applied to the growers area on 18 August 1999 (Table 31). Folicur and Fubol were applied to the forecast trial area at 0.5 litres ha^{-1} and 1.25 kg ha^{-1} respectively on the 17 July 1999. This spray was applied, to the forecast plots, in response to a prediction of ringspot inoculum production in the crop. Sprays of Plover (0.3 litres ha^{-1}) in combination with Bayfidan (0.5 litres ha^{-1}) and Folicur (0.5 litres ha^{-1}) in combination with Folio (2.0 kg ha^{-1}) were applied to the growers area on the 12 September 1999 and the 12 October 1999 respectively. One spray of Plover (0.3 litres ha^{-1}) was applied to the forecast area on the 17 September 1999 (Table 31). This spray was applied, to the forecast plots, in response to a prediction of dark leaf spot but was applied late. It was considered that this spray was also active at the secondary dark leaf spot spray threshold (21 September 1999). Folicur (0.5 litres ha^{-1}) in combination with Bravo (1.5 kg ha^{-1}) were applied to the growers area on the 3 November 1999. Plover (0.3 litres ha^{-1}) was applied to the forecast area on the 12 October 1999 to the occurrence of further significant dark leaf sporulation periods (tertiary dark leaf spot spray criteria) which occurred at the Skegness site at this time (Figure 82).

Table 31 Fungicide Treatments at field sites 1999 – Skegness

Growers Area	12.07 -	Bravo	(1.5 kg ha^{-1})
	04.08	Folio	(2.0 kg ha^{-1})
	18.08 -	Plover	(0.3 litres ha^{-1})
	-	Folio	(2.0 kg ha^{-1})
	12.09 -	Plover	(0.3 litres ha^{-1})
	-	Bayfidan	(0.5 litres ha^{-1})
	12.10	Folicur	(0.5 litres ha^{-1})
	-	Folio	(2.0 kg ha^{-1})
	03.11	Folicur	(0.5 litres ha^{-1})
	-	Folio	(2.0 kg ha^{-1})
Dark leaf spot/ringspot Forecasting Area	17.07 -	Folicur	(0.5 litres ha^{-1})
		Fubol	(2.0 kg ha^{-1})
	17.09 -	Plover	(0.3 litres ha^{-1})
	12.10 -	Plover	(0.3 litres ha^{-1})

Figure 84 Observed disease development by dark leaf spot and ringspot on leaves (Skegness trial site)



6.2.9 Observed ringspot and dark leaf spot on buttons at harvest at Skegness 1999

Buttons were harvested at Skegness on the 7 December 1999. The percentage of uninfected buttons harvested from the grower's trial area and the forecast trial area (whole plant shanks samples) are shown in Figure 85. Both trial areas had identical numbers of uninfected buttons. Approximately 75 % of buttons harvested from the forecast or growers trial areas were uninfected by either ringspot or dark leaf spot (Figure 85). The mean number of lesions per infected Brussels sprout button was 0.86 and 1.10 in the forecast and grower areas of the trial respectively at Skegness in 1999 (Figure 86). There was no significant difference between areas in the severity of infection when the whole Brussels sprout shank was assessed. Few differences were observed between the top middle and bottom of the Brussels sprout shank in the button samples removed from the growers trial area (Figure 87). Approximately 90, 50 and 30 % uninfected buttons in the button sample harvested from the top middle and bottom of the Brussels sprout shank in the forecast trial area respectively at this site. The growers area had slightly higher numbers of uninfected buttons harvested from the middle area of the shank (Figure 87). Mean lesion numbers on infected buttons were higher in the growers trial area (top and middle) than on infected buttons removed from the same areas of the forecast trial area (Figure 88).

Figure 85 Percentage uninfected buttons at Skegness 1999 (whole plant sample).

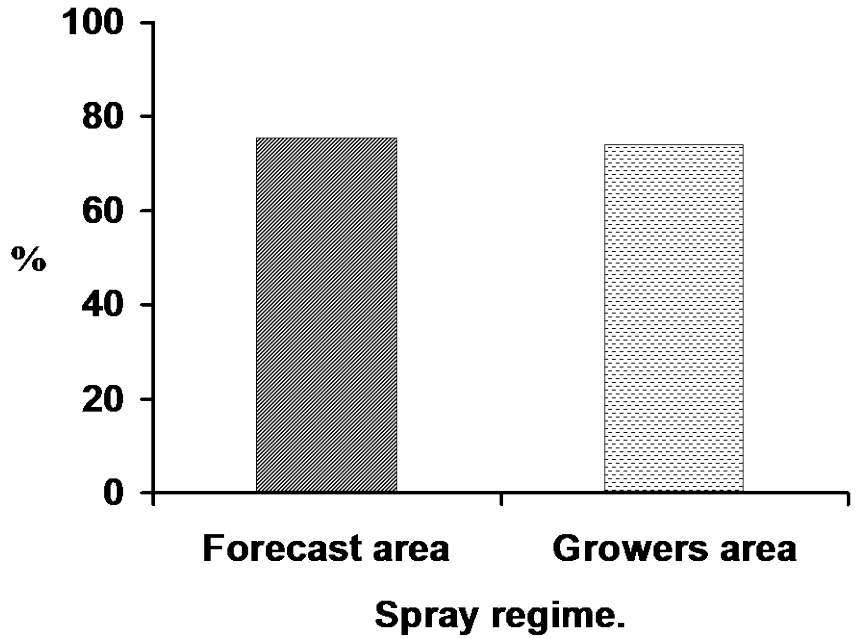


Figure 86 Mean number of lesions per button at Skegness 1999 (whole plant sample).

