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Coordinator:	Philip Effingham and Keith Harwood
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1. PRACTICAL SECTION FOR GROWERS

There are many leaf-spot diseases of vegetable brassicas, all of which must be controlled if crop quality is to be maintained. The presence of fungal leaf spots on Brussels sprout buttons or on the wrapper leaves of cauliflowers is an important factor determining their saleability. 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. Applications of fungicide to the crop are therefore necessary to control these diseases however determining the need for fungicide application is not straight forward given that the crop must be protected for long periods of time. 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 techniques can provide information on the optimal timing of fungicide application and can suggest which might be an appropriate fungicide. Saving only one or two fungicide applications will have a significant impact on the cost of production. Reduction in costs by reducing fungicide usage will be variable between years with low and high disease pressure and also between production areas. Eradicant fungicides such as tebuconazole (Folicur) and difenconazole (Plover), can now be used on Brussels sprouts means that the grower has a greater range of options for controlling these diseases. Both of these fungicides have a wide spectrum of activity against fungal diseases. However by relying solely on one type of fungicide there maybe the increased likelihood of disease resistance. Reducing the over application of fungicides in the crop by using disease forecasters will reduce this possibility.

Economic implications

Fungicides are increasingly costly economically and environmentally. The Brassica$_{spot}$ system contains models which can provide information on the optimal timing of fungicides for the control of dark leaf spot and ringspot. The models forecasting ringspot disease development have recently been added to the system. Using Brassica$_{spot}$ will enable growers to accurately target applications of fungicide and give some information on dark leaf spot 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$_{spot}$.

Reduction of fungicide costs 1998

At two of three sites in 1998 use of the Brassica$_{spot}$ system (all forecasting models used together) 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 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. 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 1a). 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 2 there was a reduction in 18 £ ha $^{-1}$ to cost of the forecast programme in comparison to the growers control programme (Table 1). This represents a 27 % reduction in the cost of disease control inputs.

The results indicate that use of the 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. This results from a tenancy 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.

Table 1 **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
y Cost (£ per hectare ex vat)	49.5	67.5

Table 2 Fungicides applied to field experiments in 1998

Chemical	Brand name	Application rate*	Cost ha^{-1} (£ ex. vat)
			1998
Iprodione	Rovral Flo	510g a.i. ha^{-1}	22.05
Triadimenol	Bayfidan	0.5 litres a.i. ha^{-1}	13.5
Mancozeb + metalaxyl	Fubol 58 WP	1.5 kg a.i. ha^{-1}	30
Difenconazole	Plover	0.3 litres a.i. ha^{-1}	12
Chlorothalonil + metalaxyl	Folio	1.5 kg a.i. ha^{-1}	48
Chlorothalonil	Bravo	1.5 litres a.i. ha^{-1}	9
Tebuconazole	Folicur	0.5 litres a.i. ha^{-1}	13.5

*except where specifically noted

Development of ringspot forecasters for cauliflower crops

The results from the second year of development of a ringspot forecaster for cauliflower crops confirmed that the forecaster developed on Brussels sprout could be used on cauliflower to reduce sprays while maintaining 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. Further experiments are necessary to ascertain the best method of using ringspot disease forecasts in commercial crops.

General conclusions

Replicated trials conducted in 1998 show that under the heavy disease pressure experienced in this season using the Brassica$_{spot}$ system (the combined dark leaf spot and ringspot forecasting models) reduced fungicide costs. The quality of all Brussels sprouts buttons in these trials was grade I marketable. In year three the addition of the MAFF sponsored white blister forecaster to Brassica$_{spot}$ will be carried out. 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.

2. INTRODUCTION

2.1 Foliar fungal disease 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 these 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, ability to control the disease is problematical 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*) require free water for spore germination and infection (Louvette & Billotte, 1964, Kennedy & Graham, 1995). At optimal temperatures of 20 °C, 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 °C 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 disease 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 critical 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 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 present the Brassica$_{spot}$ system comprises of three models covering ringspot (*Mycosphaerella brassicicola*) and dark leaf spot (*Alternaria brassicae*) 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)

Additional models describing white blister infection and disease development will be added to the system in 1999-2000. 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). 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 will gather information from weather stations, databases and predictive models. Now it is possible to use GSM and radio off-loading for weather data within MORPH. This saves time by reducing the need to physically visit the station making data transfer more easily. There is also the possibility of data sharing, but the model is still run manually. However MORPH can now be programmed to run the model or models at preset times regularly. This change in technology is currently being investigated and improved.

2.4 Use of the Brassica$_{spot}$ System within commercial Brussels sprouts crops in 1997

In 1997 the Brassica$_{spot}$ system comprised of dark leaf spot models only which were made available to participating growers for use in commercial crops of Brussels sprouts.

2.4.1 Use of the Brassica$_{spot}$ system to forecast initial dark leaf spot occurrence 1997

Environmental conditions for brassica leaf-spot diseases in 1997 were very favourable. Dark leaf spot infection on Brussels sprouts crops was observed during June or in early July 1997. Consequently there was only limited potential for use of the Brassica$_{spot}$ system to predict the initial occurrence of the disease within the crop. Dark leaf spot occurred in all crops at the end of June at all trial sites in Lincolnshire. In Scotland however dark leaf spot was not observed until the second week of August 1997 and at Ross-on-Wye the disease did not appear in the crop until the last week of July 1997. In the early maturing cultivar Diablo at the Butterwick site dark leaf spot was first noted on the 23 June 1997. Early varieties grow more rapidly consequently there is more tissue available for infection at an earlier date in the season. Dark leaf spot lesions develop more rapidly on maturing tissues than on immature tissues. Consequently on early maturing varieties where there was higher levels of mature tissue at an earlier stage in the growth season the disease will be more easily diagnosed. In later maturing varieties there will be higher amounts of immature tissues on the plant later in the season.

2.4.2 Initial occurrence of ringspot and white blister in Lincolnshire and other areas in 1997

Dark leaf spot is only one disease, which infects Brussels sprouts crops causing economic loss. There appeared to be larger differences between sites in the Lincolnshire area in the onset of other disease such as ringspot and white blister. Both ringspot and white blister appeared in the crop in July 1997 at the trial site at Donington. However at all other sites both of these diseases were observed in mid-June. Clearly the degree of infection on over-wintered crops such as cauliflowers and their location in relation to new season crops may have a big impact on the early spread and severity of diseases such as ringspot and white blister.

2.4.3 Use of the Brassica$_{spot}$ system to forecast the optimal timing of control sprays for dark leaf spot in Brussels sprouts in 1997

Dark leaf spot disease pressure was high during 1997 with dark leaf spot present at most sites from mid-June. Weather conditions were also extremely conducive for disease development. Despite this the use predicted dark leaf spot development controlled the disease to approximately the same levels as the growers control regime at most sites used in the trials with fewer fungicides applied. This was particularly evident at some test sites in Lincolnshire (Donington), Ross-on-Wye and St Andrews, Scotland. However there were sites where there was slightly poorer control of disease in the forecast plot compared to the growers areas. A factor at sites where the forecasts gave slightly poorer control of disease than the growers regime was the use of unrepresentative single plots with no replication. At the Butterwick site slightly higher levels of dark leaf spot were noted in the forecast plot however the forecast plot (15 x 15 m) was situated at the edge of the field directly adjacent to an unsprayed plot. There were also high levels of ringspot at this site and therefore it was not easy to differentiate early ringspot from early dark leaf spot on buttons. This demonstrates that diagnosis of early disease within the crop might be important in the practical usage of disease forecasters.

2.5 Trials for the development of forecasting systems for cauliflower crops in 1997

Harvest date in cauliflowers is extremely variable however by using the ringspot forecaster in relation to any projected harvest date the necessity of even one control application of fungicide could be ascertained. The results from the first year of development of the ringspot model developed on Brussels sprout could be used on cauliflower to reduce sprays applied to the crop while maintaining control. Although final disease levels on the wrapper leaves of cauliflower curds in the trial was low even on the unsprayed plots it was clear that the reduction was significant. However further experiments are necessary to confirm these results on both autumn and winter cauliflowers.

2.6 Scientific objectives of trials in 1998

Methodologies for combining the dark leaf spot and ringspot forecasters in commercial crops require investigation.

(a) Investigate (using 1997 results) 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 1998

3.1.1 Experimental Design (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 3. 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 (three plots positioned along one spray boom width as stated in Figure 1).

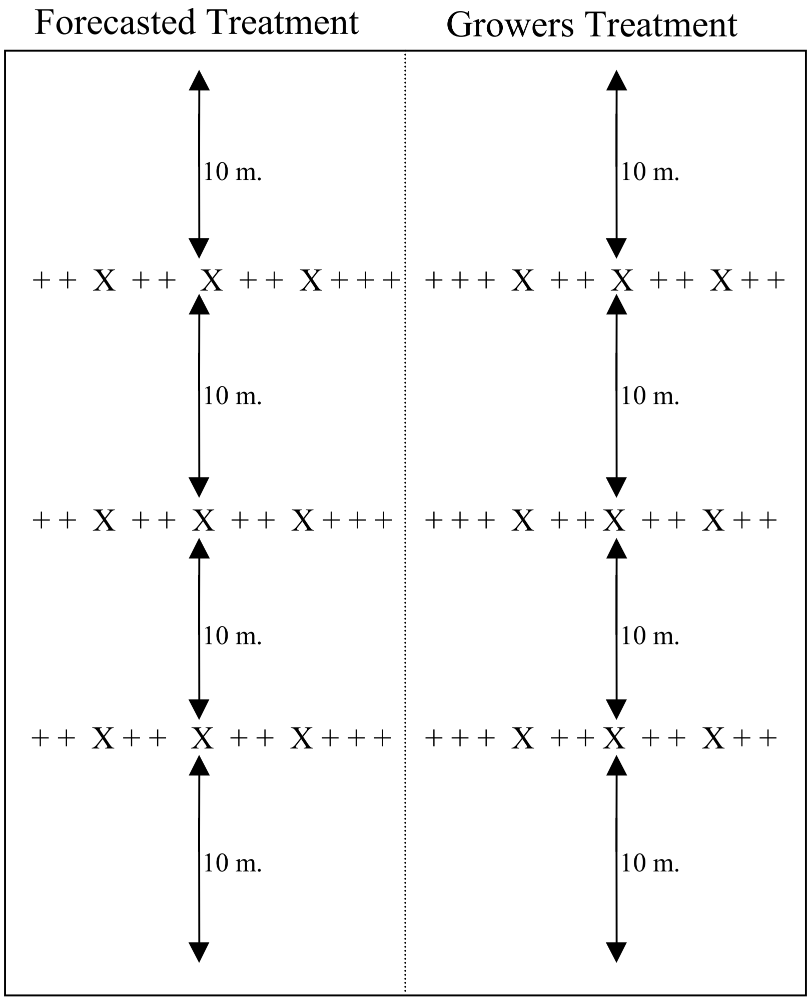
(b) The Brassica$_{spot}$ system (three plots positioned along one spray boom width as stated in Figure 1).

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 2a).

3.1.2 Experimental Design (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 2b. Trial sites consisted of single plots (15 x 15 m) from which data on environmental conditions were taken using a data logger. 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 4.

Figure 1. Brassica trial design 1998

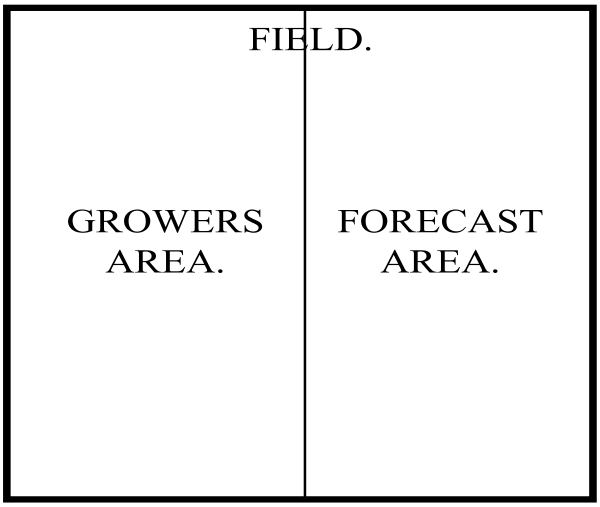


"X" = sprout plants tagged for assessing.

