Final Report
HDC Project FV 53c

BRASSICA LEAF DISEASES : FURTHER DEVELOPMENT OF WEATHER-BASED FORECASTING SYSTEMS FOR DARK LEAF SPOT AND LIGHT LEAF SPOT DISEASES

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PRACTICAL SECTION FOR GROWERS

Fungicidal sprays are necessary to control the many damaging leaf spot pathogens of Brussels sprouts crops. The introduction of new (apparently more susceptible) cultivars and the intensification of cropping has resulted in increased difficulties in effectively controlling many of these pathogens. Disease control is particularly difficult where they occur on long season vegetable crops such as Brussels sprouts, where several fungicide sprays may be necessary. The spotting on Brussels sprouts buttons which results from poor control measures can lead to a down-grading of the produce.

In the past many Brussels sprouts growers have relied on routine fungicide usage to control leaf spot pathogens. In part this approach may result from difficulty in the early diagnosis of some pathogens. However, with increasing experience, many growers now adopt control strategies which rely on their own experience of these diseases linked with more information on disease levels within the crop. The latter information is obtained by regularly walking through crops during the season and noting the presence or absence of the disease together with any potential for disease spread. This has resulted in greater targeting of fungicidal inputs, however, fungicide usage remains high. Many leaf spot pathogens are still controlled using several fungicide applications which may not have been applied at routine intervals (selectively routine). Routine (standard intervals between applications) or selectively routine (non-standard intervals between applications) programmes are costly, wasteful and potentially damaging to the environment. There is regulatory pressure to adhere strictly to label recommendations for many pesticides and market pressure to apply fungicides only when it is deemed necessary. Alternative methods which may reduce fungicide usage are needed. One promising approach to reducing pesticide usage is the application of disease forecasting techniques, which can be used to predict the need for and the optimal timing of fungicide applications. By better targeting of fungicide usage, in this way, quality of produce could be maintained while reducing fungicide usage.

Forecasting dark leaf spot

Practical disease forecasters can be developed using a number of techniques. The simplest approach is to use conditions which are favourable for the occurrence of key stages in the life cycle of each pathogen (i.e. spore production, infection) to time fungicide application. Where such conditions occur too frequently for practical use, the identification of conditions that favour the completion of the pathogen's full life cycle may be of value. A disease forecaster for *Alternaria brassicae* (dark leaf spot) on Brussels sprouts, based on the effect of temperature and surface wetness on infection and of temperature and humidity on sporulation, has been developed. The dark leaf spot forecaster predicts both when the crop may need to be examined for the occurrence of the pathogen and, if disease occurs, when fungicide applications should be made.

Commercial trials with a dark leaf spot forecaster 1994/95

Commercial trials have been conducted using the forecaster at three sites (Algakirk, Donington and Freiston) during 1994 in Lincolnshire and in 1995 at three sites one each in the Lincolnshire, Lancashire and Bedfordshire Brussel sprout growing areas. In Lincolnshire during 1994 at the three commercial sites, use of the dark leaf spot disease forecaster resulted in fewer applications of fungicide compared to both the regime used by the grower, and a routine spray treatment of iprodione (Table 1). Dark leaf spot was present within the crop and all Brussels sprouts buttons from all treatments were marketable at harvest. Similarly, when these trials were repeated in 1995 in different Brussels sprouts growing areas the use of the dark leaf spot disease forecaster resulted in fewer applications of fungicide with no reduction in Brussel sprouts button quality (Table 2).

Economic implications

The economic implications of these disease forecasting trials are considerable. However, only the cost savings relating to reduced amounts of fungicide can be quantified to any degree of accuracy (see below). The dark leaf spot forecasting system provides information which should enable growers to more accurately target the amount and timing of crop walking which would be necessary to determine the presence or absence of the disease. Estimates of cost savings resulting from reduced crop walking would depend on the prevailing weather conditions and so are not given in this report.

Reduction of fungicide costs 1994

Calculations are based on a standard contractor's charge of £12 per hectare for spraying operations and standard costs of fungicides (Table 3). The fungicide applications based on the dark leaf spot disease forecaster reduced costs at all three sites in forecasting trials in Lincolnshire during 1994 in comparison to those incurred by either the grower's individual regime or a routine fungicide treatment (Table 4a). Estimated cost of spray programmes are quoted to the nearest pound per hectare, exclusive of VAT.

Use of the dark leaf spot forecasting system saved approximately £96, £39 and £28 per hectare (excluding VAT) at Algakirk, Donington and Freiston respectively when compared with the grower's regime. Control of dark leaf spot was better using the dark leaf spot forecasting system at all three sites. The routine spray programme cost £90 more per hectare (excluding VAT) than the spray timing system and failed to maintain lower levels of disease on buttons at two of the three sites.

Table 1 **Disease at harvest - Lincolnshire 1994**

(a) Mean percentage of buttons infected:

	Routine	Treatment Spray Timing	Grower's Practice
Algakirk	22	34	47
Donington	25	30	64
Freiston	37	38	60

(b) Number of dark leaf spot sprays:

	Routine	Treatment Spray Timing	Grower's Practice
Algakirk	4	2	5
Donington	4	2	4
Freiston	5	3	5

Table 2 **Disease at harvest, Lincolnshire, Lancashire and Bedfordshire 1995**

(a) Mean percentage of buttons infected:

	Routine	Treatment Spray Timing	Grower's Practice
Lincolnshire	22	18	18
Lancashire	21	19	17
Bedfordshire	13	13	22

(b) Number of dark leaf spot sprays:

	Routine	Treatment Spray Timing	Grower's Practice
Lincolnshire	3	1	4
Lancashire	4	2	5
Bedfordshire	3	1	2

Table 3 Fungicides applied to uninoculated experiments in 1994 & 1995

Chemical	Brand name	Application rate*	Cost ha^{-1} (£ ex. vat)	
			1994	1995
Iprodione	Rovral Flo	510g a.i. ha^{-1}	30.80	37.58
Triadimenol	Bayfidan, Spinnaker	125g a.i. ha^{-1}	18.75	14.64
Fenpropimorph	Corbel	750g a.i. ha^{-1}	22.90	28.04
Mancozeb + metalaxyl	Fubol	1125g a.i. ha^{-1}	19.50	25.65
Chlorothalonil + metalaxyl	Folio	1150g a.i. ha^{-1}	42.50	49.36
Chlorothalonil	Bravo, Bombardier	1500g a.i. ha^{-1}	21.60	26.19
Tebuconazole	Folicur	250g a.i. ha^{-1}	-	39.63

*except where specifically noted

Table 4 **Comparative costs of trial spraying programmes a) 1994, b) 1995**

Pounds per hectare (ex. VAT) :

a)

	Algakirk	Donington	Freiston
Grower's Practice	257	200	189
Routine	- 6	+ 51	+ 62
Spray Timing System	- 96	- 39	- 28

b)

	Bedfordshire	Lancashire	Lincolnshire
Grower's Practice	143	266	233
Routine	+ 31	+ 50	- 5
Spray Timing System	- 68	- 124	- 130

Reduction of fungicide costs 1995

Similar results were obtained in disease forecasting trials in Lincolnshire, Lancashire and Bedfordshire in 1995 using the same costings as in 1994 (Table 3). The fungicides applied based on the dark leafspot forecasting system reduced costs at all three sites in comparison to those incurred by use of the grower's control regime or a routine treatment (Table 4b). Estimated costs of spray programmes are again quoted to the nearest pound per hectare, exclusive of VAT.

The spray timing system saved an estimated £68, £124 and £130 per hectare (excluding VAT) at Bedfordshire, Lancashire and Lincolnshire respectively when compared with the grower's practice and achieved equal control of dark leaf spot and other diseases at all three sites. The routine spray programme cost between £99 and £174 more per hectare (excluding VAT) than the spray timing system and failed to produce lower levels of disease on buttons at any of the three sites (Table 2).

General conclusions

Use of the dark leaf spot forecasting system in Brussels sprouts has been shown to reduce crop protection inputs significantly. The total costs involved in establishing environmental datalogging capability are approximately £800. This equipment is necessary to utilise the dark leaf spot forecasting system. However, the potential savings resulting from the use of the forecasting system outweigh these start up costs. The cost of environmental data capture systems are being reduced while the technology is still improving. For example, it is now possible to download information from these loggers to an office PC by radio transmitted signals. This capability would add to the cost involved in establishing environmental data capture systems. In the future it is likely that these systems will be low cost and more automated. This will enable the grower to run crop forecasting systems remotely and very cheaply.