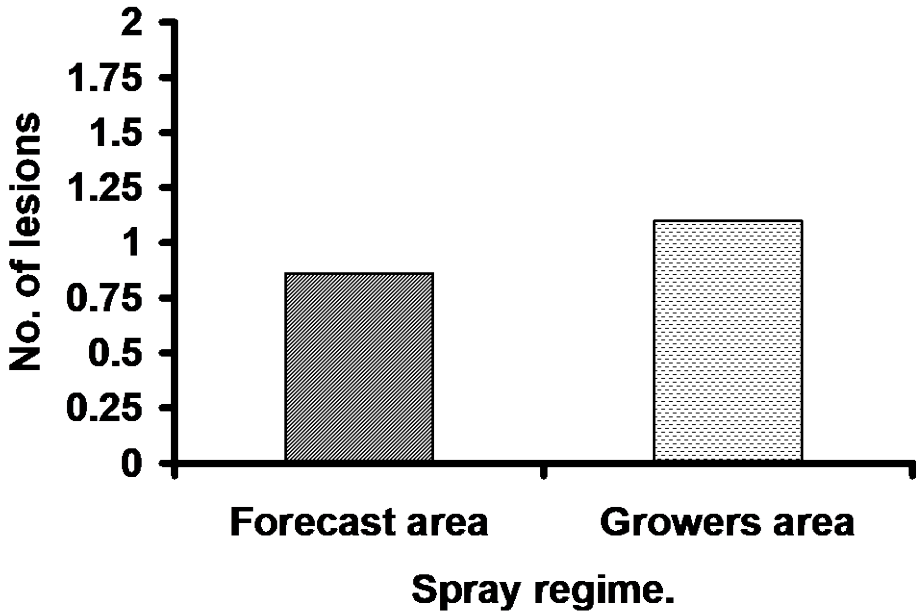


Figure 87 Percentage uninfected buttons at Skegness 1999 (Button sample)

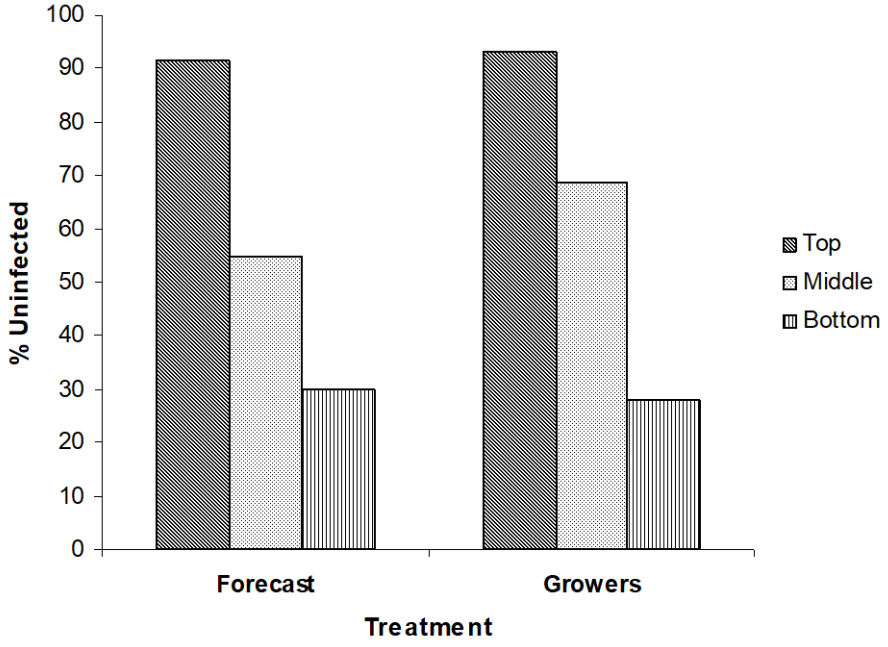
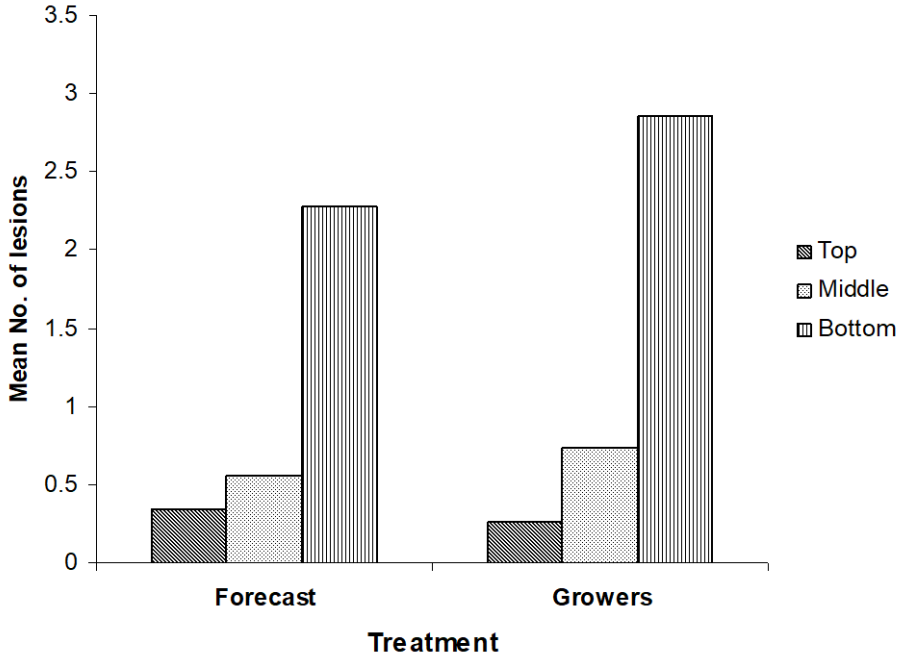


Figure 88 Mean number of lesions per infected button at Skegness 1999 (Button sample)



6.2.10 Predicted disease development Frieston Shore, Lincolnshire

Prediction of dark leaf spot development commenced at the Frieston Shore site 1 July 1999 (Table 28). However initial infection by ringspot was observed in the crop on the 1 June 1999. Predicted dark leaf spot development was not rapid and the first dark leaf spot spray threshold was not reached until the 6 September 1999 (Figure 89). The second dark leaf spot spray threshold was reached on the 25 September 1999. Ringspot development in the crop was rapid and the initial ringspot spoulation index was reached on the 20 July 1999. Further ringspot infection was observed in the crop on the 23 September 1999. Spore production from these lesions was predicted on the 14 October 1999 (Figure 89). Further new ringspot lesions were observed in the crop on the 24 October indicating that this may have arisen from a source outside the crop. However these lesions were not predicted to reach sporulation before the crop was harvested. Early high-risk white blister infection periods were recorded in the crop on the 1 June 1999 and the 2 and 3 July 1999 (Figure 90). High risk infection periods were recorded during the period 1 August 1999 until the 10 August 1999 and from the 3 September 1999 until the 7 September 1999. The highest white blister risk period occurred during the period 15 September until the 27 September 1999 however there was also significant risk periods from the 22 October 1999 until the 25 October 1999 (Figure 90).