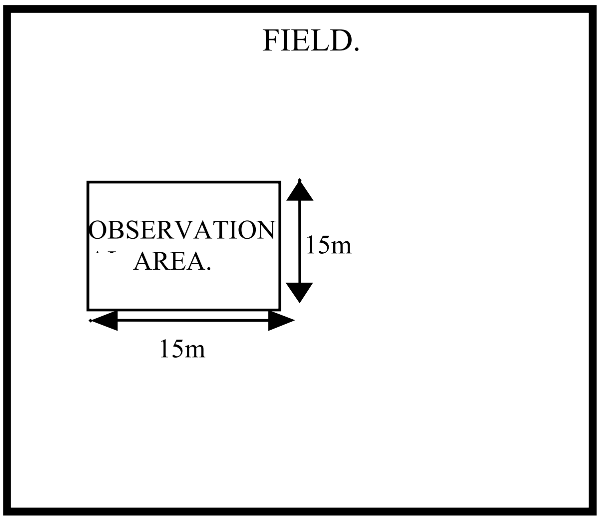
Each plot has a 50 m gap between them and the next plot.

Figure 2. Trial Designs used in 1998 experiments

A) Replicated sample



B) Non Replicated Sample



3.1.2.1 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 3 **Site experimental design, cultivar and sprayer operation (replicated sample sites)**

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

Table 4 **Observational sites used in 1997 trials**

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

3.1.2.2 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). Chemicals used to control disease in the forecast plots (using the Brassica$_{spot}$ system) are shown in Table 5.

Table 6 Fungicides used to control diseases in 1998 trials

Disease	Chemical Name	Trade Name	Dosage
Dark leaf spot (*Alternaria spp*)	Tebuconazole (early season) Difenconazole (late season) Chlorothalonil	Folicur Plover Bravo	500 mls ha^{-1} 300 mls ha^{-1} 1.5 kg ha^{-1}
Ringspot (*Mycosphaerella brassicicola*)	Tebuconazole (early season) Difenconazole (late season) Chlorothalonil	Folicur Plover Bravo	500 mls ha^{-1} 300 mls ha^{-1} 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}

3.1.2.3 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 by GSM portable phone Link (Skye Instruments Ltd, Llandrindod Wells, Powys). Meteorological data was verified before being made available to individual growers by placing the information from each logger (site) for each time period. A copy of the data was placed at the HRI web site (http://www.hri.ac.uk/site2/research/fres.htm).

3.1.3 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 2a). At observation sites it was not possible to ascertain the fungicides used in control programmes (Figure 2b). 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 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.

3.1.4 Disease assessments

3.1.4.1 Leaf Disease Assessments

Leaf disease assessments were carried out in all replicated sample trial areas (Figure 2a). No leaf assessments were taken from plants in observational trial areas (Figure 2b). The number of ringspot and dark leaf spot lesions on leaves of nine tagged plants per plot per treatment (Figure 1) 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.

3.1.4.2 Button Disease Assessments

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+

3.2 Development and validation of ringspot forecasts in cauliflower crops

3.2.1 Inoculated Cauliflower Trials (Non-Commercial)

3.2.1.1 Experimental Design

The experiment was sited at HRI Kirton and comprised of sixteen plots of 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 3). 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 3). Seeds were sown in Hassy 308 trays (9 June 1998) and transplanted into the field during on the 30 July 1998.

3.2.1.2 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.

3.2.1.3 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 ringspot prior to harvest. The following treatments were applied:

a) Ringspot model threshold 1 (5% inoculum production from lesions): 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

3.2.1.4 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.

3.2.2 Disease Assessments

3.2.2.1 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 4. Twenty plants (5 in each quadrat) were assessed for the occurrence of ringspot on leaves, in each plot, of each treatment. At approximately fourteen-day 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 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 3. Experiental design of cauliflower spray timing experiment (Kirton 1998)

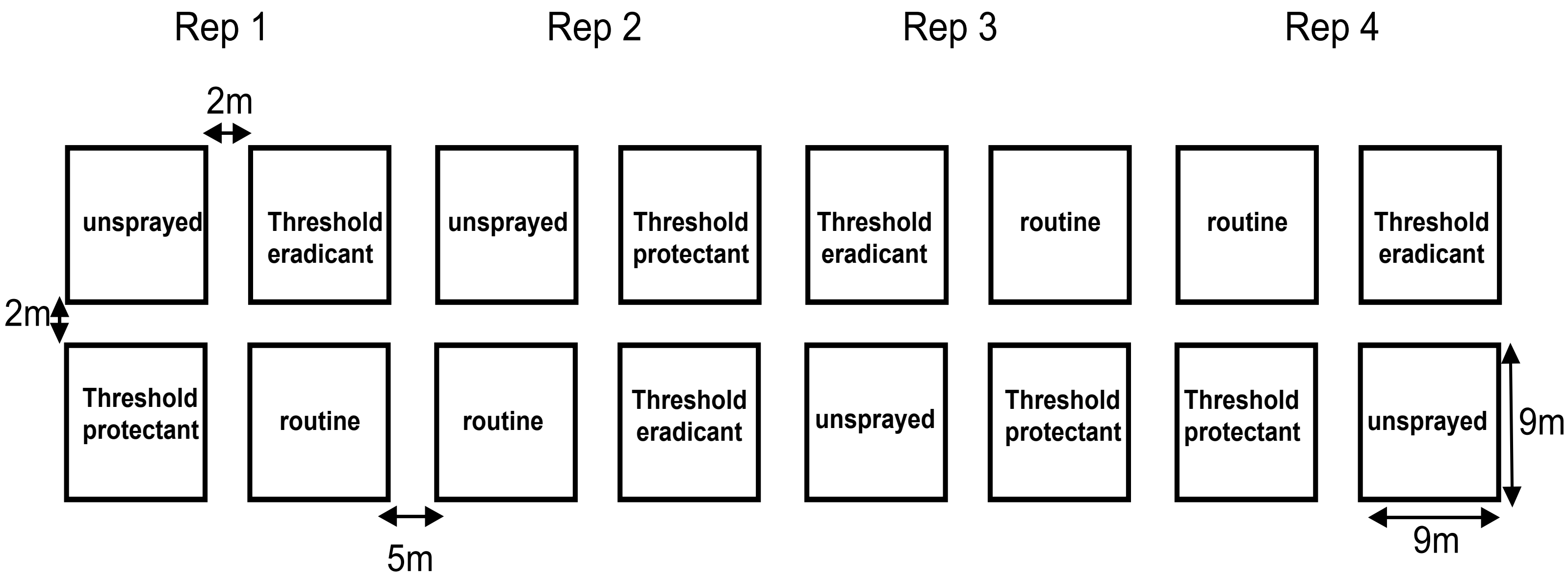
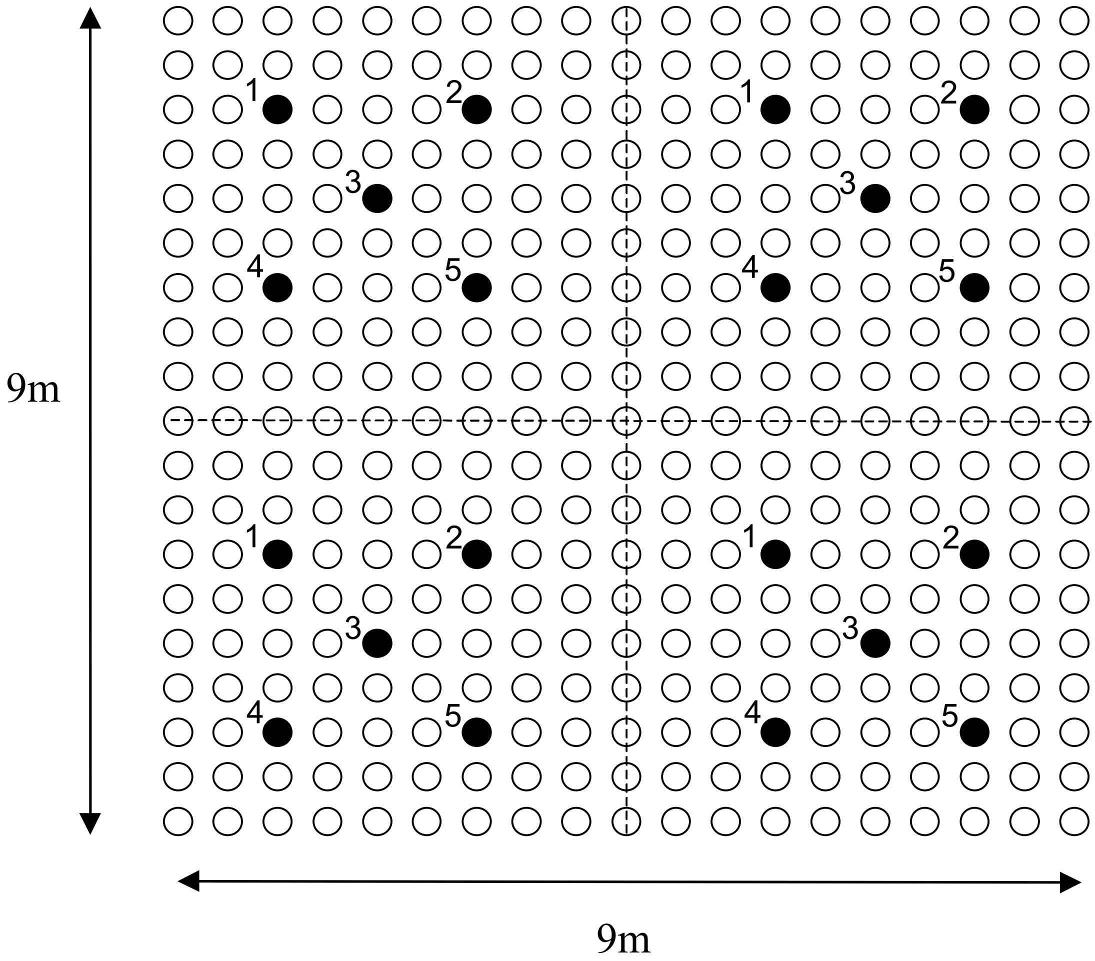


Figure 4. Layout of Quadrats in cauliflower plots.



3.2.2.2 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 4. 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.

3.2.2.3 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.

3.3 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.

4. RESULTS

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

4.1.1 1998 Lincolnshire

4.1.1.1 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 observation sites. Wet conditions observed during August 1998 was conducive to rapid disease development by all foliar pathogens which occur on Brussels sprouts (Figure 5ab, 6ab). Infection by *Mycosphaerella brassicicola* (ringspot), *Alternaria brassicae* (dark leaf spot) and *Albugo candida* (white blister) occurred at all sites (Table 6). 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.

4.1.1.2 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. Fungicide sprays applied to the crop were not monitored. 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 7). 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 6).

Table 6 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 5 Air temperature (a) and rainfall (b) Frieston shore 1998