Dark leaf spot is only one of several leaf spot pathogens which affect Brussels sprouts crops. The cost savings in this report refer only to the costs involved in controlling dark leaf spot. However, forecasters that will enable more rational use of fungicides for the control of ringspot, white blister and light leaf spot are under development. This report details further developments in a forecasting system for light leaf spot. These forecasters can ultimately be added to the existing dark leaf spot system to enable growers to control effectively all the major leaf spot pathogens of Brussels sprouts while reducing fungicide usage. Under these circumstances it can be expected that the cost savings will increase as more diseases and thus more fungicide inputs to the crop are covered.

INTRODUCTION

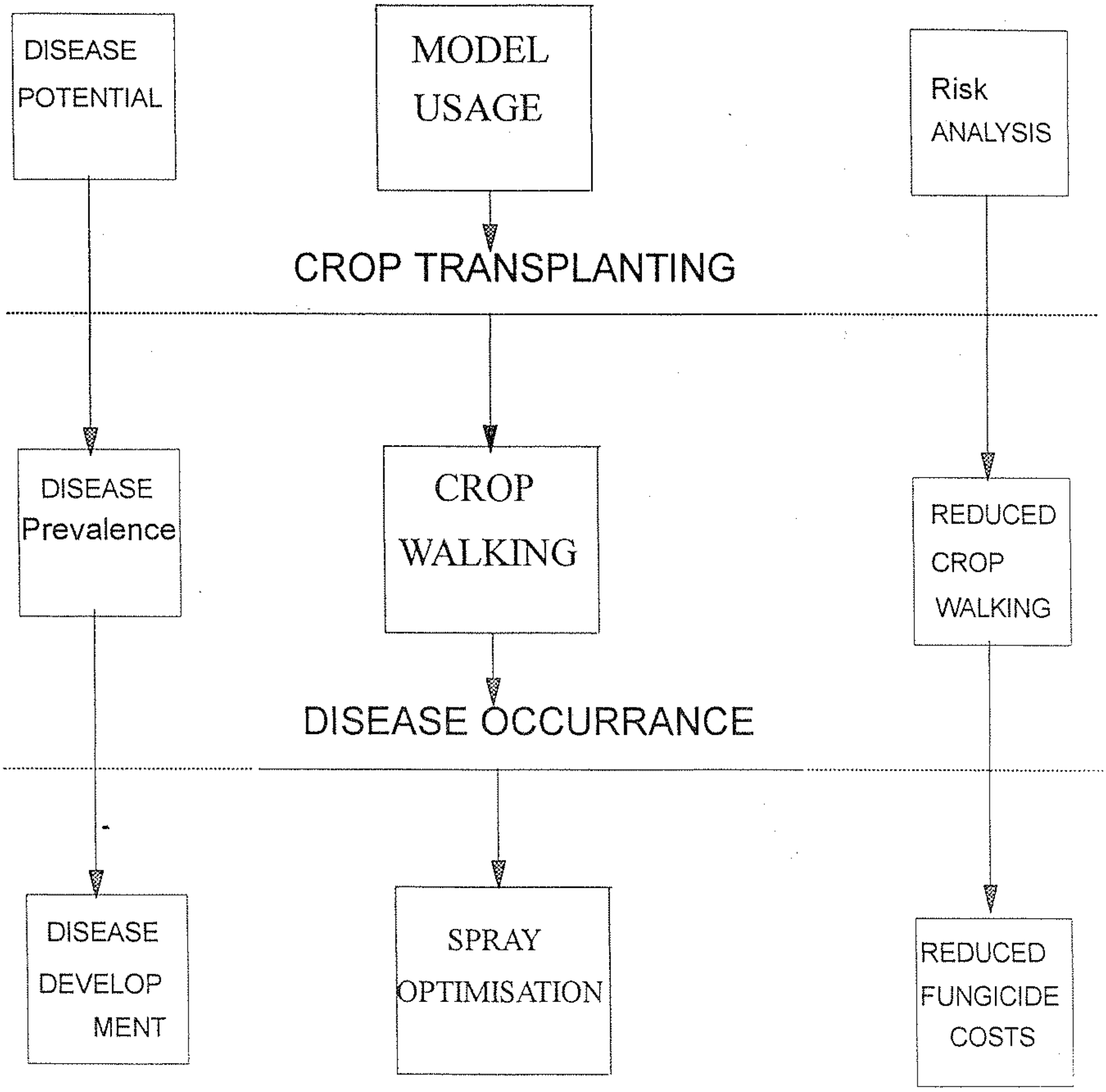
Two of the most important fungal pathogens affecting crops of vegetable crucifers are dark leaf spot (*Alternaria brassicae* and *Alternaria brassicicola*) and light leaf spot (*Pyrenopeziza brassicae*). These pathogens are particular damaging when they occur on Brussels sprouts. If either disease becomes established on the Brussels sprout buttons the blemishes caused can lead to downgrading in crop quality and in severe cases complete crop loss (Gladders, 1984).

Development of forecasting techniques

As with many airborne fungal pathogens the life cycle of both dark leaf spot pathogens is heavily dependent on certain environmental conditions, notably leaf wetness. Both pathogens require the presence of water on the leaf surface for infection to occur. The relationships between important meteorological parameters such as wetness, temperature and humidity and stages in the fungal life cycle can be determined from experiments conducted under controlled environment conditions. The relationships derived from these experiments can be used to form the basis of a forecasting system for timing the applications of fungicides for control of each pathogen. In the U.K., Brussels sprouts crops are transplanted, at which stage they are usually disease free. Disease forecasters can also be used to determine the likelihood of disease occurring on the crop after transplanting. In this way they may also help target periods when crops require inspection for the presence of disease. This application may help reduce the amount of time required to check crops for potential disease outbreaks. Stages in the potential usage of disease forecasters in Brussels sprouts crops are shown in Figure 1.

Prediction of limiting stages in the life cycle of any leaf spot pathogen can be used to determine the disease potential in any area before and after crop transplanting. The environmental conditions which occur during crop growth will determine which life-cycle stages are limiting. The location of the crop in relation to possible risk factors such as the presence of other susceptible overwintering crops (e.g. oilseed rape) will also affect disease occurrence. If disease occurs the forecaster can be used to improve the optimal timing of fungicide applications. Work at HRI with dark leaf spot has focused on the use of disease forecasting systems to improve the timing of the application of fungicides to control dark leaf spot in Brussels sprouts crops.

Fig. 1 Cost savings and potential usages of disease forecasting systems at different stages in the cropping cycle of Brussels sprouts



Dark leaf spot spray timing studies

The relationships between important meteorological parameters and infection and those affecting sporulation have been accurately determined and validated for dark leaf spot. These relationships have been incorporated into a forecasting system which was used to predict the unchecked progress of disease in crops inoculated with *Alternaria brassicae* (Kennedy and Graham, 1994). Although a difference in optimal temperature for infection has been observed for the two *Alternaria* species causing dark leaf spot (Humpherson-Jones & Hocart, 1983) this is not expected to affect the epidemiology of this disease. As *Alternaria brassicae* is the more prevalent of the two fungal species causing dark leaf spot in horticultural ware crops, field experiments have concentrated on this pathogen.

Dark leaf spot disease forecasts have been constructed which can predict any increase in disease within the Brussels sprouts crop. Predictions of infection and sporulation by dark leaf spot in infected Brussels sprouts crops can be used to determine the development of disease thresholds. Determining the duration and level of disease in relation to button susceptibility and leaf to leaf spread can be used to determine the necessity and timing of control measures (Kennedy *et al.* 1995). The final disease incidence or severity on Brussels sprouts buttons will also be determined by the duration over which the crop is at risk. This potentially varies considerably between cultivars, however only late season cultivars have been used to determine effective disease thresholds.

During 1994 field experiments were established to determine effective predicted disease thresholds (at which fungicides are applied) derived from forecasts of infection and sporulation within commercial crops in Lincolnshire. Using these thresholds the timing of fungicide applications for disease control could be determined solely from measured weather conditions, once the initial presence of the disease within the crop had been established. The spray timing system was compared, at three trial sites in the brassica growing area of Lincolnshire (Algakirk, Donington and Freiston), with a routine spray regime and the control strategy used by the grower - based on the growers disease observations within the crop. A trial was also established at HRI Wellesbourne, in plots inoculated with dark leaf spot, to compare disease control when fungicides were applied at different predicted disease thresholds with a routine treatment and unsprayed control plots.