Figure 89 Predicted disease development (Frieston Shore trial site 1999)

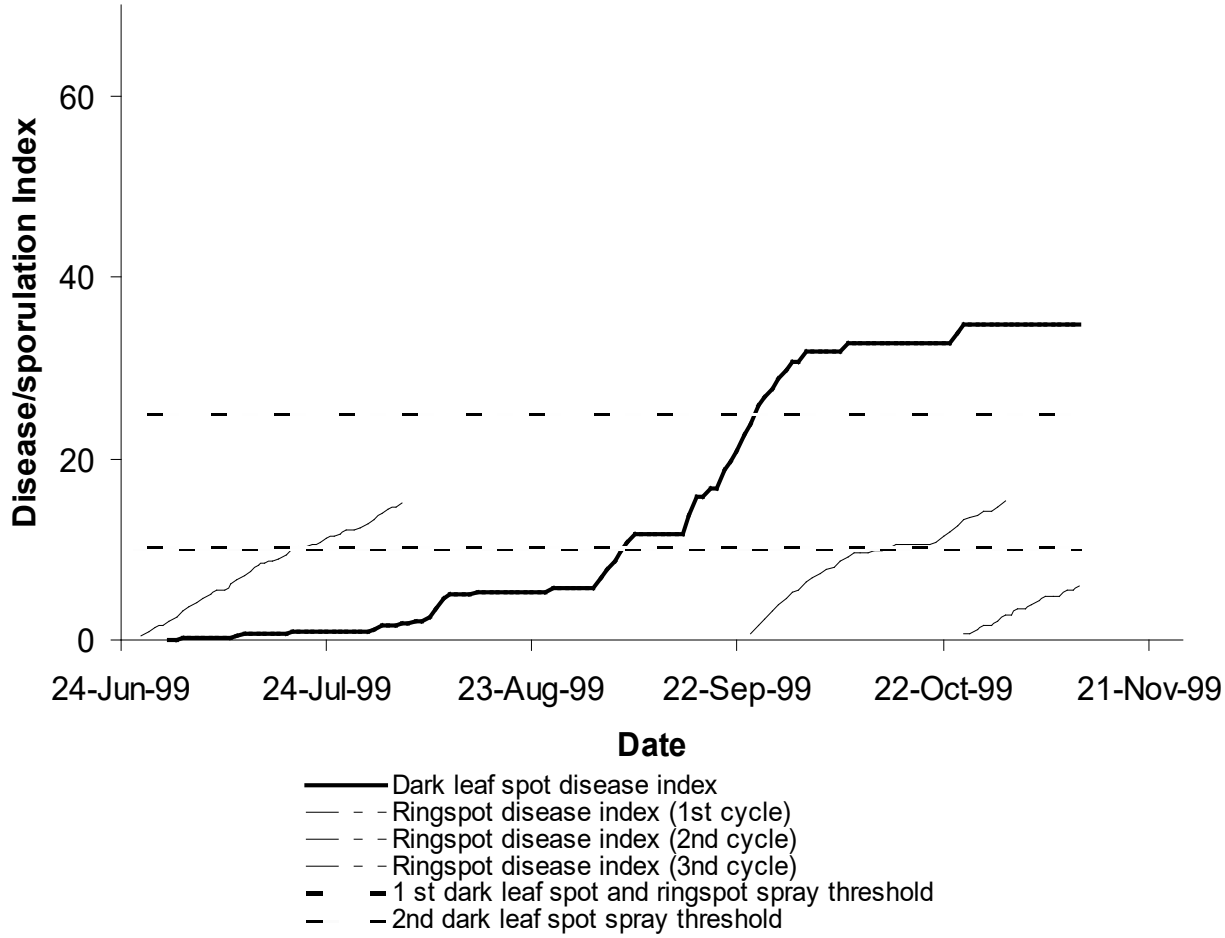
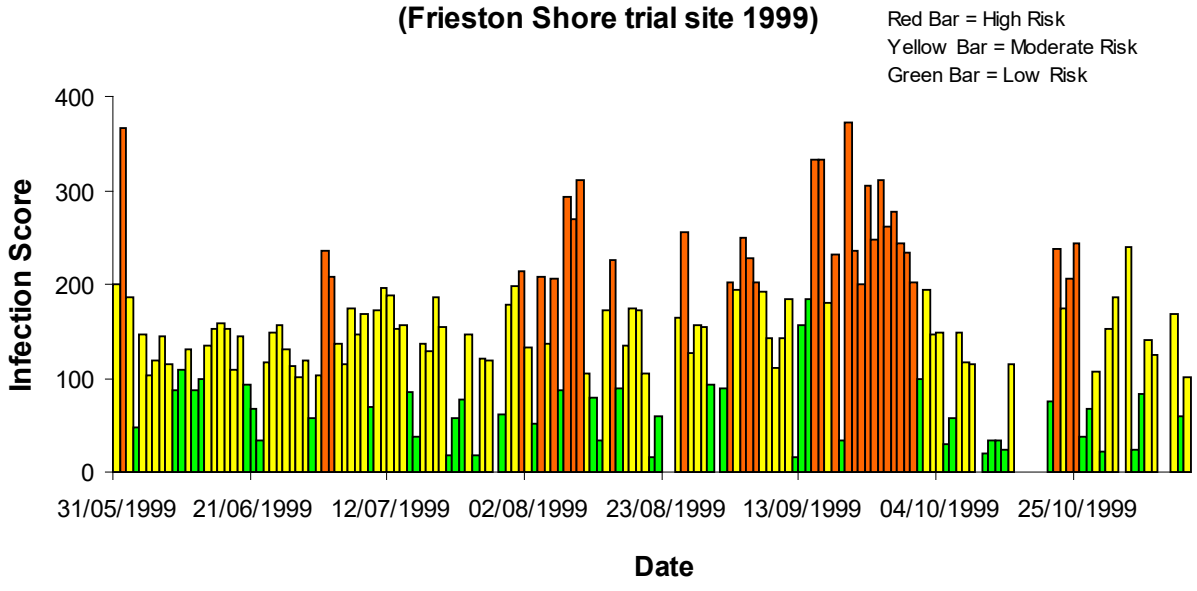


Figure 90 Predicted infection (50 % threshold) by *Albugo candida* (Frieston Shore trial site 1999)



6.2.11 Observed ringspot and dark leaf spot on leaves during the growth season at Frieston Shore in 1999

The mean numbers of lesions on leaves assessed in the forecast and growers trial areas are shown in Figure 91 at Frieston Shore. There were on average approximately 2 lesions per leaf on leaves assessed in the growers trial area on 22 July 1999. The number of lesions per leaf decreased to 0.44 when further leaves were assessed on the 9 September 1999. However the numbers of lesions per leaf on leaves assessed in the forecast trial area on the 22 July was 0.99 per leaf and this declined to 0.25 in assessments taken on the 9 September 1999 (Figure 91).