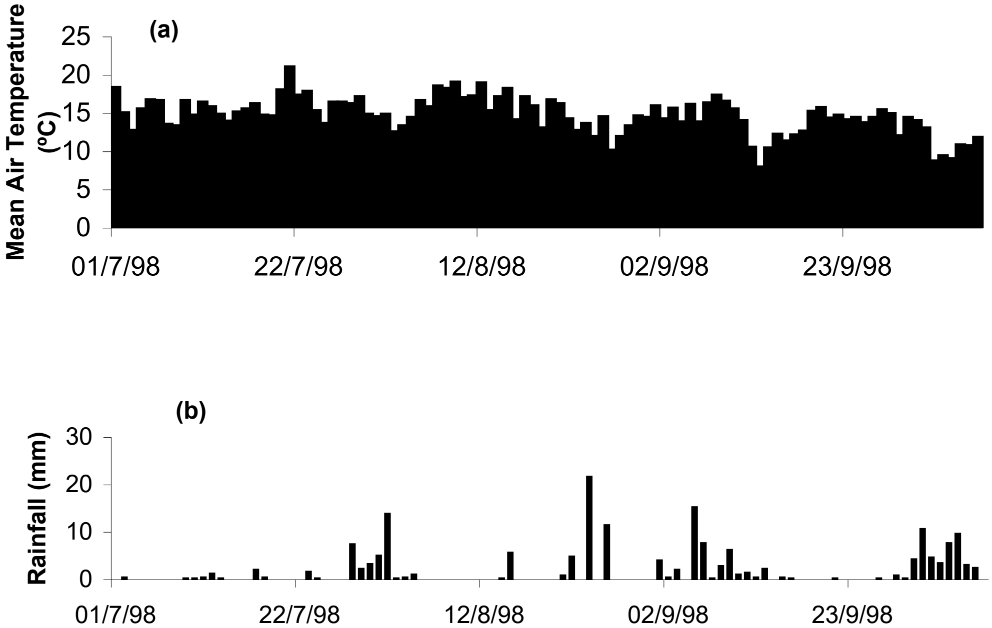


Figure 6 Air temperature (a) and rainfall (b) at Hesketh Bank 1998

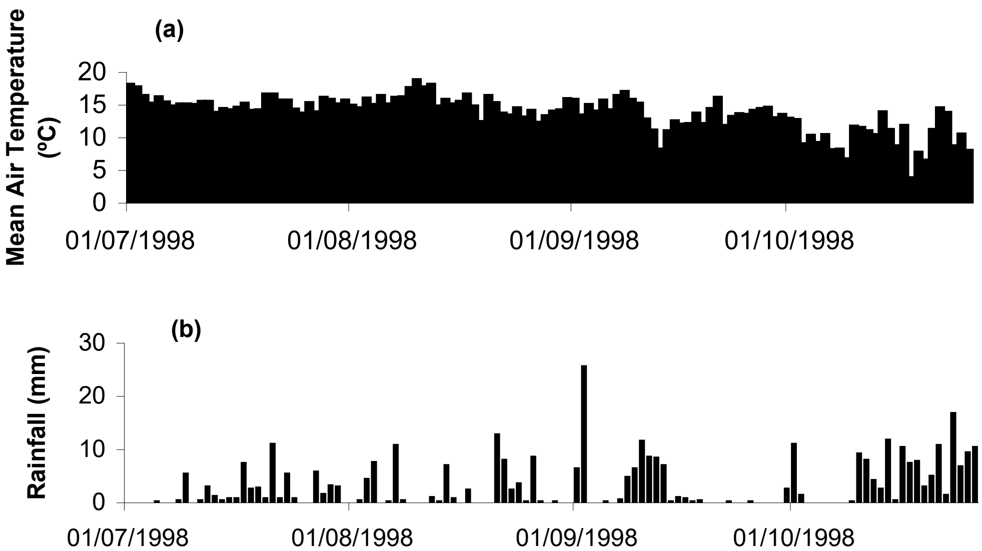
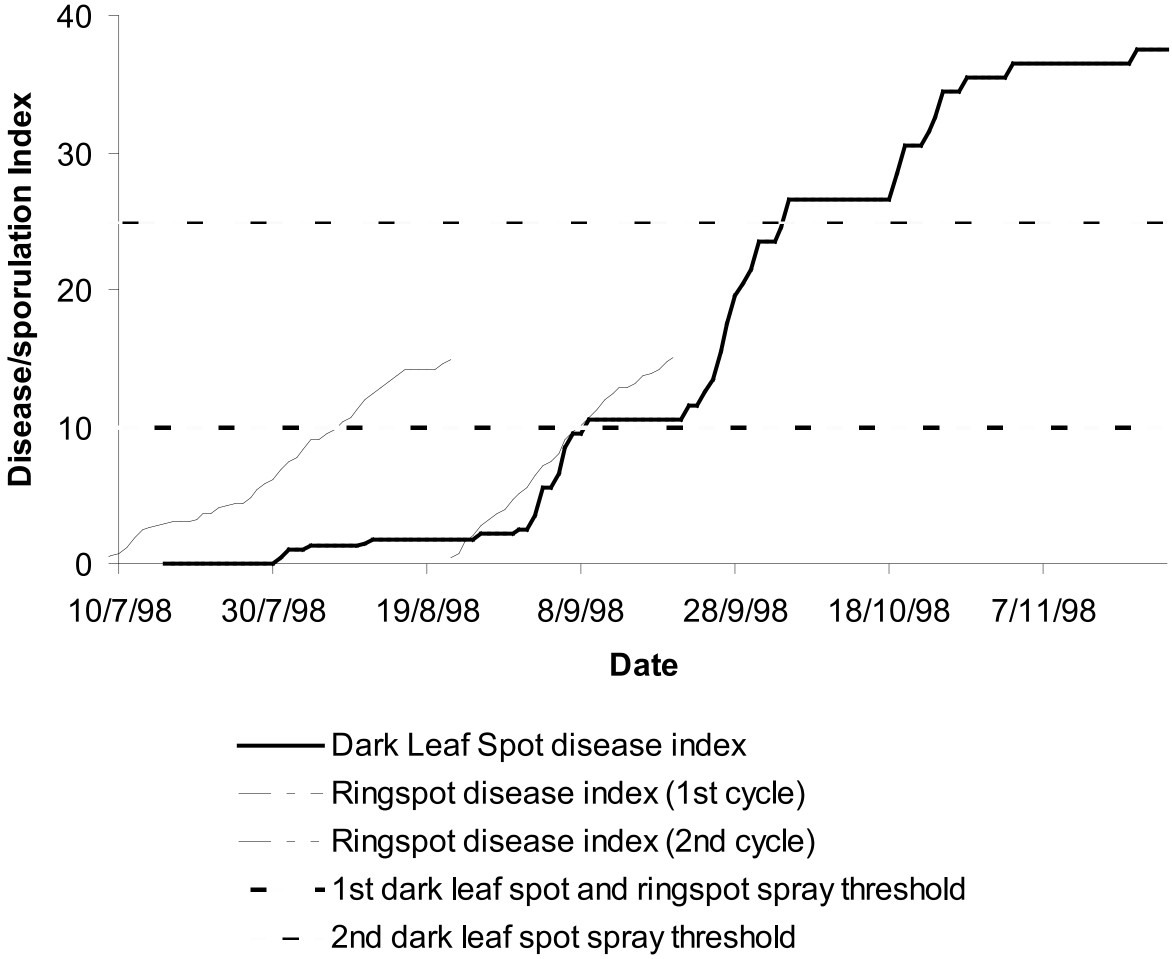


Figure 7 Predicted disease development (Butterwick trial site 1998)



Holbeach

Dark leaf spot and ringspot were initially observed at the Holbeach site on the 10 July 1998 (Table 6). 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 very 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 8). 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 6). 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 9). 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 8 Predicted disease development (Holbeach Hurn trial site 1998)

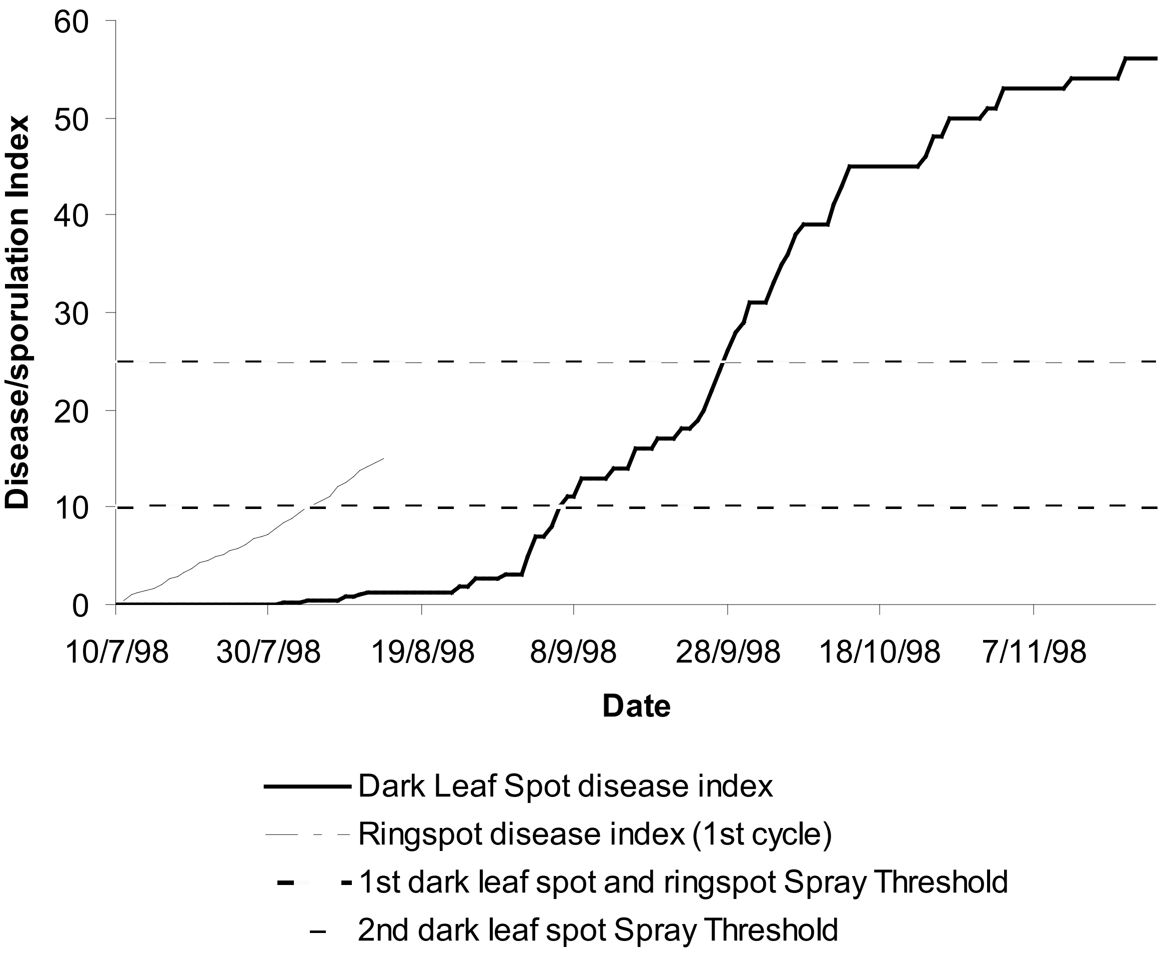
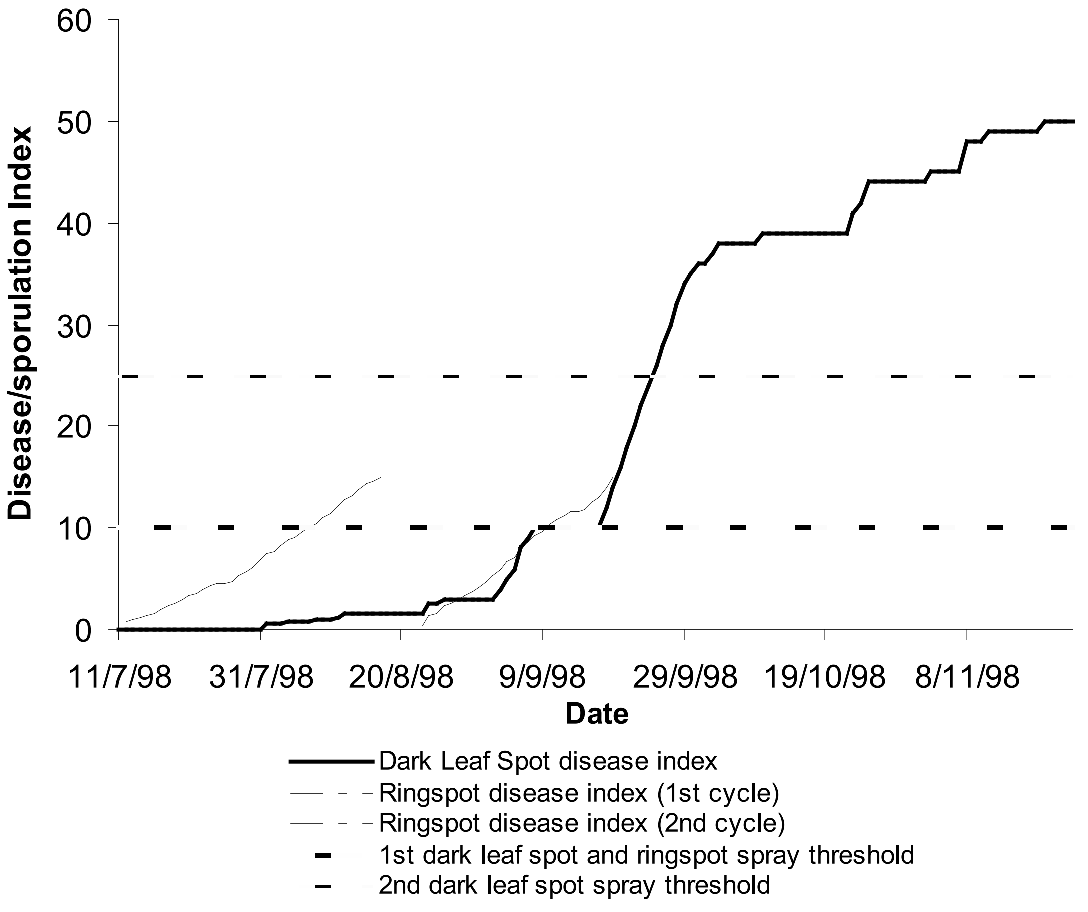


Figure 9 Predicted disease development (Donington trial site 1998)



4.1.1.3 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 10 and 11. There were higher numbers of uninfected buttons harvested at Butterwick from the middle and top of the plant (Figure 10). 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 11).