Field trials during 1995 investigated the use of the forecasting system in the main areas of Brussels sprouts production within the U.K. The optimal system derived from the 1994 experiments was used in identical trials in Lincolnshire, Lancashire and Bedfordshire. Trials at HRI carried out in 1994 were repeated during 1995. The main objective of these trials was to assess the potential of the dark leaf dark leaf spot disease forecasting system to improve control of the disease with reduced fungicide usage.

The autumn of 1994 was notable for being extremely mild throughout England. The mean air temperature at Wellesbourne was 3°C above the average for the preceding three years during October and November, and a similar 2°C elevation was observed in Lincolnshire (Fig. 2). High temperatures and regular rainfall gave optimal conditions for dispersal of fungal spores and was conducive for development of dark leaf spot.

In 1995 at HRI Wellesbourne the air temperature was approximately 4° C above average during October, but returned to average values during November (Fig. 3). The rainfall during the Autumn of 1995 was below average. The mean air temperature patterns for the autumn of 1995 at HRI Kirton (Lincolnshire) were similar to Wellesbourne, with an approximate 3°C increase in average temperatures during October. Rainfall in October 1995 was considerably drier than average. However temperatures and rainfall at Hesketh Bank in Lancashire and Beeston Green in Bedfordshire were higher than at HRI Wellesbourne and HRI Kirton, Lincolnshire (Fig. 4).

The warm, wet conditions of 1994 would have been conducive to dark leaf spot disease at all sites. In contrast, the extremely warm but dry weather conditions of October 1995 did not promote the spread of disease. Field trials in both 1994 and 1995, therefore, tested the dark leaf spot forecaster under two extreme weather scenarios.

Light leaf spot studies

Little information is available on the epidemiology of the light leaf spot pathogen *Pyrenopeziza brassicae* on vegetable brassicas. Experiments were conducted to determine the duration of periods of leaf wetness required for infection of host tissue at different temperatures under controlled environmental conditions. Light leaf spot has a relatively long latent/incubation period. Determination of the environmental parameters which affect latent/incubation duration in combination with infection criteria could be utilised in any future disease forecasting system for light leaf spot.

Experiments during 1995 tested existing relationships (for oilseed rape), describing the effect of temperature on latent/incubation period of light leaf spot on oilseed rape, and compared this with Brussels sprouts seedlings inoculated with light leaf spot.

Fig. 2 Meteorological data summary 1994 - a) HRI Wellesbourne, Warwickshire
- b) HRI Kirton, Lincolnshire

a)

b)

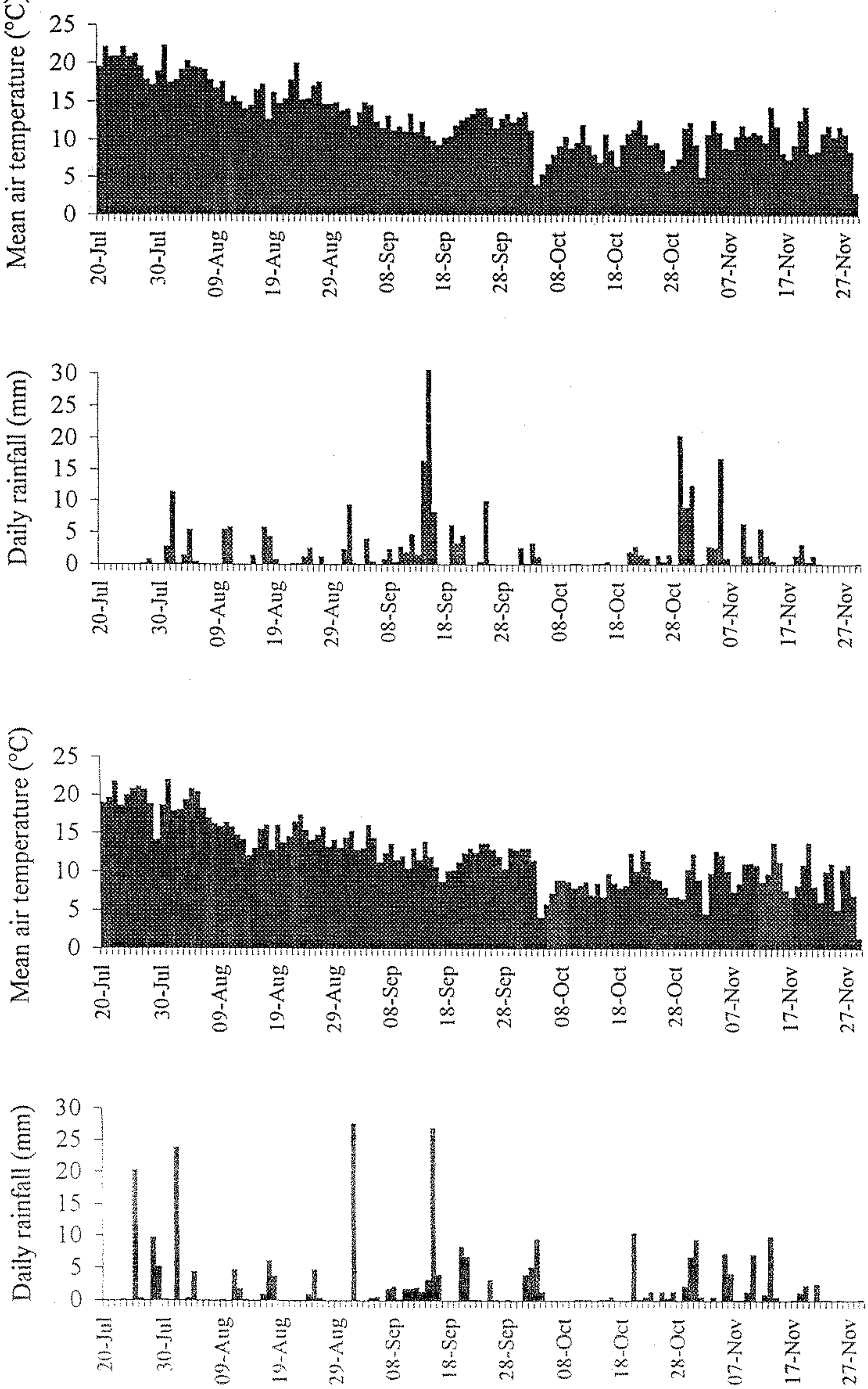
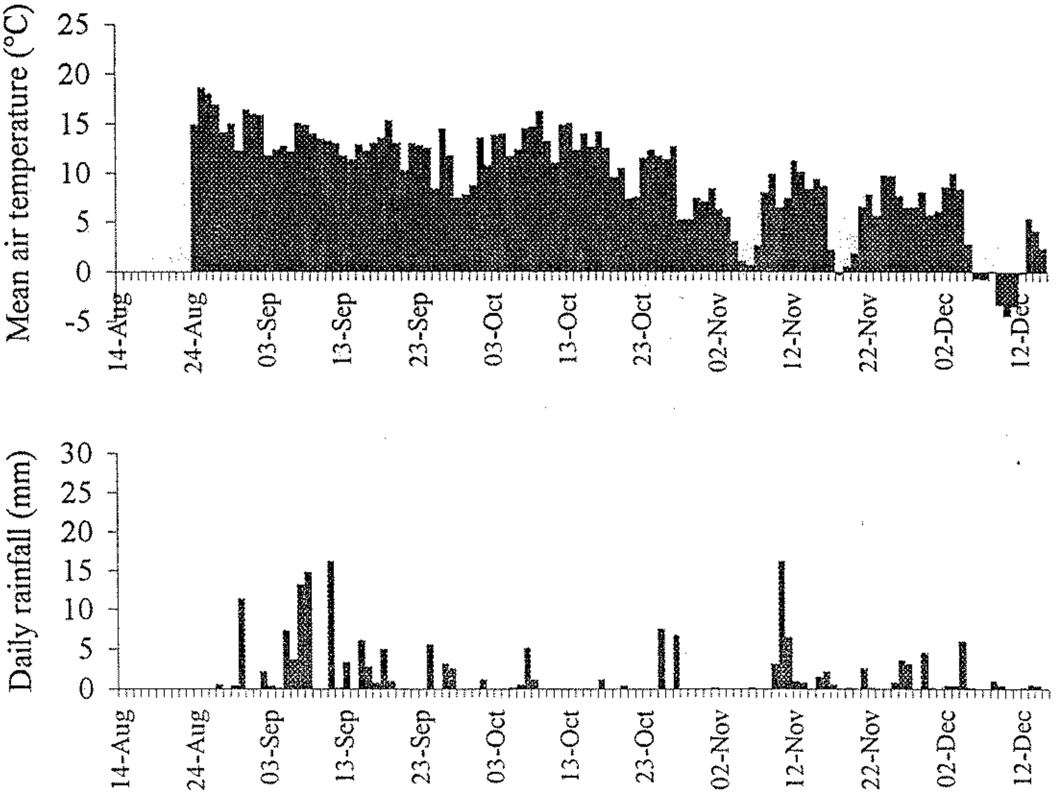