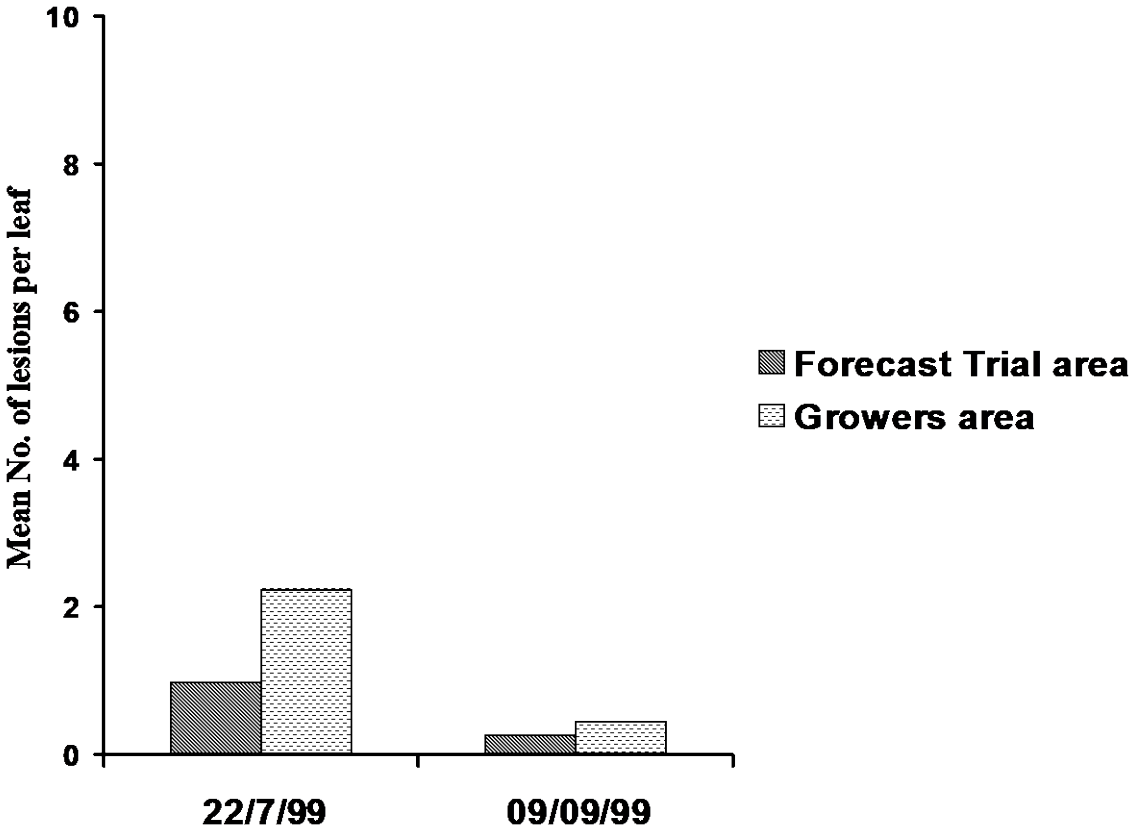
6.2.12 Fungicide sprays applied at the Frieston Shore trial site in 1999

Fungicides applied at the Frieston shore trial site are shown in Table 32. A spray of Folicur was applied at 0.5 litres ha^{-1} on the 2 and 3 July 1999 to the growers and forecast trial areas respectively. This spray was applied in response to the first observation of dark leaf spot at this site. A further spay of Plover at 0.3 litres ha^{-1} was applied to both areas on the 19 July 1999. This spray was applied to the forecast area in response to predictions of ringspot sporatation. Folicur and Folio were applied to the growers trial area at 0.5 litres ha^{-1} and 2.0 kg ha^{-1} respectively on the 6 August 1999. However Folio alone (at the same rate) was applied on the same day to the forecast trial areas. This spray was applied, to the forecast plots, in response to white blister disease risk. A further spray of Folio at the same rate was applied to the forecast area on the 7 September 1999. However Folio was applied with Plover (at 0.3 litres ha^{-1}) on the same date to the growers trial area (Table 32). Two further spays of Plover (at 0.3 litres ha^{-1}) were applied to the forecast area on the 10 September (in response to the first predicted dark leaf spot disease threshold) and 16 October 1999. The later spray was applied in response to the predictions of ringspot sporatation. The growers area had a further spray of Folicur (at 0.5 litres ha^{-1}) applied on the 28 October 1999.

Table 32 Fungicide Treatments at field sites 1999 – Frieston Shore

Growers Area	02.07 - Folicur	(0.5 litres ha^{-1})
	19.07 - Plover	(0.3 litres ha^{-1})
	06.08 - Folicur	(0.5 litres ha^{-1})
	- Folio	(2.0 kg ha^{-1})
	07.09 Plover	(0.3 litres ha^{-1})
	- Folio	(2.0 kg ha^{-1})
	28.10 Folicur	(0.5 litres ha^{-1})
Dark leaf spot/ringspot Forecasting Area	03.07 - Folicur	(0.5 litres ha^{-1})
	19.07 - Plover	(0.3 litres ha^{-1})
	06.08 - Folio	(2.0 kg ha^{-1})
	07.09 - Folio	(2.0 kg ha^{-1})
	10.09 - Plover	(0.3 litres ha^{-1})
	16.10 - Plover	(0.3 litres ha^{-1})

Figure 91 Observed disease development by dark leaf spot and ringspot on leaves (Frieston Shore trial site)