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 (Figure12). 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 (Figure13). 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 14). Approximately 30 % of the buttons harvested from the top of the canopy were uninfected. Infected buttons harvested from the bottom of the canopy had approximately 4 lesions of either ringspot or dark leaf spot on each button (Figure 15). Infected buttons harvested from other canopy positions had lower numbers of lesions per button.

Figure 10 Percentage (%) clean buttons at Butterwick (1998)

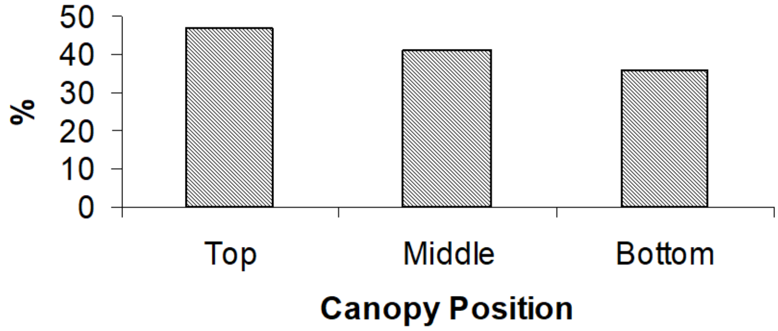


Figure 11 Mean lesion number per infected button at Butterwick (1998)

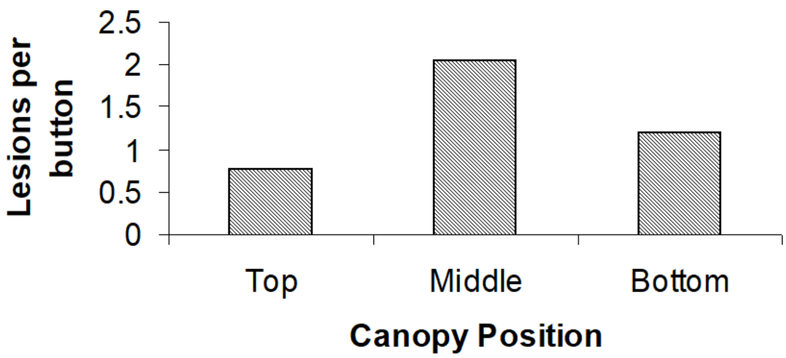


Figure 12 Percentage (%) clean buttons at Holbeach (1998)

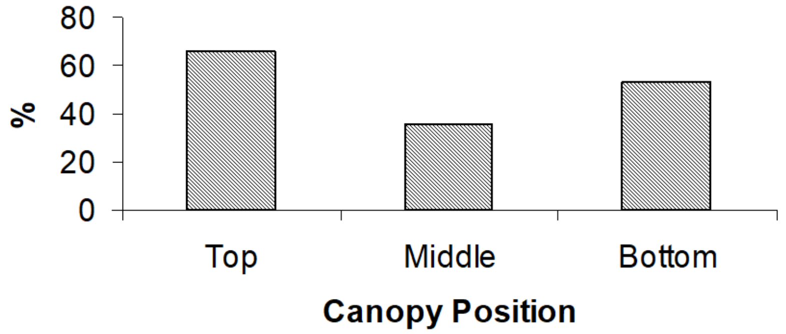


Figure 13 Mean lesion number per infected button at Holbeach (1998)

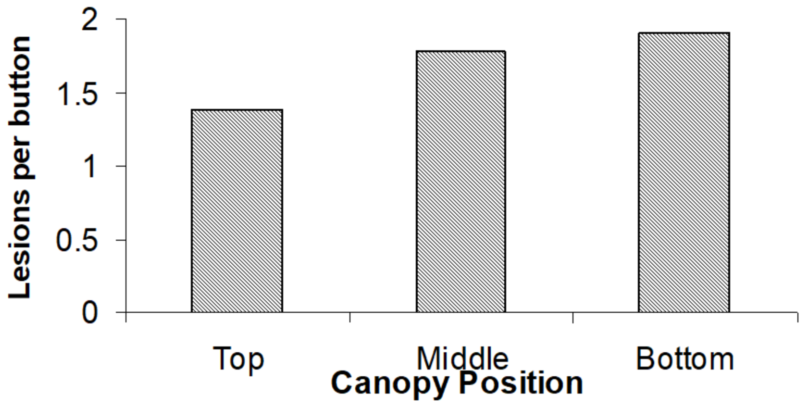


Figure 14 Percentage (%) clean buttons at Donington (1998)

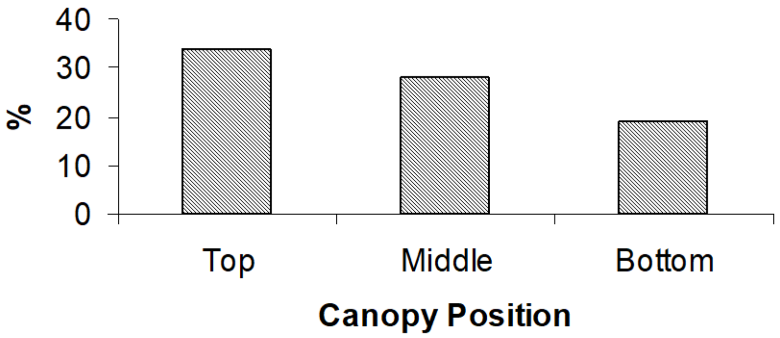
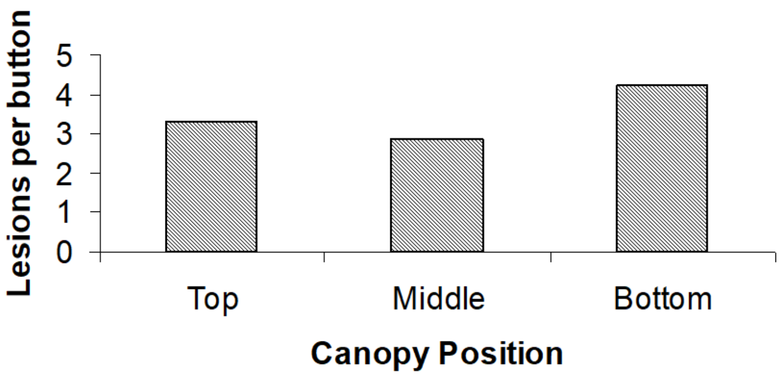


Figure 15 Mean number of lesions per infected buttons at Donington (1998)



4.1.2 1998 Other test sites

4.1.2.1 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 intitial 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 6). 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.

4.1.2.2 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 6). The initial dark leaf spot disease threshold was reached on the 4 September 1998. 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 6). The ringspot sporulation index reached the spray threshold on the 23 August 1998 (Figure 17). 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 16 Predicted disease development (St Andrews trial site 1998)

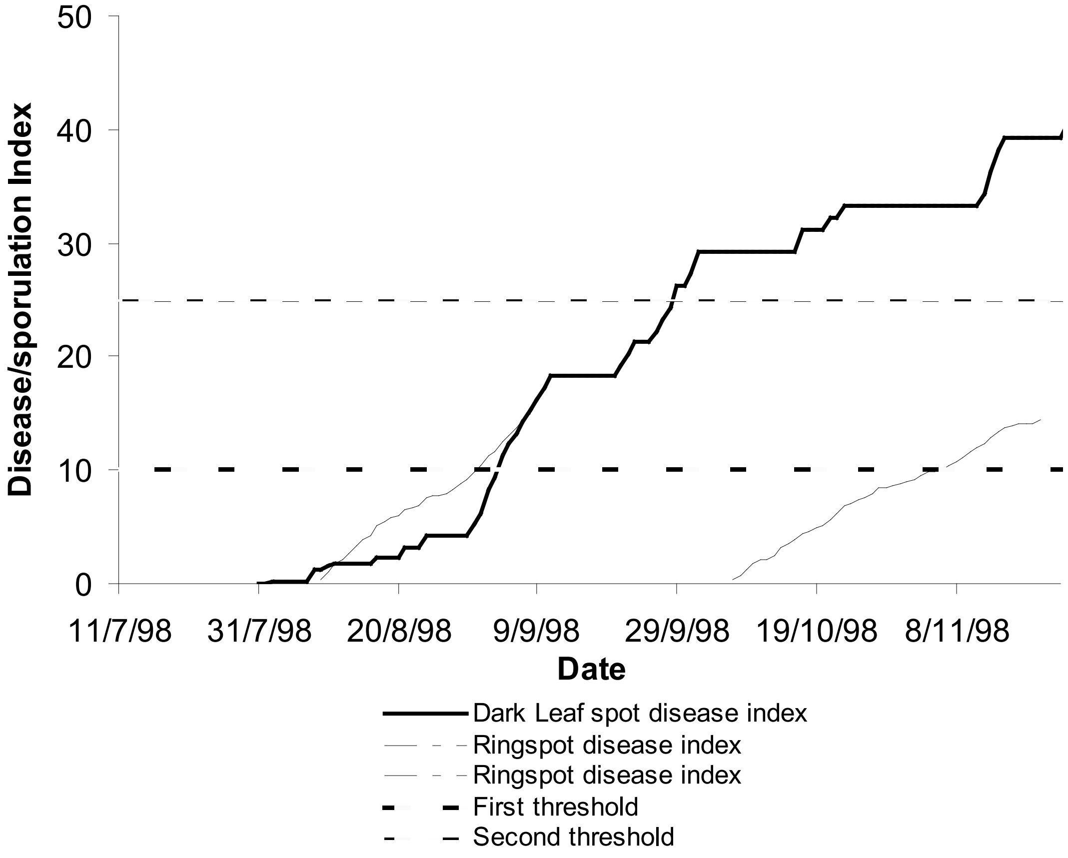
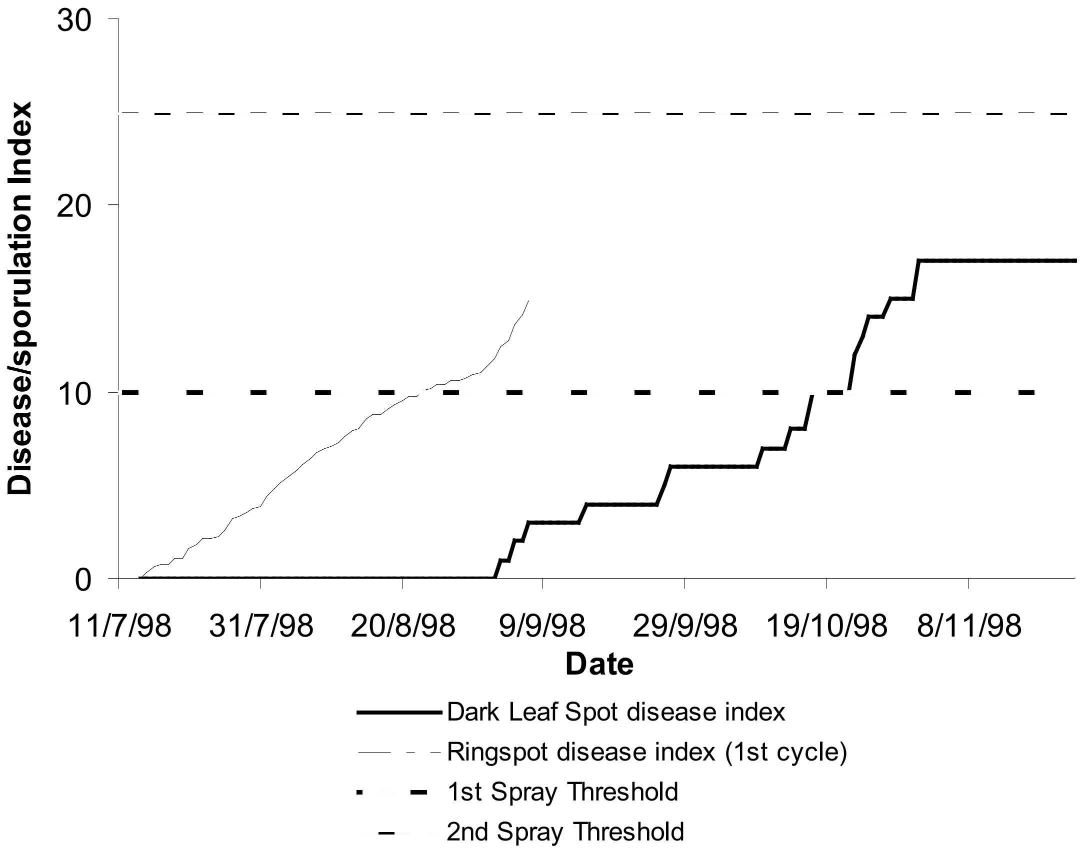


Figure 17 Predicted disease development (Ross-on-Wye) trial site 1998)



4.1.2.3 Observed ringspot and dark leaf spot on buttons at harvest

Both types of button harvests were taken at these sites as outlined in section 3.1.4.2. A sample of buttons was removed from the top, middle and bottom of the Brussels sprout shank and assessed. Additionally 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.