Fig. 3 Meteorological data summary 1995 - a) HRI Wellesbourne, Warwickshire
- b) HRI Kirton, Lincolnshire

a)



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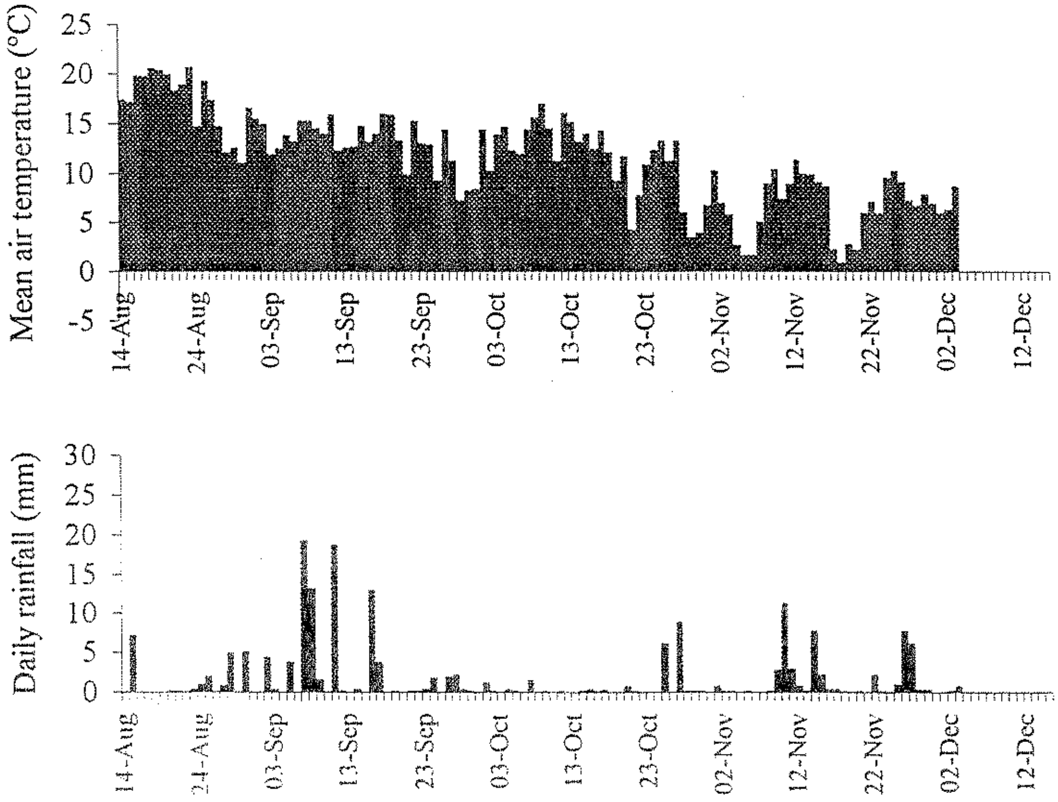
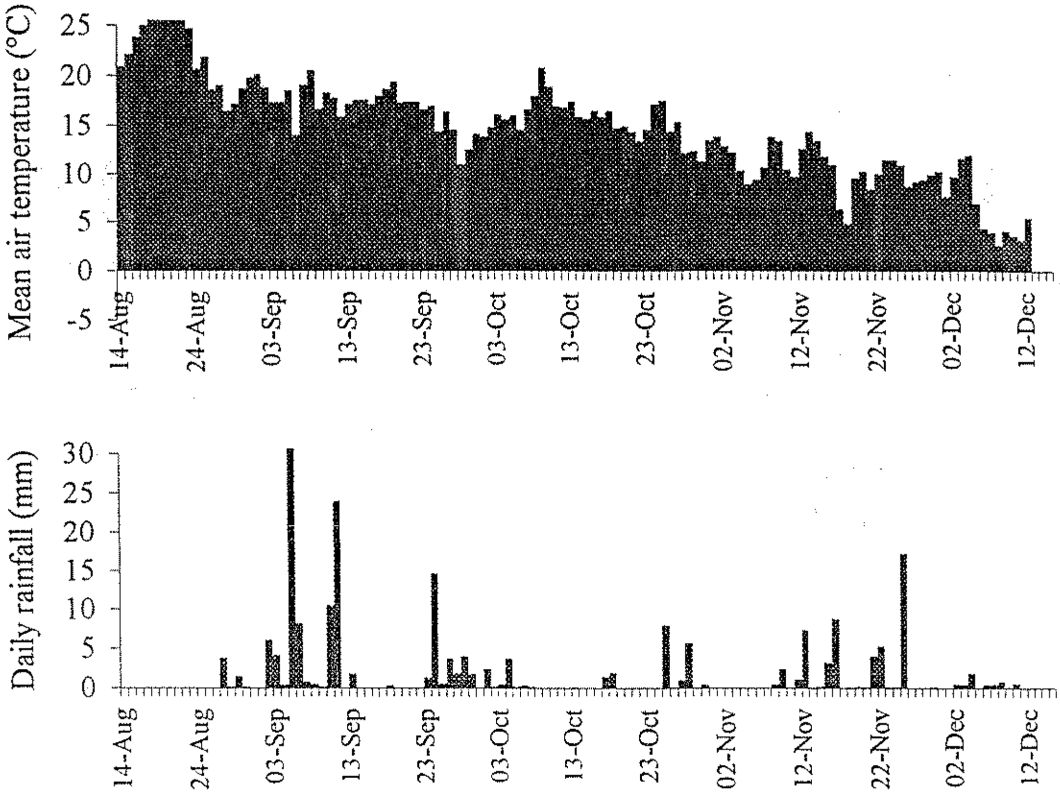


Fig. 4 Meteorological data summary 1995 - a) Hesketh Bank, Lancashire
- b) Beeston Green, Bedfordshire

a)



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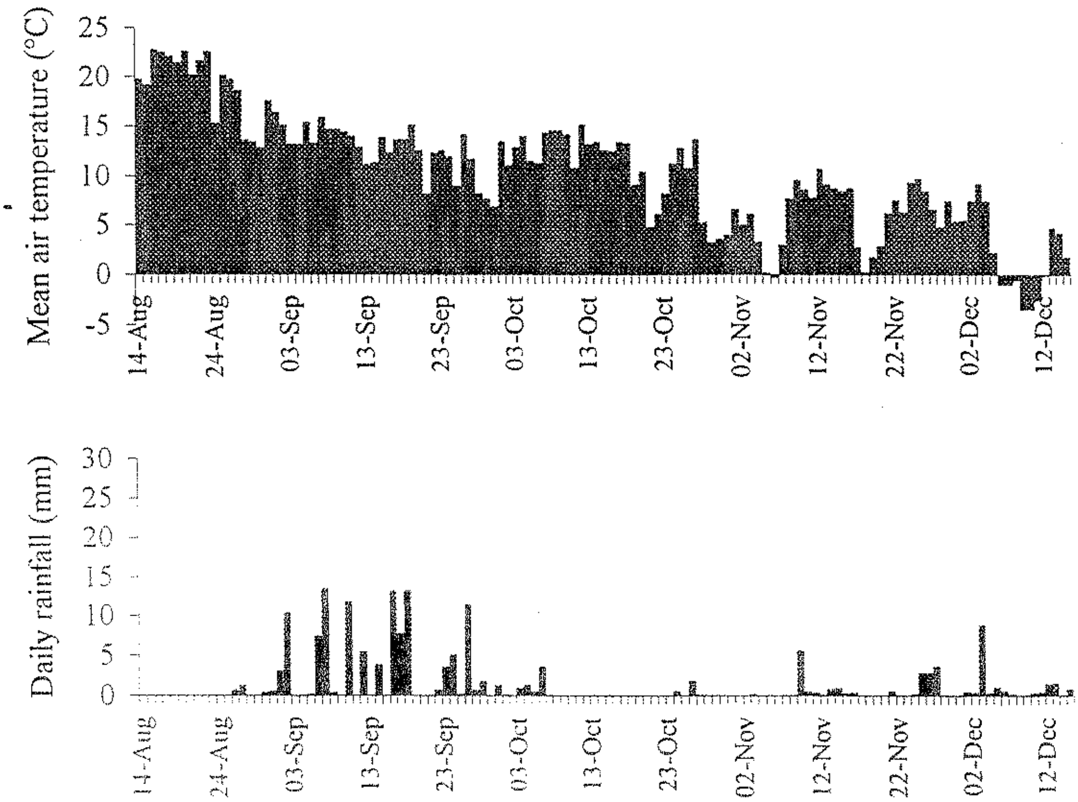