6.2.5 Observed ringspot and dark leaf spot on buttons at harvest at Frieston Shore 1999

Buttons were harvested at Skegness on the 16 November 1999. The percentage of uninfected buttons harvested from both trial areas (whole plant shanks samples) are shown in Figure 92. There was little difference in the number of uninfected buttons from the forecast area or growers area. Approximately 60 % of buttons harvested from the forecast or growers trial areas were uninfected by either ringspot or dark leaf spot (Figure 92). The mean number of lesions per infected Brussels sprout button was 0.91 and 1.03 in the forecast and grower areas of the trial respectively at Frieston Shore in 1999 (Figure 93). There was no significant difference between areas in the severity of infection when the whole Brussels sprout shank was assessed. There were higher numbers of uninfected buttons harvested from the top of the Brussels sprout stem in forecast treatments in comparison to growers areas (Figure 94). Approximately 30 – 40 % of buttons in the growers trial area were uninfected regardless of the area of the Brussels sprout stem that the buttons were harvested from. The forecast area had higher numbers of uninfected buttons harvested from the top area of the shank (Figure 94). Mean lesion numbers on infected buttons were higher in the growers trial area (top and middle) than on infected buttons removed from the same areas of the forecast trial area (Figure 95).

Figure 92 Percentage uninfected buttons at Frieston Shore 1999 (whole plant sample).

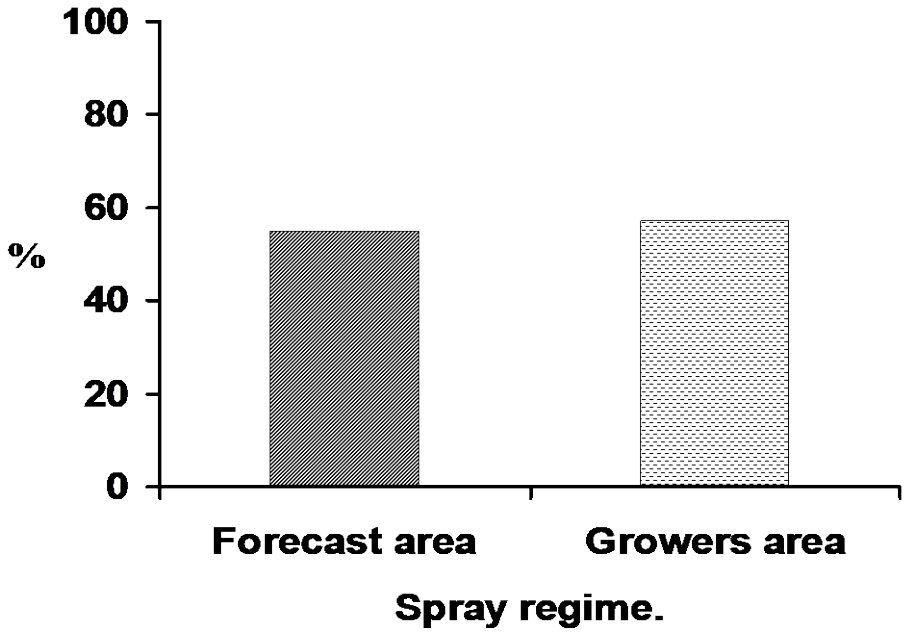


Figure 93 Mean number of lesions per button at Frieston Shore 1999 (whole plant sample).

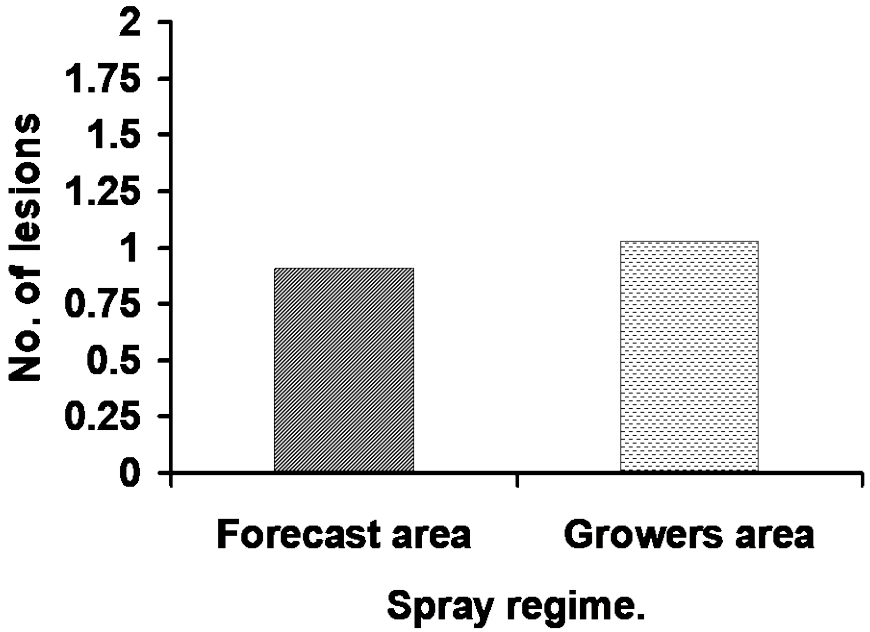


Figure 94 Percentage uninfected buttons at Frieston Shore 1999 (Button sample)