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 18). 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 19). The mean lesion numbers on infected buttons harvested from the shank was low at under two lesions per infected button (Figure 19).

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 20). 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 21). The mean number of lesions per button was higher from infected buttons taken from the shank sample (1.5).

Figure 18 Percentage (%) clean buttons at St Andrews (1998)

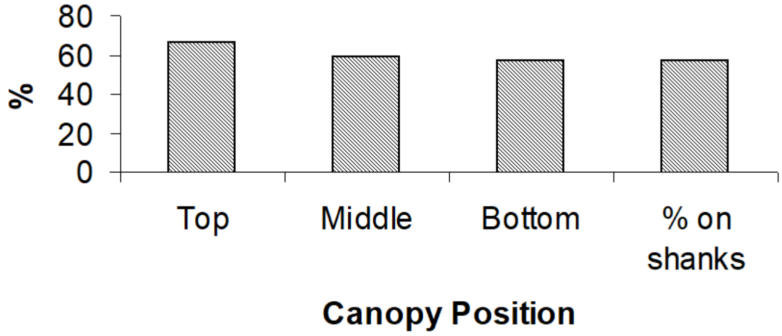


Figure 19 Mean number of lesions per infected buttons at St Andrews (1998)

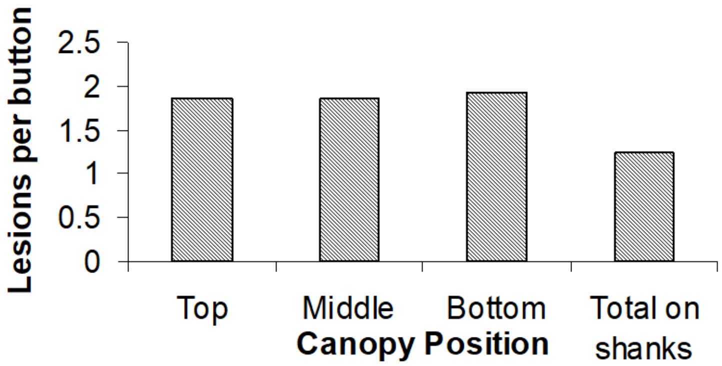


Figure 20 Percentage (%) clean buttons at Ross-on-Wye (1998)

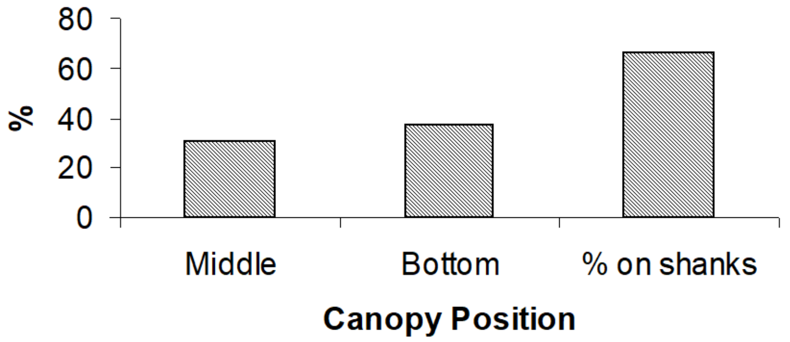
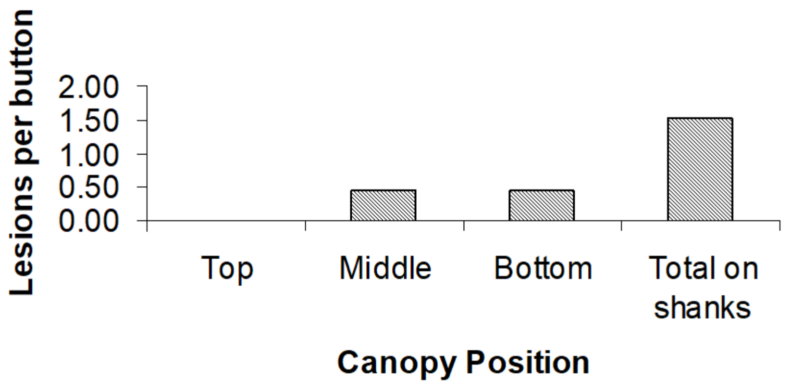


Figure 21 Mean number of lesions per infected buttons at Ross-on-Wye (1998)



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

4.2.1 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 8). 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 which time disease predictions commenced. At this site *Xanthomonas campestris* pv. *campestris* (black rot) and *Peronospora parasitica* (downy mildew) were also present.

Table 7 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

4.2.2 Predicted Disease Development Hesketh Bank

Prediction of dark leaf spot and ringspot development commenced at the Hesketh bank site 23 July 1998 (Table 7). 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 22). 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 22). 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.

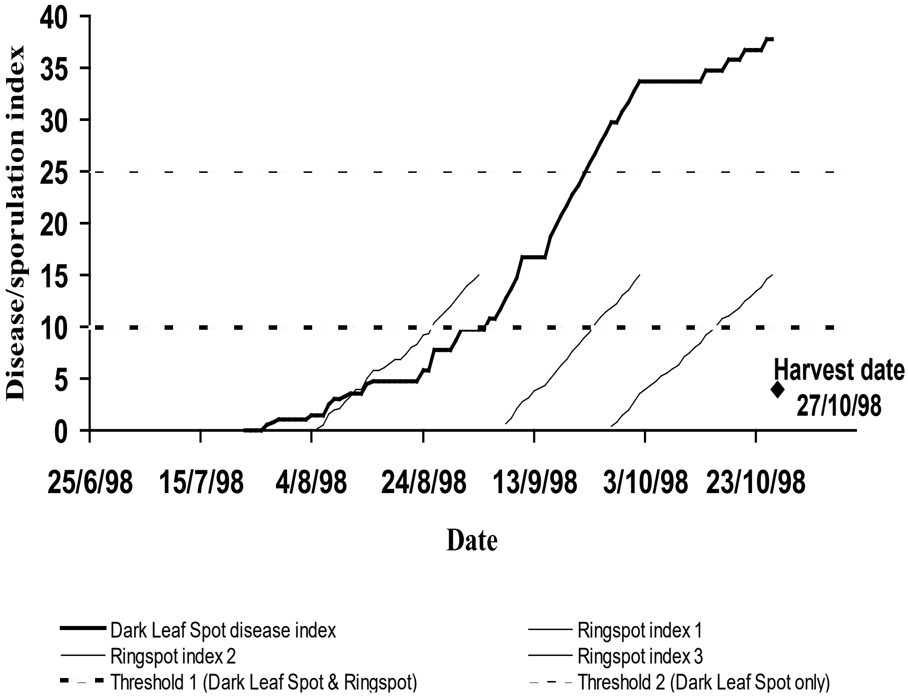
4.2.3 Observed ringspot and dark leaf spot on leaves during the growth season

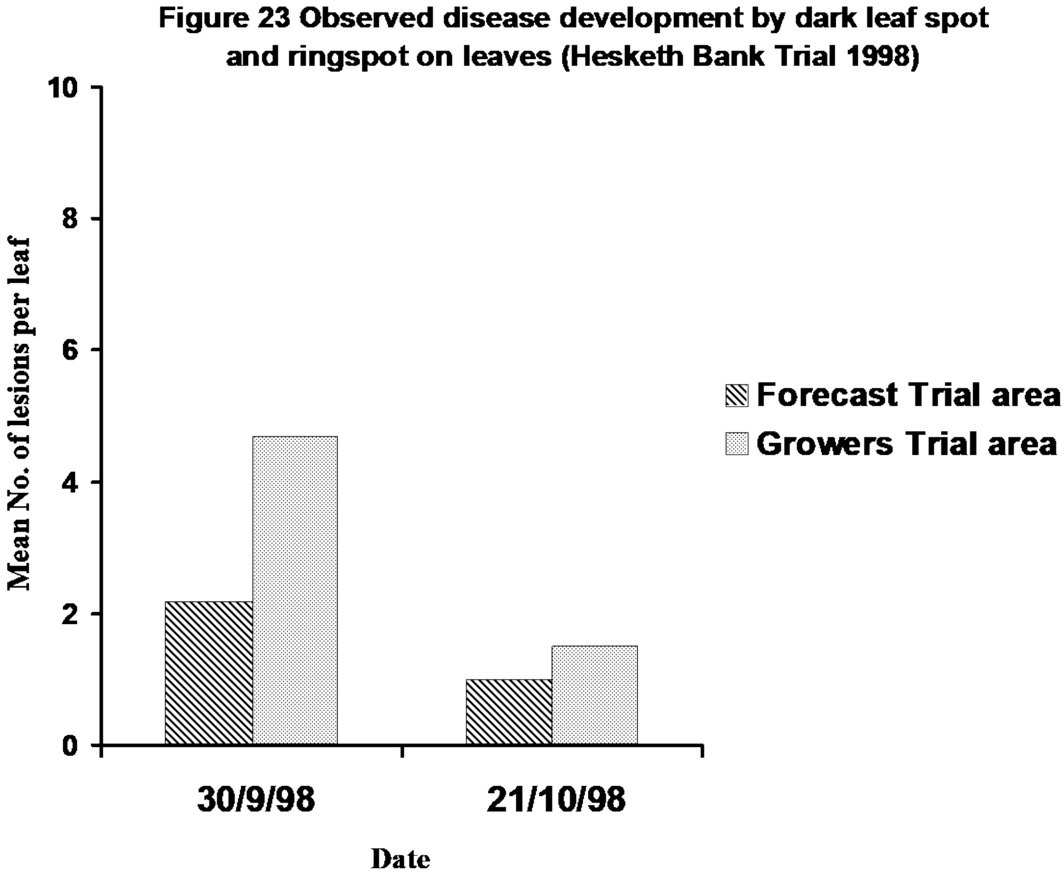
Higher mean numbers of lesions were observed on counts taken from leaves of plants in the growers plot in comparison to those taken from plants in the forecast plot (Figure 23). There were on average 5 lesions per leaf in counts taken from the growers trial area at Hesketh bank on the 30 September 1998 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).

4.2.4 Fungicide sprays applied at the Hesketh Bank trial site

Fungicides applied at the Hesketh Bank site are shown in Table 8. 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 22 Predicted Disease Development (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 8 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	25.07 -	Folicur	(0.5 litres ha^{-1})

Forecasting Area	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 $^{-1}$)

4.2.5 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 24. 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 25). 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 26). There were approximately 60, 30 and 20 % uninfected buttons in the button sample harvested from the top middle and bottom of the Brussels sprout shanks 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 27). Higher infection levels were observed on buttons harvested from the bottom of the canopy.

Figure 25 Mean number of lesions per button at Hesketh Bank (Whole plant sample)

Figure 24 Percentage uninfected buttons at Hesketh Bank 1998 (Whole plant sample)