3. MATERIALS & METHODS

3.1 Dark leaf spot forecaster formulation and validation

3.1.1 Dark leaf spot spray timing experiments, Wellesbourne 1994 & 1995

Experimental Design

The experiment comprised of fifteen plots of Brussels sprouts (cv. Sheriff) each 9m square grown at 50cm spacing. These were arranged as three replicate plot treatment^{-1} with each control treatment in a randomized block design with a 4m spacing between blocks. Untreated control plots were isolated from each other and from the other treatment blocks by a distance of at least 500m. The same experimental design was used in both 1994 and 1995.

Pot-grown Sheriff plants at the seventh to tenth true leaf stage were infected with *Alternaria brassicae* by applying 5 ml plant^{-1} of a spore suspension (5×10^4 ml^{-1}) prior to misting the plants at 15-17°C for 72 hours to maintain leaf wetness. Infected plants were transplanted in the centre of each plot on 27th July in 1994 and the 14th August in 1995 to act as sources of infection. Inoculation was delayed in 1995 due to unfavourable weather conditions. Pests were controlled using insecticides applied after visual inspection of the plots. Buttons were harvested at the end of November 1994 and at the beginning of December in 1995.

Spray timing treatments

No fungicide sprays were applied to the untreated control plots in either year. A routine spray regime consisting of pre-determined applications of iprodione (as Rovral Flo at 2 l ha^{-1} in 200 to 600 l) was applied on the 31st August, 23rd September and 25th October in 1994. Routine sprays were applied on 29th September and 31st October in 1995. The initial August spray was not used in 1995 due to the prevailing hot and dry conditions.

A data logger and electronic sensors to record hourly values of temperature, humidity, wetness and rainfall, were sited within one of the treatment plots of cultivar Sheriff and weather conditions monitored within the crop. Predictions of sporulation and infection using hourly weather measurements commenced from the date of crop inoculation on the 27th July 1994 and 14th August 1995 respectively. Three spray timing regimes were tested based on varying predicted disease thresholds as predicted by the dark leaf spot forecaster. Thresholds at 10 and 25 points on the cumulative disease index scale were used in one treatment to determine (two) spray applications. A second regime delayed the application of the first spray until a threshold of 15 and in a third the second spray application was delayed until a threshold of 30. Iprodione was applied with a tractor-mounted Hardi LY800 Sprayer, with 'Ceramic 24' nozzles, operating at a pressure of 250 KPa.

Disease Records

Each 9m square plot was divided into nine 3m square segments containing 36 plants. At assessments on the 20th October, 8th November and 21st November 1994, three plants were randomly selected in each segment. Numbers of lesions were counted on randomly selected leaves in the lower, middle and upper canopy areas of the plant. Leaf disease assessments were taken on 21st September and 20th October 1995. Dark leaf spot incidence and severity on buttons at harvest was assessed on 22nd November 1994 and 7th December 1995. A systematic button sample was taken from each of the eighteen rows in each plot to assess the level of dark leaf spot infection on buttons. One button was randomly selected from each stem level of every fifth plant in a row (ie. three buttons per stem level per row) in 1994. In 1995 buttons from every fourth plant (ie. four buttons per stem level per row) were taken. Button diameter and numbers of dark leaf spot lesions per button in a sub-sample of twenty-seven buttons from each canopy level from each replicate plot in each treatment was assessed in both years.

3.1.2 Validation of dark leaf spot spray timing system in commercial crops

3.1.2.1 Spray timing treatments used in 1994 and 1995

Three different fungicide control regimes were compared on grower's holdings in 1994 and 1995. A routine spray programme, based on pre-determined calendar dates, was used to determine best possible control of dark leaf spot. This was compared with a spray programme determined by usage of the dark leaf spot forecasting system in which meteorological data measured within a Brussels sprout crop was used to derive spray application times. The grower's own fungicide programme, as determined by visual observations within the crop and his own experience was used as the industry comparison. Crops of late season Brussels sprouts (cv. Stephen) were used in all trials.

3.1.2.2 1994 Lincolnshire

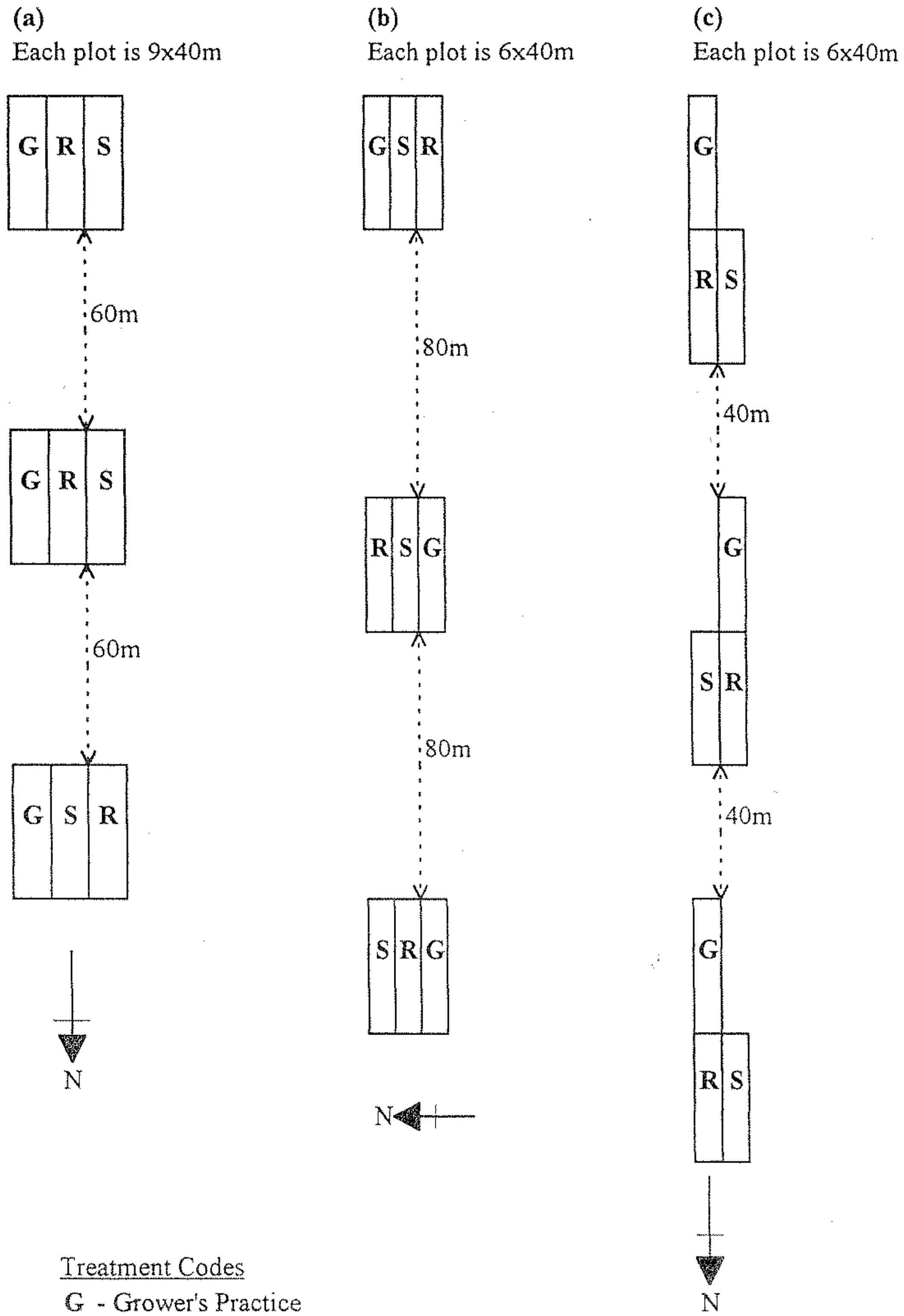
Experimental Design

Trial sites were chosen in co-operation with Univeg (Manor Rd., Kirton, Lincs.). Sites at Algakirk (near HRI Kirton), Donington on the western perimeter of the vegetable growing area, and Freiston (north of Boston) were used. Natural infection occurred at all three sites within each block. Experimental plots were positioned within fields of cultivar Stephen planted at 60cm spacing with each site consisting of three replicate blocks. One plot of each treatment was randomly arranged within each block (Figs. 5 a-c). Pests were controlled with insecticides (Appendix 1) at identical rates to other areas outside the trial blocks. Crops were harvested at the end of November 1994.