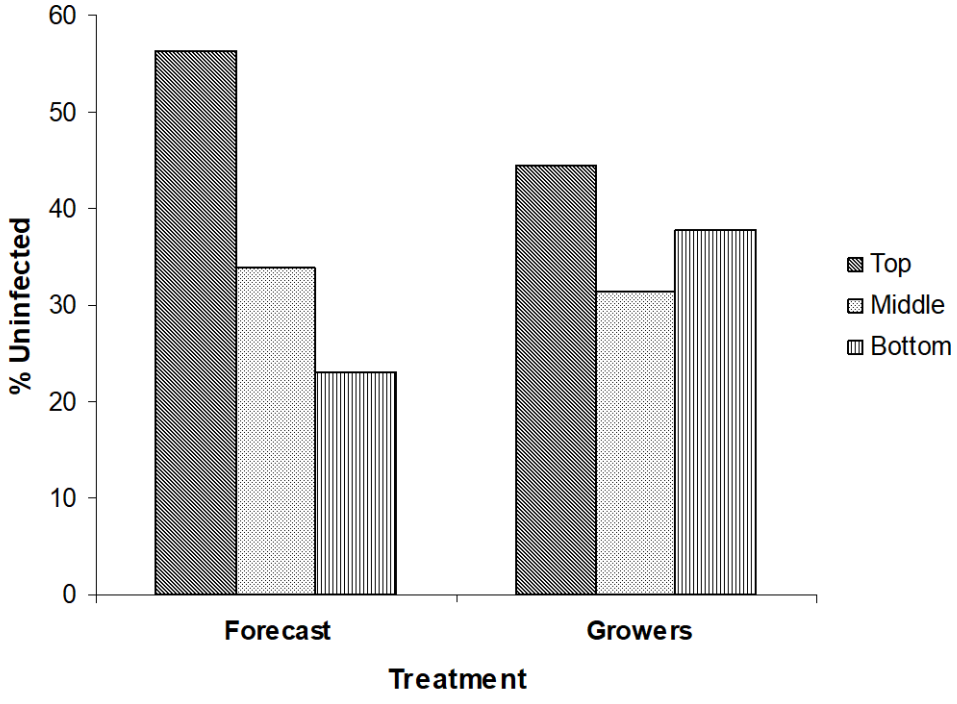
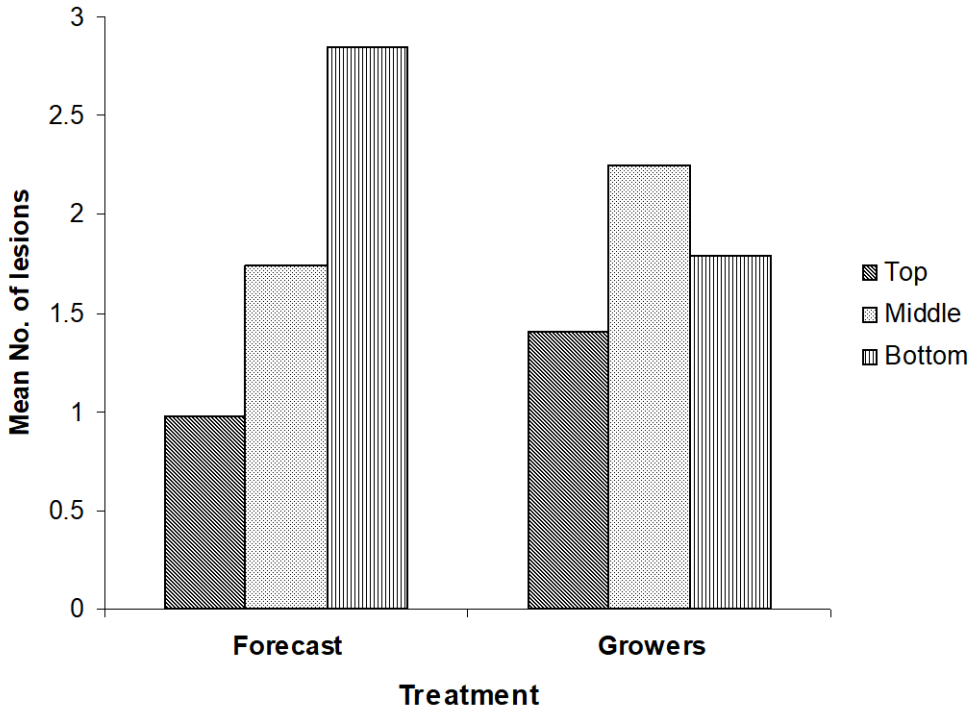


Figure 95 Mean number of lesions per infected button at Frieston Shore 1999 (Button sample)



6.3 Use of the ringspot forecaster in commercial cauliflower crops

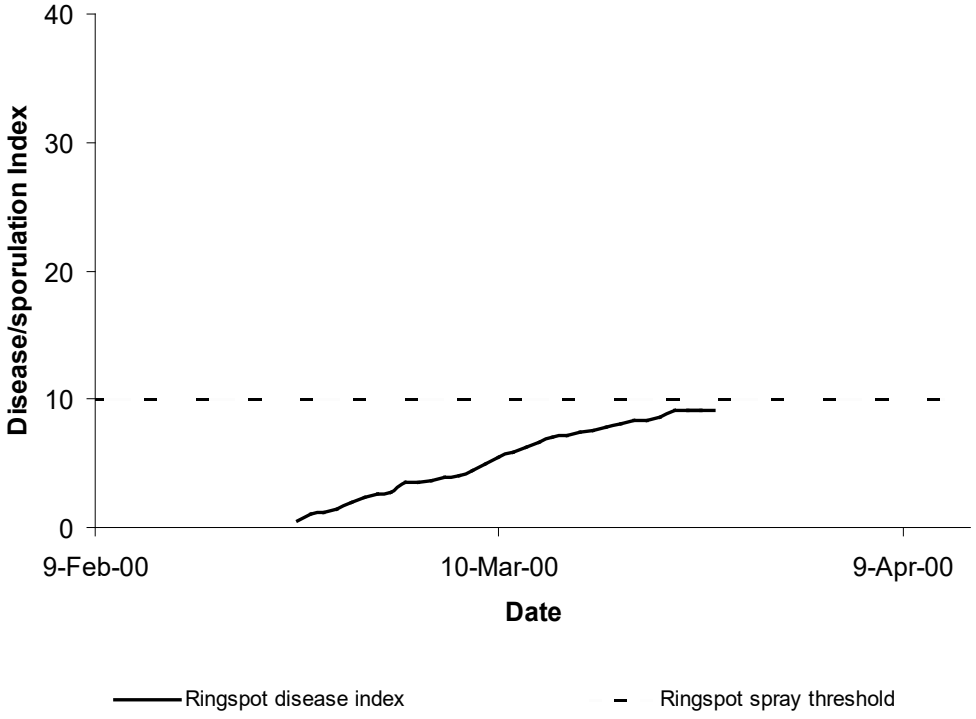
6.3.1 Observed disease development in a commercial crop of cauliflowers

In an over-wintered cauliflower crop in Cornwall in 1999/2000 there was no new ringspot lesions observed in the crop until 23 February 2000. Dry conditions occurred during late February 2000 and early March 2000. Therefore the numbers of ringspot lesions in the crop were very low. Infected leaves which had ringspot at the bottom of the plant were shed and no new ringspot developed on the new leaves. Some new ringspot lesions were observed within the crop on the 23 February 2000.