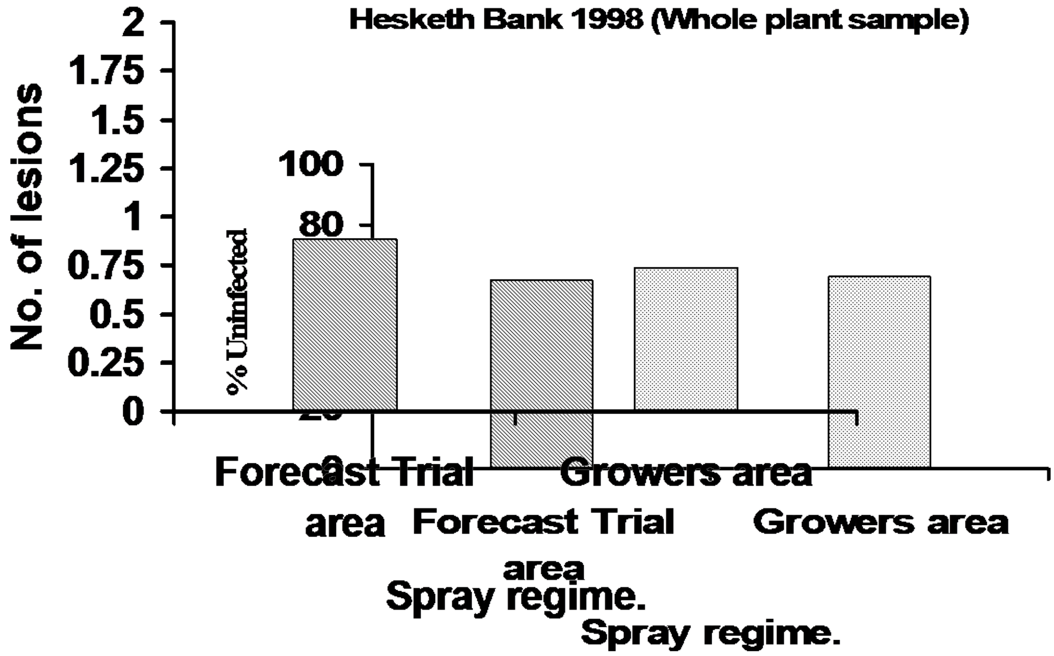
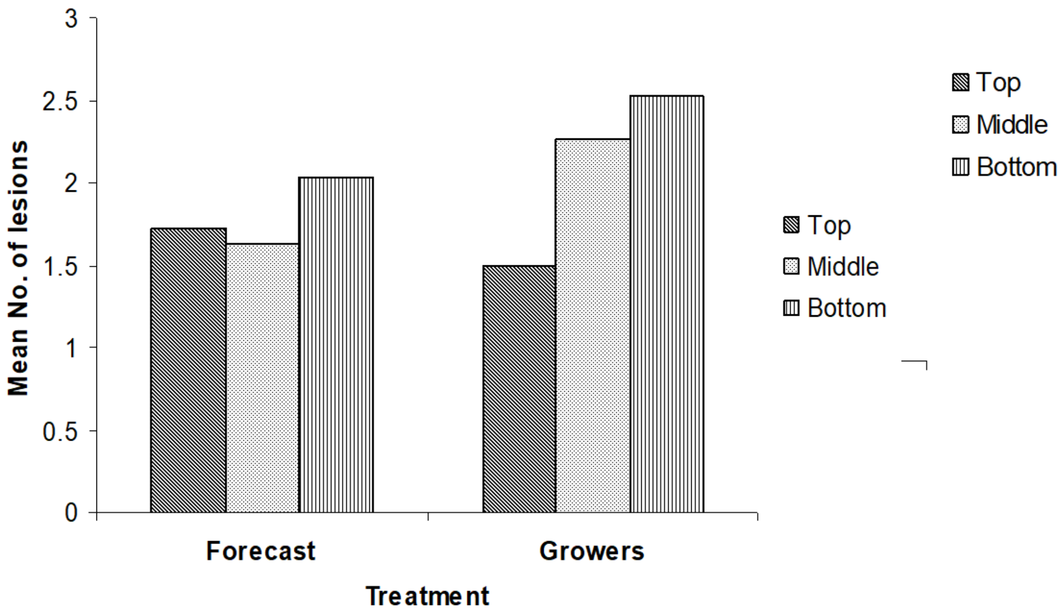


Figure 26 Percentage uninfected buttons at Hesketh Bank 1998 (Button sample)

Figure 27 Mean number of lesions per infected button at Hesketh Bank 1998 (Button sample)



4.2.6 Predicted Disease Development Skegness

The predicted disease development at the Skegness trial site is shown in Figure 28. 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. 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 28).

4.2.7 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 29). However at the second assessment date there was little difference between treatments in the amount of lesions numbers with on average only one lesion of either ringspot or dark leaf spot per leaf.

4.2.8 Fungicide sprays applied at the Skegness trial site

Fungicides applied at the Skegness site are shown in Table 9. 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 either 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 28 Predicted Disease Development (Skegness trial site 1998)

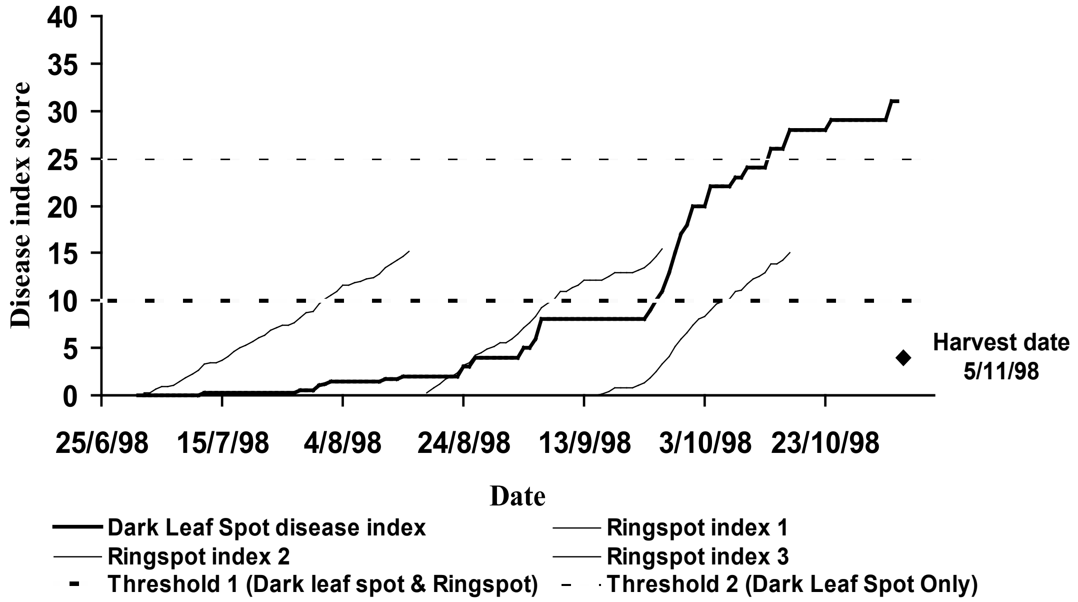


Figure 29 Observed disease development by dark leaf spot and ringspot on leaves (Skegness trial site)

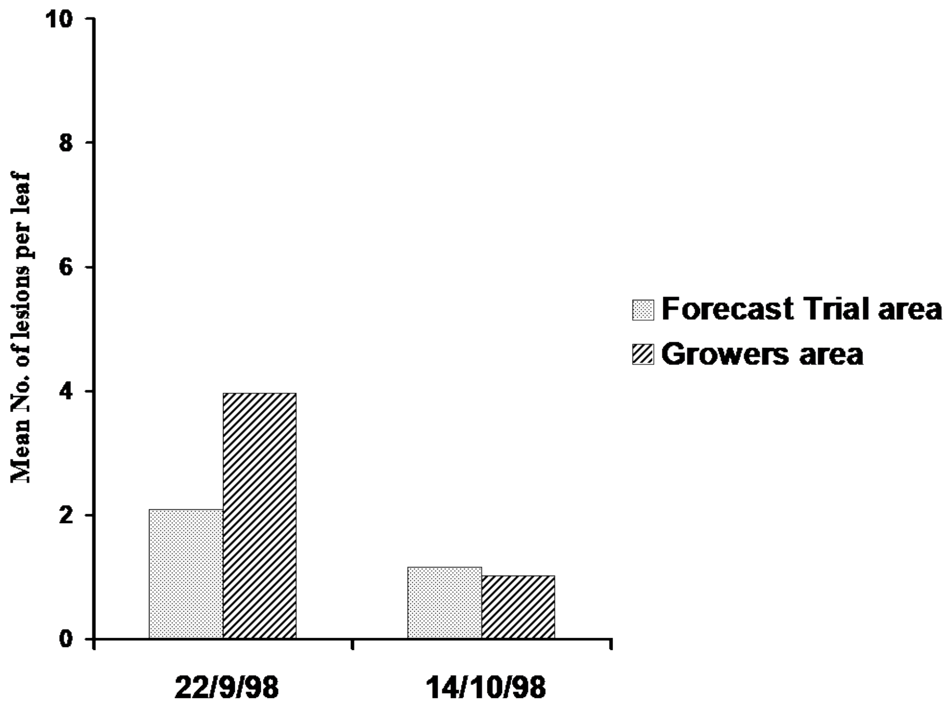


Table 9 Fungicide Treatments at field sites 1998 – Skegness site

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})

4.2.9 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 30). 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 31). 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 32). 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 32). There were significantly higher mean numbers of lesions on buttons harvested from the middle and bottom part of the canopy in the growers trial area in comparison to the forecast trial plots. (Figure 33). 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 30 Percentage uninfected buttons at Skegness site 1998 (Whole plant sample)

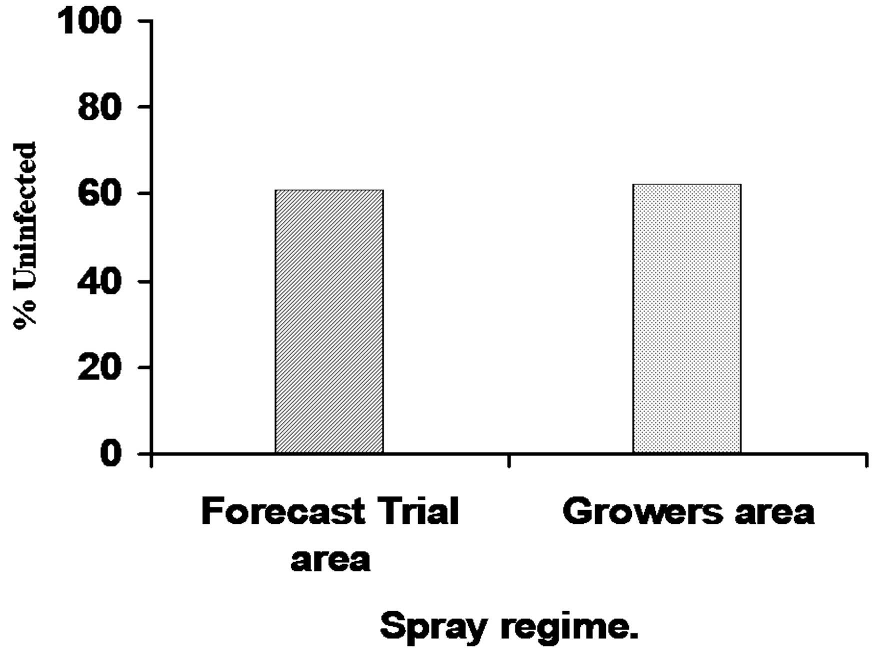


Figure 32 Percentage uninfected buttons at Skegness 1998 (Button sample)

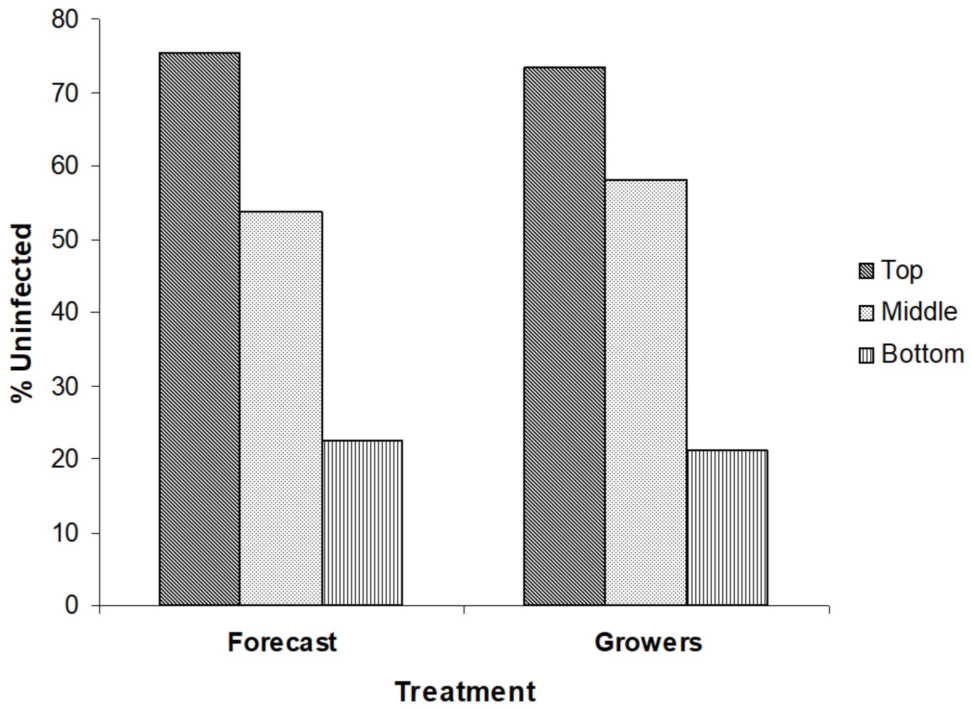
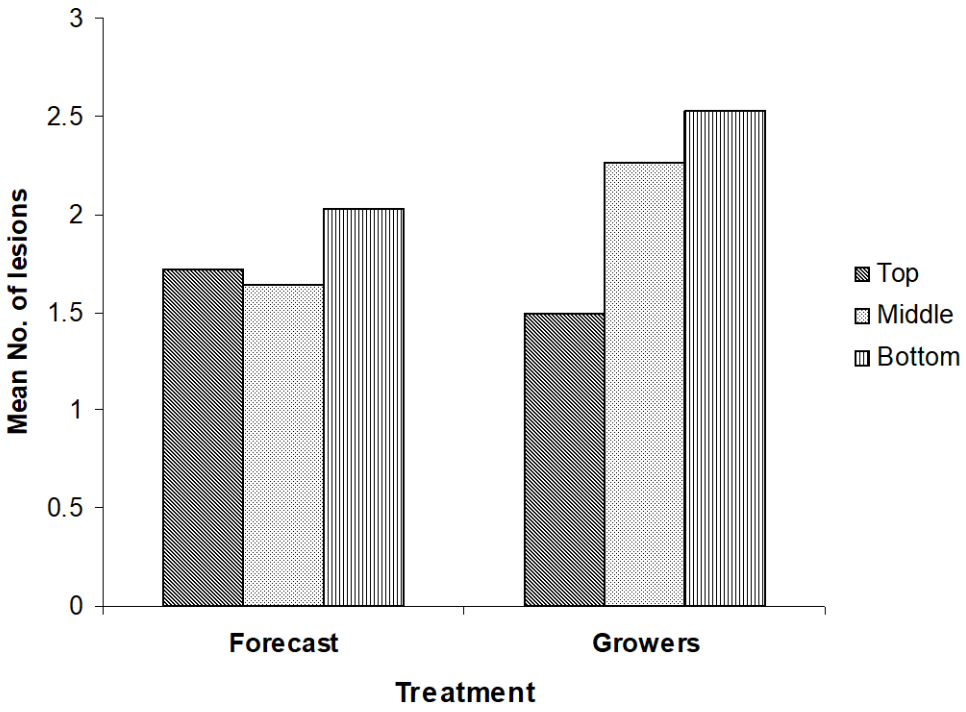