Treatments

Data loggers and electronic weather sensors were sited within the crop at Donington and Freiston to record hourly values for temperature, humidity, surface wetness and rainfall. Spray timing forecasts for Algakirk were based on weather data collected (as above) at HRI Kirton. The diseases observed at the sites are shown in Table 3. The grower's practice differed between trial sites, however, the routine treatment was applied identically on all three sites (see Table 12, 14, 16) with the exception of Freiston where chlorothalonil was applied before the start of the trial. Iprodione was applied for control of dark leaf spot in the routine and forecast plots at all sites. Triadimenol (as Bayfidan) and mancozeb + metalaxyl (as Fubol) were applied to control ringspot (*Mycosphaerella brassicicola*) and white blister (*Albugo candida*) respectively. After three applications of iprodione (the maximum legally permissable) the projected harvest date of plots in the routine treatment was within the legal interval allowed for crop sale. Therefore, a tank mix of fenpropimorph (as Corbel) and triadimenol were applied (15 November) against dark leaf spot in all routine and forecast treatment plots. Spray applications were made with a Sands hydrostatic 2500 with Albuz grey nozzles operating at a pressure of 300

Fig. 5 **Experimental layouts at field sites in Lincolnshire 1994**
(a) Algakirk, (b) Donington and (c) Freiston



Treatment Codes
G - Grower's Practice
R - Routine Spray Treatment
S - Spray Timing System

Table 5 **Incidence of foliar diseases observed at sites in 1994**

	Algakirk		Donington		Freiston	
	leaf	button	leaf	button	leaf	button
Dark Leaf Spot	**	**	***	**	**	**
Ringspot	-	-	*	-	**	-
White Blister	*	-	**	-	*	-

- Negligible   * Low   ** Medium   *** High

KPa. The fungicides were applied in 440 l ha^{-1} and the concentrations used are given in Table 3.

Disease Records

Dark leaf spot and other diseases were recorded on the leaves of three replicate plants in each of two lateral transects of each treatment plot, ten metres from either end of the plot. Leaf disease assessments were taken on 29th September, 17th October and 11th November 1994 at Algakirk. At Donington and Freiston leaf disease assessments were taken on 4th October, 17th October and 2nd November 1994. Leaves were tagged at three canopy levels (lower, middle and upper) and the same leaves at each time interval assessed over the duration of the experiment. The levels of dark leaf spot on buttons were assessed at 1-2 week intervals close to button maturity.

At harvest on the 28/29th November at all sites a systematic button sample was taken from the four middle longitudinal rows of each treatment plot. One button was randomly removed from each canopy level of every third plant in each of four longitudinal rows selected for each plot. A sub-sample of fifty buttons was removed from the main sample for each treatment plot and assessed for dark leaf spot lesion number and button diameter.

3.1.2.3 1995 Bedfordshire, Lancashire, Lincolnshire

Experimental Design

A trial site at Beeston Green, Bedfordshire was chosen in co-operation with F. J. Cope & Son (Manor Farm, Beeston Green, Sandy). An experimental site in Lancashire at Ince Blundell with the assistance of C. Molyneaux & Son (Asmall House Farm, Scarisbrick) was also used. The trial site used in Lincolnshire was in co-operation with Univeg (10 Manor Rd., Kirton, Lincs.), on land at Algakirk near HRI-Kirton.

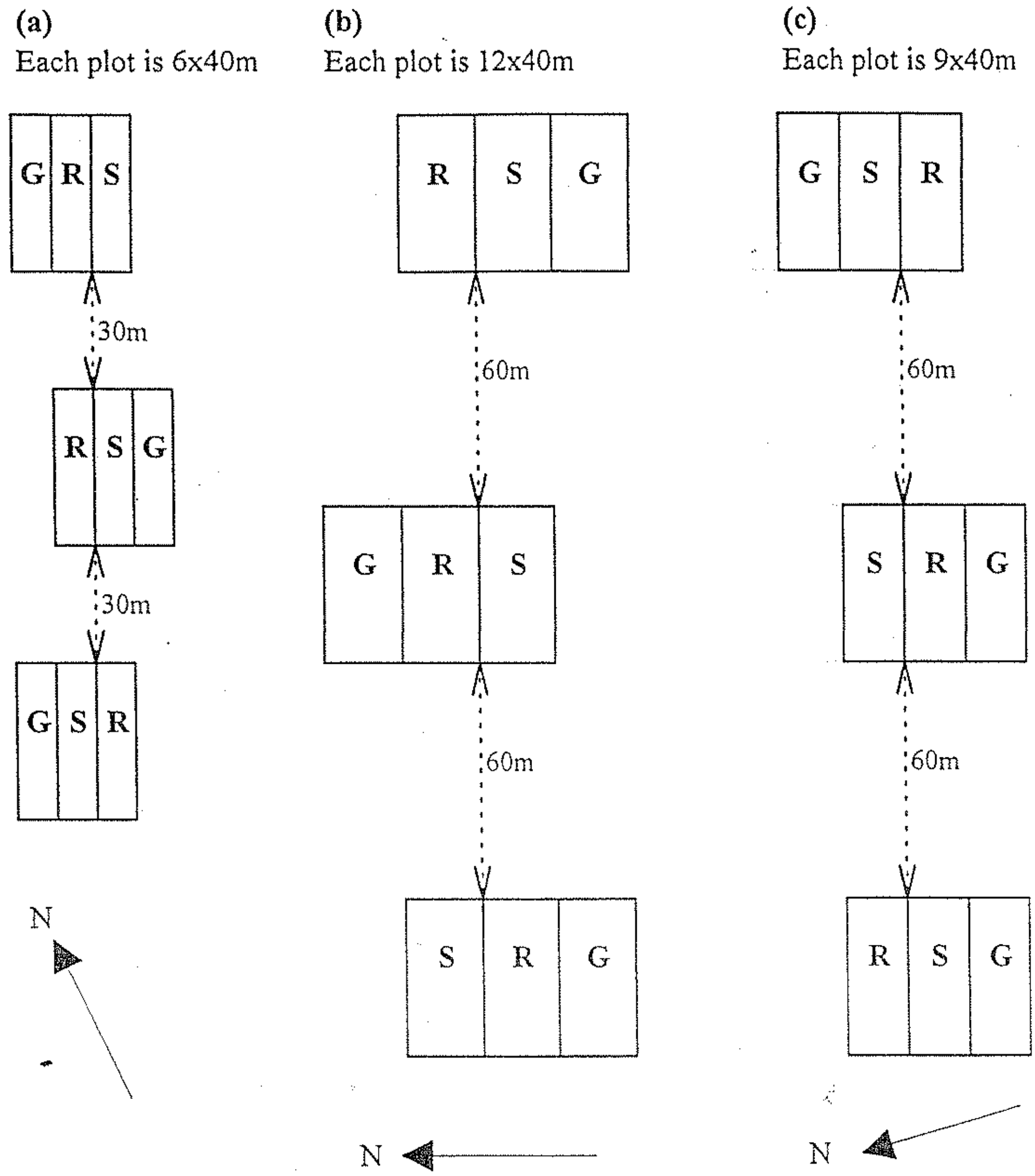
The trials in Bedfordshire and Lincolnshire (cv.Stephen) and in Lancashire (cv.Odette) were in fields of Brussels sprout planted at spacings of 55 - 65 cm. Each site consisted of three replicate blocks where one plot of each treatment was randomly arranged within each block (Fig. 6). Natural infection by dark leaf spot occurred within all blocks. Brussel sprouts were harvested on 12th December 1995 in Lancashire, 15th December in Lincolnshire and the 1st February 1996 in Bedfordshire. Pests were controlled with insecticides (Appendix 2) at identical rates to other areas outside the trial blocks.