6.3.2 Predicted inoculum production at the field site in Cornwall

The predicted inoculum production, based on observations taken in the crop, are shown in Figure 96. New ringspot lesions were observed in the crop on the 23 February 2000. However these lesions did reach the sporulation index before harvest on the 23 March 2000. No sprays were applied to the crop

Figure 96 Predicted disease development (Cornwall trial site 2000)



6.3.3 Observed ringspot on cauliflower heads at harvest

At harvest observations taken from the crop showed that ringspot was present only at very low levels. All cauliflowers plants harvested from the plot had zero ringspot present on the wrapper leaves. There was no significant effect of ringspot on cauliflower yield with average yields of 856 g. Harvested heads had 0 lesions per plant.

7. Statistical treatment of results

7.1 Whole Plant data

7.1.1 Percentage Infection

Variate: a%clnbut% of buttons that are clean(angular transformation)

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Year.Site.Rep stratum					
Year.Company	5	11737.99	2347.60	8.69	0.001
Residual	12	3242.02	270.17	1.38	
Year.Site.Rep.Regime stratum					
Regime	1	6.86	6.86	0.03	0.855
Year.Site Regime	5	1883.85	376.77	1.92	**0.165**
Residual	12	2356.46	196.37	2.81	
Year.Site.Rep.Regime.Plant stratum					
	287(1)	20030.27	69.79		
Total	322(1)	39213.35			

Tables of Means

Year	Site Regime	Forecast	Growers
1998.	Hesketh Bank	53.11	52.97
	Skegness	51.54	52.56
	Frieston Shore	44.41	46.12
1999.	Farndon	69.09	59.01
	Skegness	54.39	60.25
	Frieston Shore	48.93	48.80

*** Least significant differences of means (5% level) ***

Table	Regime	Year Site	Year Site Regime
rep.	162	54	27
l.s.d.	3.392	6.892	8.591
d.f.	12	12	23.41

Except when comparing means with the same level(s) of
Year.Site 8.310
d.f. 12

7.1.2 Mean number of lesions per infected button

Variate: lmnlesinmean number of lesions per infected button (log trans)

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Year.Site.Rep stratum					
Year.Site	5	17.2959	3.4592	24.74	<.001
Residual	12	1.6782	0.1398	0.43	
Year.Site.Rep.Regime stratum					
Regime	1	0.2977	0.2977	0.92	0.357
Year.Site.Regime	5	0.6563	0.1313	0.40	**0.836**
Residual	12	3.8902	0.3242	1.96	
Year.Site.Rep.Regime.Plant stratum					
	287(1)	47.5886	0.1658		
Total	322(1)	71.3714			

Tables of Means

Year	Site Regime	Forecast	Growers
1998.	Hesketh Bank	0.759	0.646
	Skegness	1.066	1.156
	Frieston Shore	0.657	0.737
1999.	Farndon	0.338	0.530
	Skegness	1.008	1.071
	Frieston Shore	0.651	0.703

*** Least significant differences of means (5% level) ***

Table	Regime	Year Company	Year Company Regime
rep.	162	54	27
l.s.d.	0.1378	0.1568	0.2728
d.f.	12	12	20.73
Except when comparing means with the same level(s) of			
Year.Company			0.3376
d.f.			12

The results indicate that there were no significant differences between growers and forecast trial areas in the percentage uninfected buttons and in the mean number of lesions per infected button removed from whole plants which had been harvested in each area. This indicates that on the six replicated sites where signicantly lower numbers of pesticide applications had been made there was no significant effect on disease. At many sites the percentages of uninfected buttons was higher in the forecast area in comparison to the growers area. With a higher number of replicated sites this increase in percentage number of uninfected buttons may well have been significant. There were similar results for the numbers of lesions of dark leaf spot or ringspot per infected button.

8. CONCLUSIONS

Forecasting initial dark leaf spot occurrence

Considerable variation in the occurrence of both dark leaf spot and ringspot was observed at all trial sites in all seasons. Both ringspot and dark leaf spot require wetness for infection and disease development. During trials conducted in 1997, 1998 and 1999 environmental conditions for brassica leaf-spot diseases were very favourable. Over-wintered cauliflower crops had high levels of disease which resulted from cool wet conditions during March and April in each year. Ringspot appeared earlier in crops located in the Butterwick and Frieston Shore areas. In Scotland dark leaf spot was not observed until the second first week of August 1998 and 1999. Ringspot was observed at this Scottish site (St Andrews) in 1998 before dark leaf spot presence was confirmed. However no ringspot was observed at the Arbroath trial site in 1999. There was therefore little scope for determining initial disease infection using the dark leaf spot and ringspot models because environmental data was not collected from time of crop transplanting. In 1999 the risk of dark leaf spot, ringspot and white blister occurrence in crops could be ascertained.

Variation in Predicted Ringspot and Dark leaf spot Disease Development 1998

Considerable variation was observed in the predicted disease development of both ringspot and dark leaf spot in all years even and at the same sites in both years. In Lincolnshire, all sites used in observational trials had similar predicted dark leaf spot and ringspot disease development curves in 1998 indicating that variation in the weather patterns between locations north and south of the wash. However there was more variation in predicted disease development in 1999. A similar effect was observed in 1997 when there was significant differences between these sites. This indicates other factors are potentially important in disease development. One missing factor may have been inoculum production. The rate of ringspot inoculum production was not significantly different between sites although the rate increased at different cropping times. For example ringspot lesions developing during July required approximately 30 days (according to predictions from the ringspot model) to produce fresh inoculum. However ringspot lesions developing in mid to late August 1998 required only 15 days for fresh inoculum to be produced. This effect could be attributed to longer periods of leaf surface wetness occurring during the night. While the temperatures occurring during these night periods would have a significant effect on dark leaf spot sporulation they would have been unlikely to have an inhibitory effect on ringspot sporulation. This is the result of different temperature optima required for spore production by dark leaf spot and ringspot. However once ringspot infection has occurred, spore development

can progress at temperature below 5 C in the presence of wetness. The results suggest that the differences between sites in the degree of button infection by dark leaf spot and ringspot was affected more by choice of fungicide product and application timing than by variation between location in weather criteria necessary for disease development. At many sites there was constant night periods of leaf surface wetness but differences in disease development were observed. It was not possible at these sites to obtain information on fungicide type or application timing used to control the disease in 1998. In 1999 some data on fungicide sprays on observation trial sites suggested that choice of fungicide was important even when critical timings were reached. Forecasting models suggested that critical timings for application of fungicidal control was around the 5 – 10 September 1998 and the 15 – 21 September 1999 .