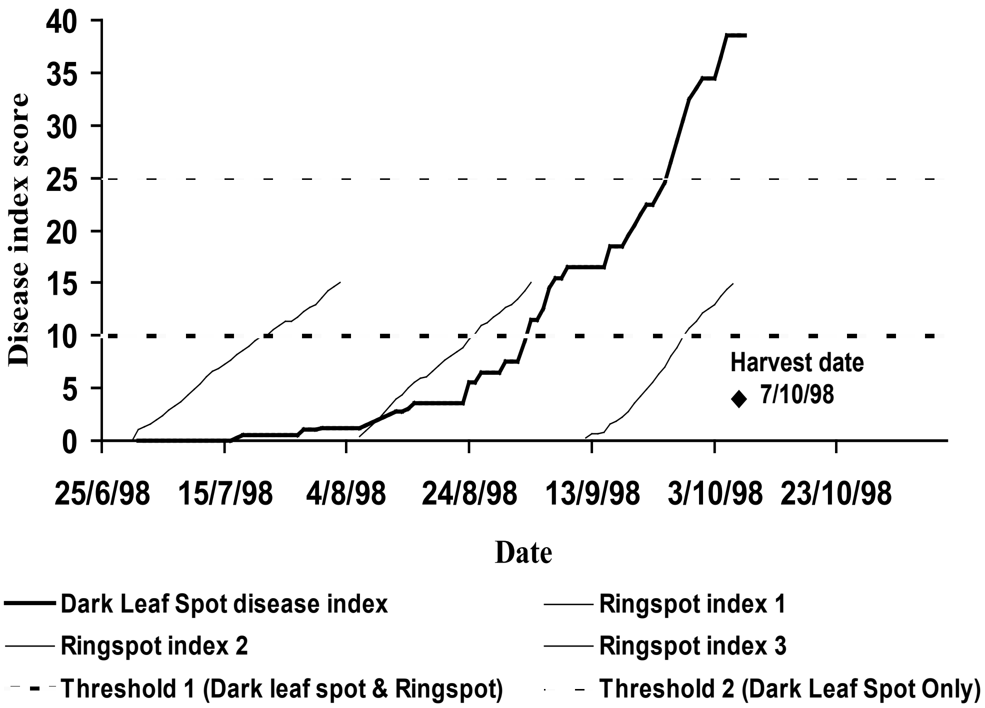
Figure 33 Mean number of lesions per infected button at Skegness 1998 (Button sample)



4.2.10 Predicted Disease Development Frieston Shore

The predicted disease development at the Frieston Shore trial site is shown in Figure 34. Dark leaf spot and ringspot were observed in the crop on the 29 June 1998. 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 34).

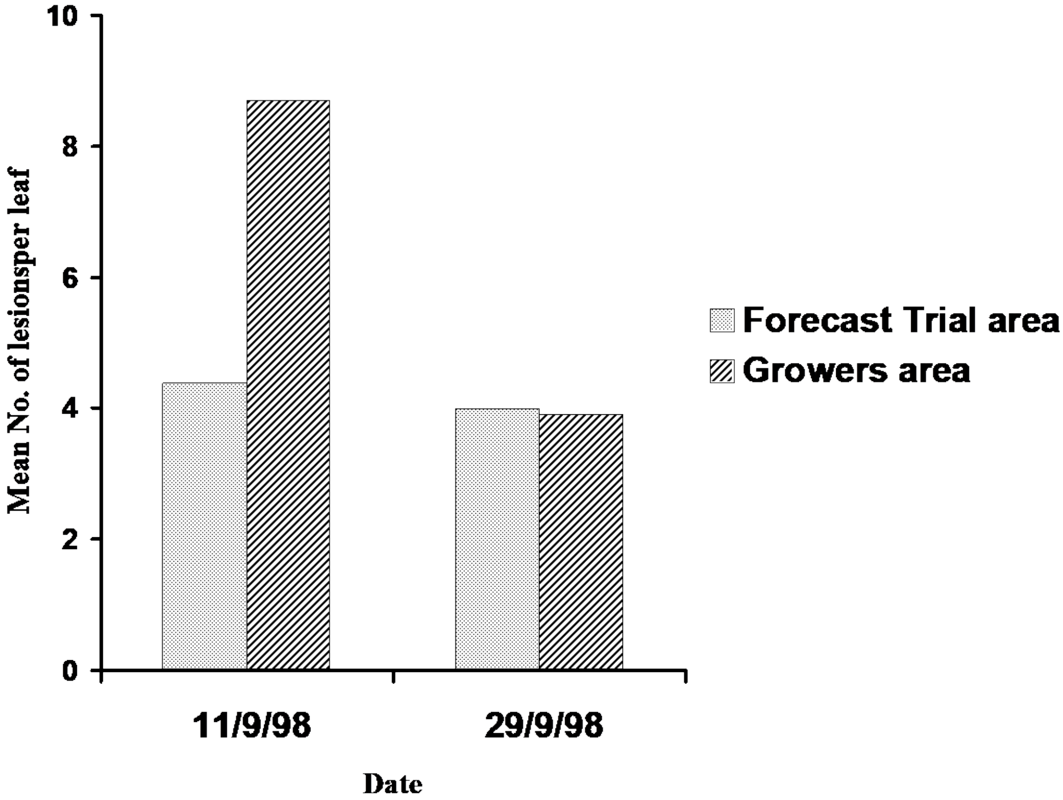
Figure 34 Predicted Disease Development (Frieston shore trial site 1998)



4.2.11 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 35. 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 35 Observed disease development by dark leaf spot and ringspot on leaves (Frieston shore trial site)



4.2.12 Fungicide sprays applied at the Frieston Shore trial site

Fungicides applied at the Frieston Shore site are shown in Table 10. 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 10 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})

4.2.13 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 36). 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 37). 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 36 Percentage uninfected buttons at the Frieston shore site (Whole plant sample)

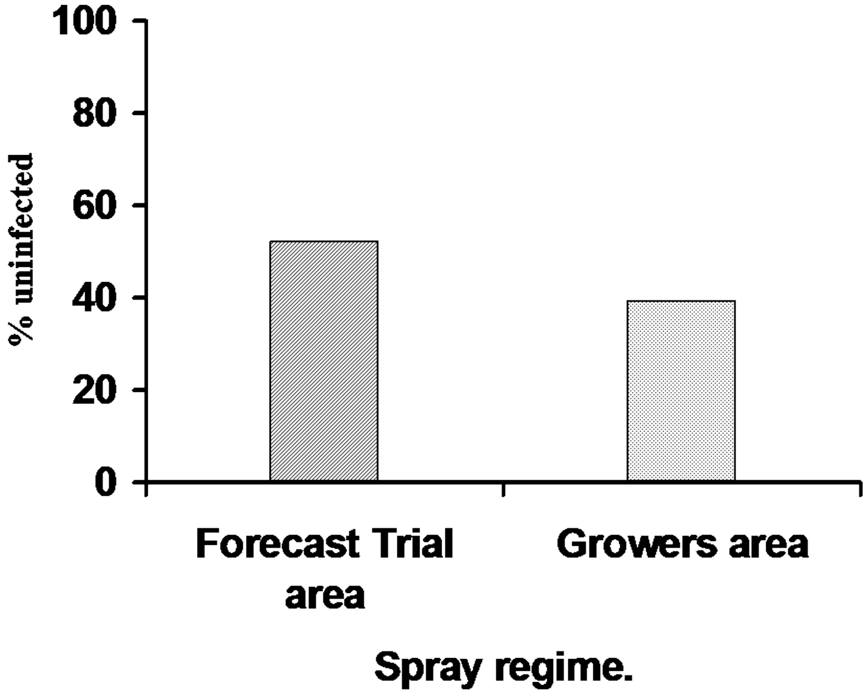


Figure 37 Mean number of lesions per button at the Frieston shore site (Whole plant sample)

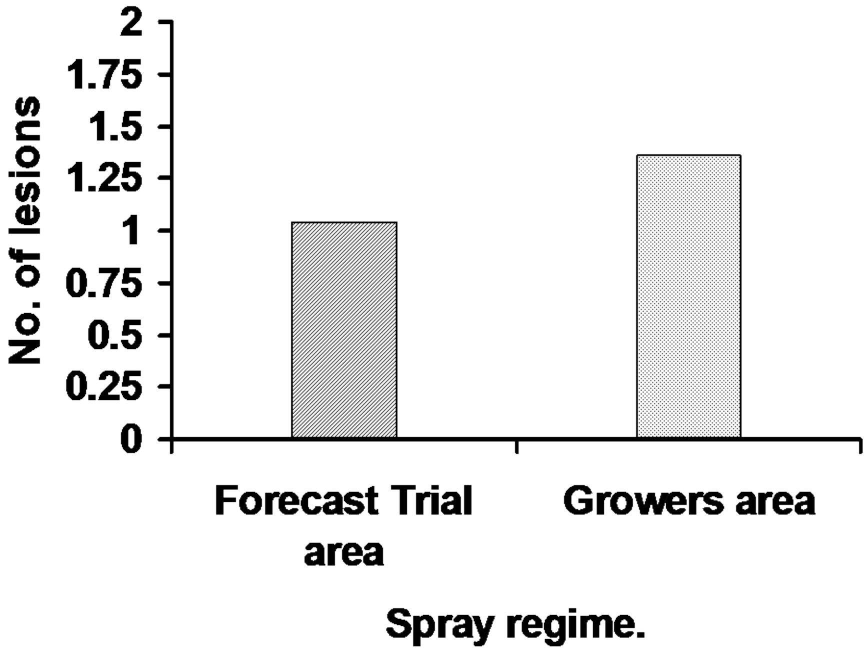
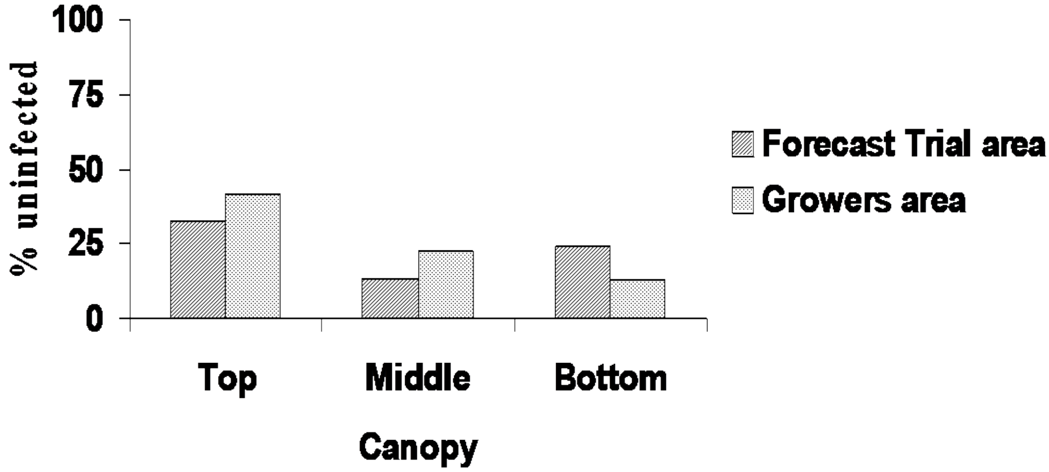