Treatments

Data loggers and electronic weather sensors were sited within the crops at Bedfordshire and Lancashire to record hourly values for temperature, humidity, surface wetness and rainfall. Spray timing forecasts for Lincolnshire were based on weather data collected nearby at HRI Kirton. The diseases observed differed between sites (Table 4). Sprays applied according to the grower's experience differed between the trial sites and the routine treatment differed slightly in application dates and type of fungicide used between sites (Tables 16, 19 & 21). Iprodione was applied for control of dark leaf spot three times in the routine treatment at all sites. Triadimenol was applied to control ringspot (*Mycosphaerella brassicicola*) in Lancashire in both the routine and forecast treatments. However, fenpropimorph was used against ringspot in Lincolnshire on 29th October. Chlorothalonil + metalaxyl (Folio) or mancozeb + metalaxyl (Fubol) were used to control white blister (*Albugo candida*) in all treatments at all sites.

Spray applications were made in Bedfordshire with a tractor mounted Hardi LY sprayer with 08 or 10 F110 nozzles at 0.5m spacing operating at a pressure of 3 or 3.5 bars. In Lancashire a Bateman self-propelled sprayer was used, and in Lincolnshire sprays were applied with a Sands hydrostatic 2500 with Albuz grey nozzles operating at a pressure of 300 KPa. The fungicides were applied in 440 l ha^{-1} and the concentrations used are given in Table 1.

Fig. 6 **Experimental layouts at field sites in 1995**
(a) Bedfordshire, (b) Lancashire and (c) Lincolnshire



Treatment Codes

G - Grower's Practice
R - Routine Spray Treatment
S - Spray Timing System

Table 6 **Incidence of foliar diseases observed at sites in 1995**

	Bedfordshire		Lancashire		Lincolnshire	
	leaf	button	leaf	button	leaf	button
Dark Leaf Spot	**	*	*	*	*	*
Ringspot	-	-	**	*	*	-
White Blister	*	-	-	-	*	-
Powdery Mildew	*	-	*	-	*	-
Virus	***	***	-	-	**	*

- Negligible   * Low   ** Medium   *** High

Disease Records

Dark leaf spot on Brussels sprouts leaves and buttons was assessed on a systematic sample of thirty plants within each plot. Leaf disease on all leaves of every third plant along longitudinal transects in each treatment plot were recorded. Leaf disease assessments were taken on 11th October and the 1st November 1995 in Bedfordshire. In Lancashire leaf disease assessments were taken on 10th October and 2nd November, however, in Lincolnshire leaf disease assessments were taken on 5th and 3rd of October and November 1995 respectively. Harvest assessments on buttons were as described for 1994 (see section 3.1.2.2).

3.1.3 Statistical treatment of results

Differences between treatments were tested using analysis of variance in Genstat (Payne *et al*, 1987). Log-transformed data for button disease severity and angular transformed data for button disease incidence were used in T tests to denote significant differences between treatments..

3.2 Effect of environmental factors on light leaf spot infection and latent/incubation period

3.2.1 Investigation of the effect of temperature and wetness on infection

Experiments to validate existing relationships describing the effect of temperature and wetness on infection using natural and artificial inoculum were carried out under controlled environment regimes. Inoculum from infected leaf tissue was compared with conidia from cultures grown on 2% malt agar. The effect of temperature and wetness on infection was tested on both Brussels sprouts (cv. Sheriff) and oilseed rape (cv. Cobra) at 16° C (optimal temperature) and 8° C (sub-optimal).

Twenty sets of ten seedlings in each treatment were inoculated with 100 ml spore suspensions at a concentration of $10^5 ml^{-1}$. Leaf wetness was maintained in Sanyo-Gallenkamp Plant Growth Cabinets SGC970/C/RO-HFL. Two replicate sets of ten seedlings for each treatment were removed from the cabinets 0, 12, 24, 30, 42, 54, 66, 78, 90, 114 and 168 hours after inoculation. The leaves were dried rapidly by a flow of cool air. Plants were transferred to a glasshouse with a day/night regime of 18° C/18° C.

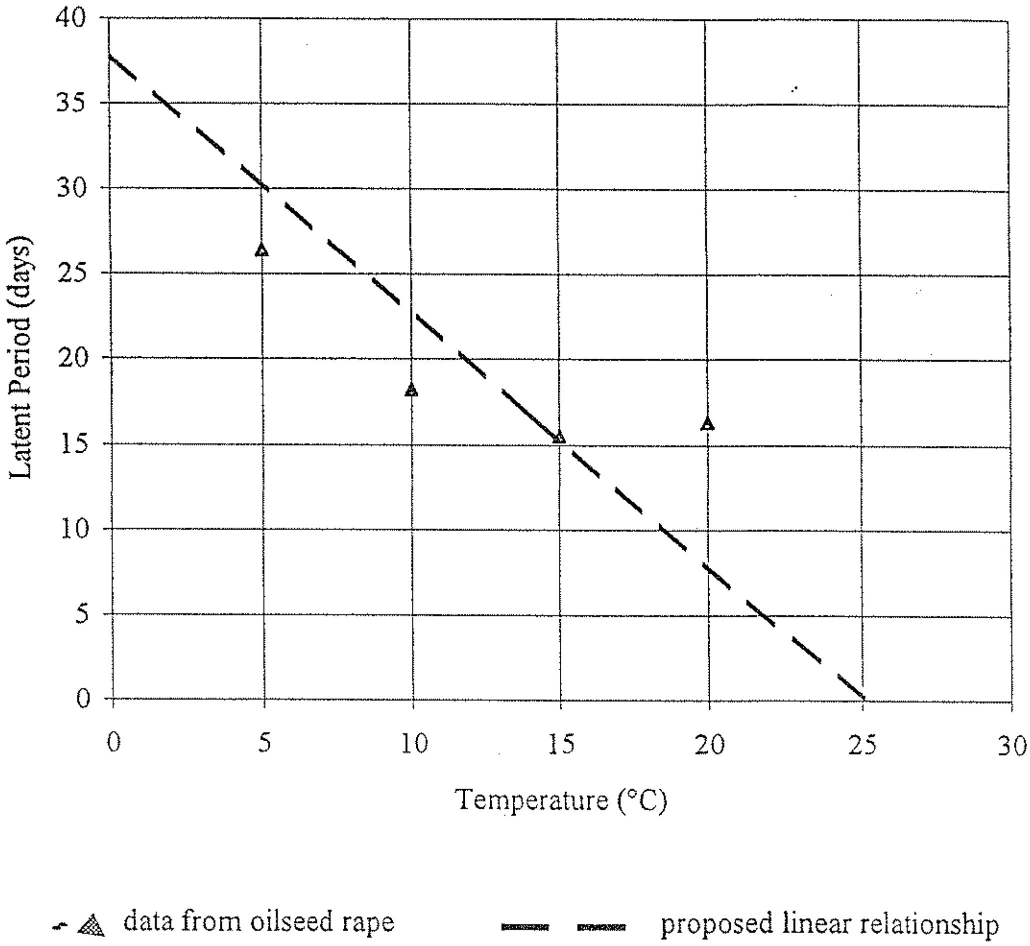
Leaves were assessed for numbers of lesions four, five and six weeks after inoculation. In the first experiment minimal infection was observed. The results are not given in this report due to the low infection levels.

3.2.2 Investigations on the latent/incubation period

Information on the effect of temperature on latent incubation period of light leaf spot was obtained from oilseed rape (Figueroa, 1993). This relationship was used to investigate the latent/incubation period of light leaf spot on vegetable brassicas.

A straight line inverse relationship with temperature (Fig. 7) has been described covering a temperature range of 5 - 20 °C. The relationship appeared to approximate the effect of temperature on latent/incubation period on oilseed rape from the field. However, the relationship was not validated over temperatures which were outside the range from which it was derived.