Predicted ringspot and dark leaf spot development at St Andrews and Arbroath in 1999 was more rapid than in Lincolnshire. However this was not surprising given the wetter conditions experienced there. There appeared to be little difference in the time required for sporulation from lesions regardless of the season. Dark leaf spot development was predicted to be significantly more rapid. One possible explanation for this may be that the time of initial crop infection was not accurately defined (due to the difficulty in visiting the site regularly). However an alternative possibility maybe that significant periods of sporulation and infection were occurring at this site simultaneously. This indicates that the amount of inoculum produced is an important factor at this site. In contrast disease development at the Ross-on-Wye site was predicted to be slower. Both ringspot and dark leaf spot development was considerably slower than in Lincolnshire and Scotland. The secondary dark leaf spot threshold was not reached at Ross-on-Wye. This pattern of predicted development would be indicative of dry cooler conditions. It would be interesting to compare the durations of leaf wetness at this site with those in Lincolnshire. However weather information was collected at the Ross-on-Wye site using Adcon weather stations and it is possible that there may have been some positional effects between probes within the Adcon system in comparison to the Skye weather stations used at all other sites. N 1999 it was not possible to generate disease predictions for Ross-on-Wye. Most of the differences between sites would suggest that the main differences were between those located in coastal areas and those located inland. Coastal sites would have more conducive conditions for sporulation at night.

Optimal timing of control sprays for dark leaf spot in Brussels sprouts

Information on the accuracy of application timing of fungicides at different sites according to the Brassica*spot* system for dark leaf spot and ringspot can be ascertained from the replicated trial information. At all replicated trial sites in 1998 and 1999 use of

the models improved control of dark leaf spot and ringspot while also reducing fungicide usage. Despite high initial levels of ringspot at the Frieston Shore site use of the Brassica*spot* system to time applications of fungicide reduced significantly the percentage of infected buttons at this site in comparison the growers control programme. There was also a reduction in the number of lesions per infected button. It is possible that part of the difference results from differences in fungicides used between forecast and growers areas. For example in 1998 during the early part of the season the grower applied Bayfidan spray whereas the forecast areas were sprayed with Folicur. The grower then followed the general timings predicted by the Brassica*spot* models. At Frieston shore disease pressure was high with three periods of ringspot disease development. Despite this by following timings derived from the Brassica*spot* models the disease was controlled and all harvested buttons were grade I marketable. When the Brassica*spot* models were used at the Skegness trial site fungicide usage was reduced by 33 % in 1998 and 50 % in 1999 with no loss of disease control. Control of ringspot and dark leaf spot was improved as the infected buttons had fewer numbers of lesions per button in comparison to buttons harvested from the grower's area. The results indicate that use of the Brassica*spot* system will reduce the numbers of applications of fungicide necessary to control ringspot and dark leaf spot. Growers will be able to cut out unnecessary fungicide applications which will reduce costs. Lower levels or equivalent amounts of disease will occur on crops if spray applications can be timed according to the system. This will offer the possibility of further reducing fungicide usage on many crops if information on other problem diseases is included within the system. With the exception of the Skegness site in both 1998 and 1999 there was a tendency for participating growers to follow application timings used in the forecast areas. This in part resulted from the fact that growers were applying fungicides to both treatment areas. It is therefore not surprising that the highest reduction in fungicide usage of all three sites was observed at Skegness where there was different application schedules between the growers area and the forecast plots. Additionally if information on the occurrence of inoculum can be developed the prospects for reducing fungicide usage to low levels becomes an achievable prospect.

Further development of Brassica*spot* on vegetable brassicas

With forecasts for more than one disease in the crop there is increasing opportunities for synergy in fungicide sprays. This has become evident in trials conducted in 1998 and 1999. If forecasts are triggered separately the grower may consider applying both an eradicant and protectant fungicide in the same application. The addition of forecasts for white blister in 1999 to the system increased the potential for synergy. White blister control depends on the application of fungicides containing metalaxyl. This chemical is

usually combined with either chlorothalonil or mancozeb (however Fubol has now lost its approval for use on horticultural brassicas). Chlorothalonil has activity against both ringspot and dark leaf spot. It is obvious that forecasted timings for white blister control will further investigation in relation to forecasts of ringspot and dark leaf spot. With the ability to detect inoculum in the crop further areas for development of Brassica*spot* are now open. The detection of inoculum in the field for these diseases combined with the Brassica*spot* models offers the potential for determining spatial variation in disease risk. Combining spatial risk with information on timing fungicide applications gives growers an immensely powerful tool to reduce fungicide usage to very low levels. It also can suggest cropping areas in each season which may not require fungicide treatments because the grower will be able to determine that the disease will not reach a level which will cause an economic impact. Growers will also be able to detect disease in fields before it becomes visible. In these ways growers will be able to improve disease control while reducing fungicide usage further.

Development of forecasting systems for cauliflower crops

The results from the three year of development of the ringspot forecaster on cauliflower confirms that the forecaster developed on Brussels sprout can be used on cauliflower to reduce sprays applied to the crop while maintaining control. In year two an over-wintered crop of cauliflower was used in field trials. Disease development on the wrapper leaves of the curd was very low on the unsprayed plots. However the timing of cauliflower harvest will affect the potential for the disease to transfer on to the wrapper leaves. It would clearly be useful to make some estimates of the harvest date and try and incorporate these into the forecasts. This is potentially important as the harvest interval after application of eradicant fungicides such as Folicur (3 weeks) must be considered when deciding if a fungicide application is beneficial. As the forecaster can determine the likelihood of inoculum production before it occurs an alternative strategy may be to use high dosages of protectant chemicals such as chlorothanonil as an alternative treatment to eradicants such as Folicur or Plover. Protectant chemicals such as Bravo have an advantage of having shorter harvest intervals after application (1 week). Alternatively eradicant applications could be used to reduce the overall development of ringspot in the crop at an earlier stage of growth. This might have the effect of reducing the overall levels of disease development making disease transfer from the cauliflower leaves to the curd wrapper leaves unlikely. Year three trials in commercial cauliflower crops were largely inconclusive due to very dry conditions however control of ringspot using the ringspot model has been demonstrated in non commercial trials.

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