Figure 38 Percentage uninfected buttons at Frieston shore (Button sample)



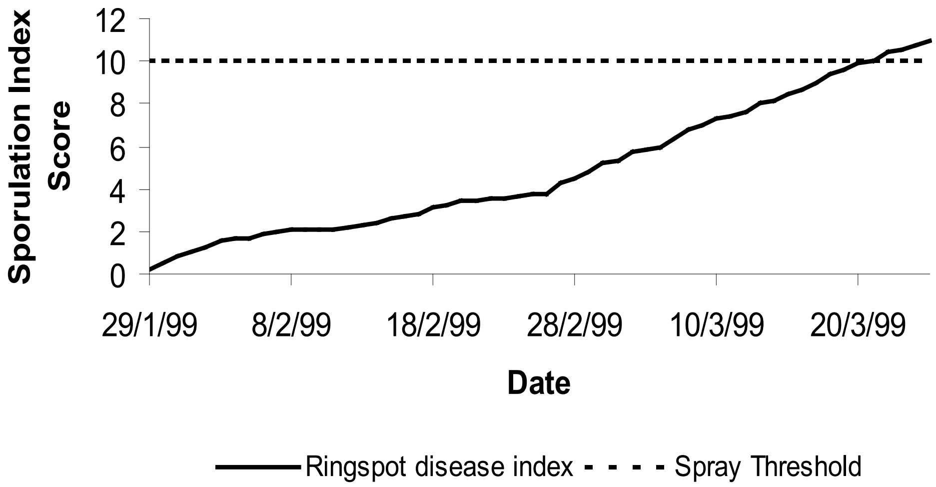
samples taken from the top middle and bottom of the canopy (Figure 38). Approximately 41 % of buttons harvested from the top of the canopy were uninfected in the grower's trial area. However 33 % of buttons sampled from the top of the canopy were uninfected in the forecast trial plots. Approximately 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.

4.3 Development and validation of ringspot forecasts in cauliflower crops

4.3.1 Predicted ringspot development

An over-wintered cauliflower crop (cv. Jerome) was used in the 1998 trials. 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. Predicted ringspot inoculum production from lesions is shown in Figure 39. Inoculum production from these lesions was predicted on the 21 March 1999 (5 % of lesions producing inoculum). However the secondary spray criteria (50 % of lesions producing inoculum) was not used in the trial.

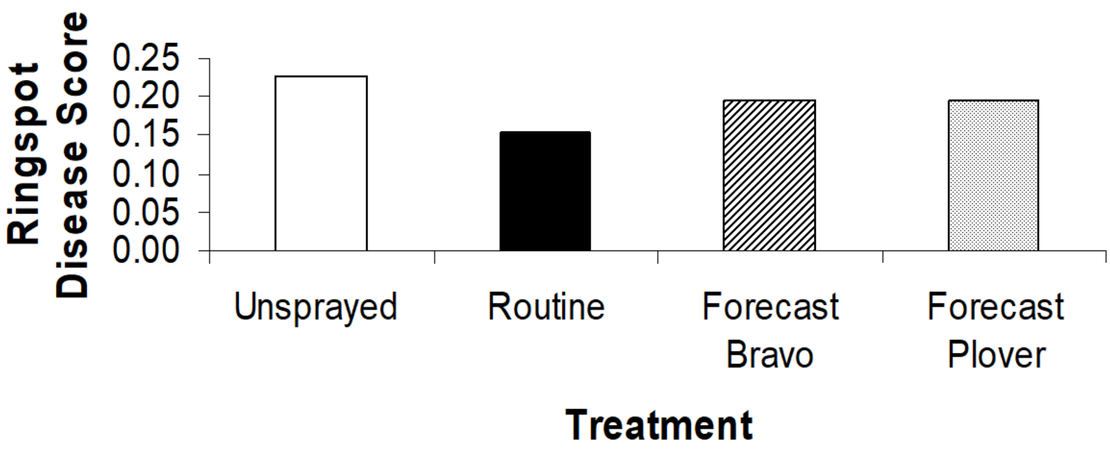
Figure 39 Predicted ringspot inoculum production (Over-wintered cauliflowers HRI Kirton)



4.3.2 Observed ringspot on cauliflower heads at harvest

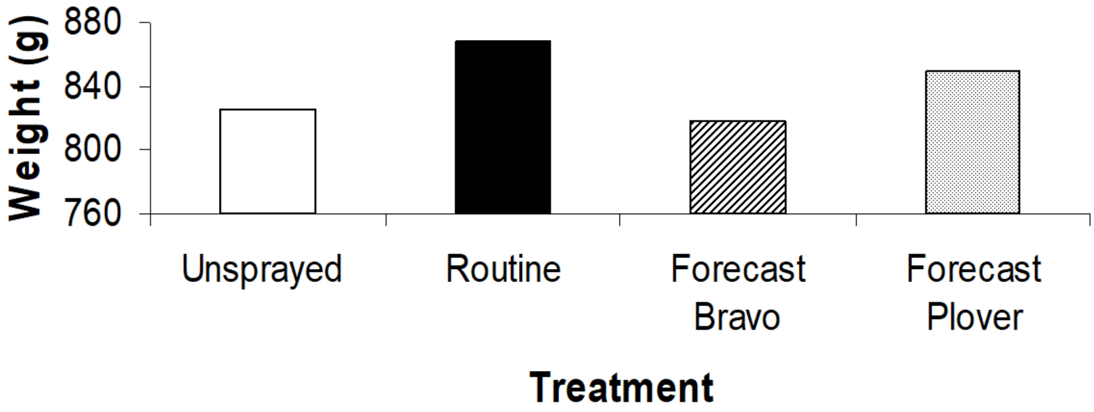
The treatments used in the cauliflower trial are stated in section 3.2.1.3. However a spray of Folio (2 litres ha^{-1}) was applied to all treatment plots on the 28 August 1998 to control white blister infection which had occurred within the plots. Three applications of Plover (0.3 litres ha^{-1}) were 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 40). Mean ringspot severity scores of approximately 0.22 were observed on heads harvested from unsprayed plots on the 15 April 1999 (Figure 40). Lower severity scores of approximately 0.19 were recorded on heads harvested from forecast plots spayed 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 40 Ringspot disease scores on harvested cauliflower heads 1998 (HRI Kirton)



The weight of cauliflower curds at harvest is shown in Figure 41. 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 42). The results suggest that there was little effect of ringspot on cauliflower yield.

Figure 41 Mean head weight of cauliflowers heads in 1998 (HRI Kirton)



4.3.3 Ringspot development on cauliflower leaves pre harvest

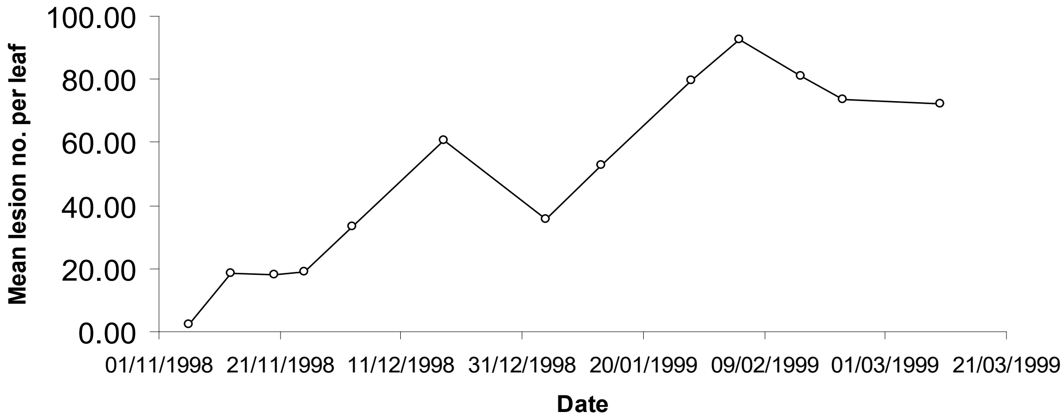
Very low levels of ringspot were observed in all treatments due to the predominantly to dry conditions which occurred in January 1999. There were few differences between treatment in the numbers of lesions per leaf. Mean numbers of ringspot lesions per leaf were approximately 1 (data not presented).

3.3 Use of the ringspot forecaster in commercial cauliflower crops

4.4.1 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 42). 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.

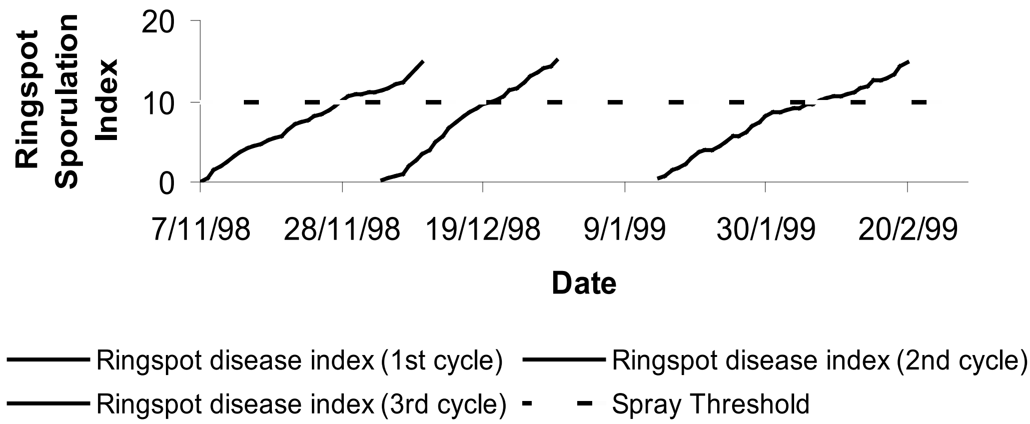
Figure 42 Mean number of lesions per leaf on commercial cauliflower plants in Cornwall 1998/99



4.4.2 Predicted inoculum production at the field site in Cornwall

The predicted inoculum production, based on observations taken in the crop, are shown in Figure 43. 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 (2 nd cycle), and the 7 February 1999 (3 rd 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.

Figure 42 Predicted ringspot disease development in a commercial cauliflower crop in 1998 (Camborne, Cornwall)



5. CONCLUSIONS

Forecasting initial dark leaf spot occurrence 1998

Both ringspot and dark leaf spot require wetness for infection and disease development. During 1998 environmental conditions for brassica leaf-spot diseases were very favourable. Inoculum from high levels of infection on over-wintered cauliflower crops was available as a result of high levels of rainfall which occurred in April 1998. There was however considerable variation in the occurrence of both dark leaf spot and ringspot. Ringspot appeared earlier in crops located in the Butterwick area. In Scotland dark leaf spot was not observed until the second first week of August 1998. Ringspot was observed at this Scottish site (St Andrews) in 1998 before dark leaf spot presence was confirmed. 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.

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 observational trials. 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 were not significantly different in their predicted effects on disease development in 1998. However this effect has been shown to vary between years as in 1997 there was significant differences between these sites. The rate of inoculum production by ringspot was also not significantly different between sites used although the rate increased by 50 % when the production of initial and secondary ringspot inoculum in crops was compared. 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 production to be predicted. The effect is probably due to longer periods of leaf surface wetness occuring 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 between these species required for spore production. The occurrence of spore production periods would have a dramatic effect on dark leaf spot. 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. It was not possible at these sites to obtain information on fungicide type or application timing used to control the disease. However the models suggested that critical timings for application of fungicidal control was around the 5 – 10 September 1998.

Predicted ringspot and dark leaf spot development at St Andrews 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 production from lesions regardless of the time period. 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. 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 this site. 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.

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 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 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 presure 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 % 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. 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. It should be noted that the results of these trials probably reflect the minimum amount of fungicides that can be saved. With the exception of the Skegness site 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* for other leaf spot pathogens on vegetable brassicas

With forecasts for more than one disease in the crop there is increasing opportunities for synergy in fungicide sprays. This has already become evident in trials conducted in 1998. If forecasts are triggered separately the grower may consider applying both an eradicant and protectant fungicide in the same application. In further trials in 1999 it will be important to fully confirm the effects of using two forecasts within the field to time fungicide application. The addition of forecasts for white blister in 1999 to the system will require further consideration. 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 need to be fully investigated in relation to forecasts of ringspot and dark leaf spot.

Development of forecasting systems for cauliflower crops

The results from the second year of development of the ringspot forecaster on cauliflower confirmed that the forecaster developed on Brussels sprout could 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. Further experiments are necessary to ascertain the best method of using ringspot disease forecasts in commercial cauliflower crops.

6. ACKNOWLEDGMENTS

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