Fig. 7 **Proposed model describing the effect of temperature on latent/incubation period for light leaf spot caused by (*Pyrenopeziza brassicae*) after Figueroa (1993)**



A sequential series of experiments was carried out to test the relationship on inoculated seedlings of oilseed rape and vegetable brassicas. Oilseed rape (cv. Cobra) and Brussels sprout (cv. Sheriff) were grown in FP11 pots in a clean glasshouse. At approximately the tenth true leaf stage, fifteen plants of each were inoculated with one of three isolates of *Pyrenopeziza brassicae*. Inoculated plants were misted for three days at 15°C to promote infection. After misting inoculated plants were exposed to external conditions in an open frame, or to approximately 15°C constant temperature in the glasshouse. The temperature in both environments was monitored hourly. Sets of plants were infected and exposed routinely from November 1995 to March 1996. The time and extent of symptom expression was recorded at weekly intervals thereafter. Three isolates of light leaf spot, isolated from vegetable crucifers, (PB 8, 9 and 10) were used in the investigation.

4. RESULTS

4.1 Model Formulation and Validation

4.1.1 Dark leaf spot experiments, Wellesbourne 1994

Predicted dark leaf spot disease development

The disease index reached 30 during the spray timing experiment at Wellesbourne in 1994 (Fig. 8), and all spray timing treatments received two applications of iprodione (rate as in Table 1). Sprays were applied on 23 September (threshold ≥10), 28 September (threshold ≥15), 2 November (threshold ≥25) and 16 November (threshold ≥30).

Observed dark leaf spot on buttons

The level of dark leaf spot at three stem levels was measured on the sample of buttons taken at harvest on 22nd November (Table 7a). Significantly higher numbers of lesions were observed on buttons from the unsprayed control than from the routine spray treatment ($p<0.001$), and the spray timing system with the initial spray applied at threshold 10 ($p<0.05$) (Table 7a). Due to variability between plots, there was no significant difference in the severity of dark leaf spot between buttons from the spray timing treatment which had sprays applied at predicted thresholds 15 and 25 (delayed first threshold) and untreated plots. Disease severity (lesions/button) was not significantly higher in treatments given a control spray at predicted disease thresholds of 10 and 25 in comparison to the routine treatment. However when either of the thresholds was delayed (treatment thresholds 15 & 25 or 10 & 30) the severity of disease at harvest was significantly higher than in the routine treatment ($p<0.05$). The unsprayed treatment had significantly greater incidence of dark leaf spot (number of infected buttons) than all other treatments ($p<0.001$) (Table 5b). All forecast treatments had significantly greater incidence of dark leaf spot on buttons ($p<0.05$) than the routine treatment.

Delaying treatment with fungicides at each threshold resulted in higher levels of dark leaf spot on buttons. Routine application of fungicides resulted in the lowest incidence and severity of dark leaf spot on buttons at harvest. Use of a forecasting system to time control sprays resulted in one fewer application of iprodione but there was a significantly greater incidence of disease when compared to the routine treatment.

Fig. 8 **Predicted disease progress, Wellesbourne 1994, and the disease thresholds used to time sprays.**

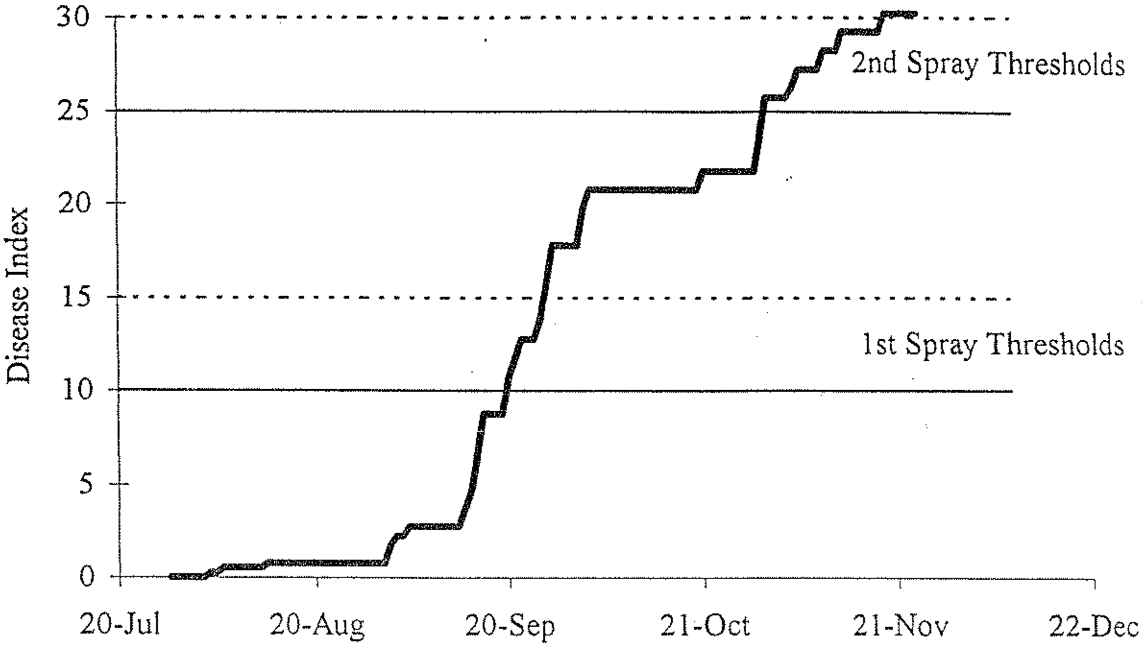


Table 7 **Disease at harvest, Wellesbourne 22.11.94 - (a) Severity, (b) Incidence**

(a) Mean number of lesions on 27 buttons, back-transformed from $\log_{10}$ values for three replicates.

	Routine Spray	Treatment Spray Timing System Spray Thresholds 10 & 25	10 & 30	15 & 25	Unsprayed Control
Lower Stem	20	39	48	65	133
Middle Stem	10	20	25	44	91
Upper Stem	9	10	19	16	40

(b) Mean percentage of buttons infected, three replicates. Data angular transformed for T-test and analysis of variance.

	Routine Spray	Treatment Spray Timing System Spray Thresholds 10 & 25	10 & 30	15 & 25	Unsprayed Control
Lower Stem	44	56	63	72	90
Middle Stem	28	47	43	56	88
Upper Stem	25	33	37	42	72

4.1.2 Dark leaf spot spray timing experiments, Wellesbourne 1995

Predicted dark leaf spot disease development

Predicted disease levels increased slowly within the crop in 1995 (Fig. 9). The first threshold (index ≥10) spray was applied on 22nd September. Threshold 15 was reached in mid November. Unfavourable weather made the ground unsuitable for spray operations and this treatment was not applied. As a consequence treatments with spray applications at 15 were modified to become single spray treatments only applied at a disease index of 25. However, due to the onset of unfavourable conditions for dark leaf spot, threshold 25 was not reached before harvest.

Observed dark leaf spot on buttons

The presence of some unsprayed plots within the main experimental block (plots which did not reach treatment thresholds during the experiment) may have biased the results. The severity and incidence of dark leaf spot on the buttons at harvest is shown in Table 8.

The more heavily infected infector plants used in 1995 may have contributed to higher dark leaf spot incidence and severity on buttons at harvest in 1995 compared with 1994 (Table 7). Higher ($p<0.01$) disease severity (Table 8a) and incidence (Table 8b) was observed on buttons from the unsprayed control plots than from either the routine spray or threshold 10 spray plots. Unsprayed control plots had the highest severity of dark leaf spot at all stem levels ($p<0.001$). However dark leaf spot incidence and severity on buttons was similar, when expressed as a mean of all stem levels regardless of treatment.

There were no significant differences found in dark leaf spot levels between buttons from the routine and threshold 10 forecast treatments as expressed on a plant basis. However, buttons from the threshold 10 treatment on the lower stem had significantly higher disease severity ($p<0.05$) than those from the routine treatment. These results could be attributed to the more recent application of iprodione to the routine treatment (31st October) compared with the threshold 10 treatment (22nd September). The persistence of this later application at a time of increased button susceptibility may have contributed to better protection of the lower stem buttons on the routine treatment in comparison to those plants in the threshold 10 plots. There were no significant differences in the incidence of dark leaf spot on buttons regardless of stem position between the forecast treatment and routine treatment (Table 8b).

Fig. 9 **Predicted disease progress, Wellesbourne 1995, and the disease thresholds used to time sprays.**

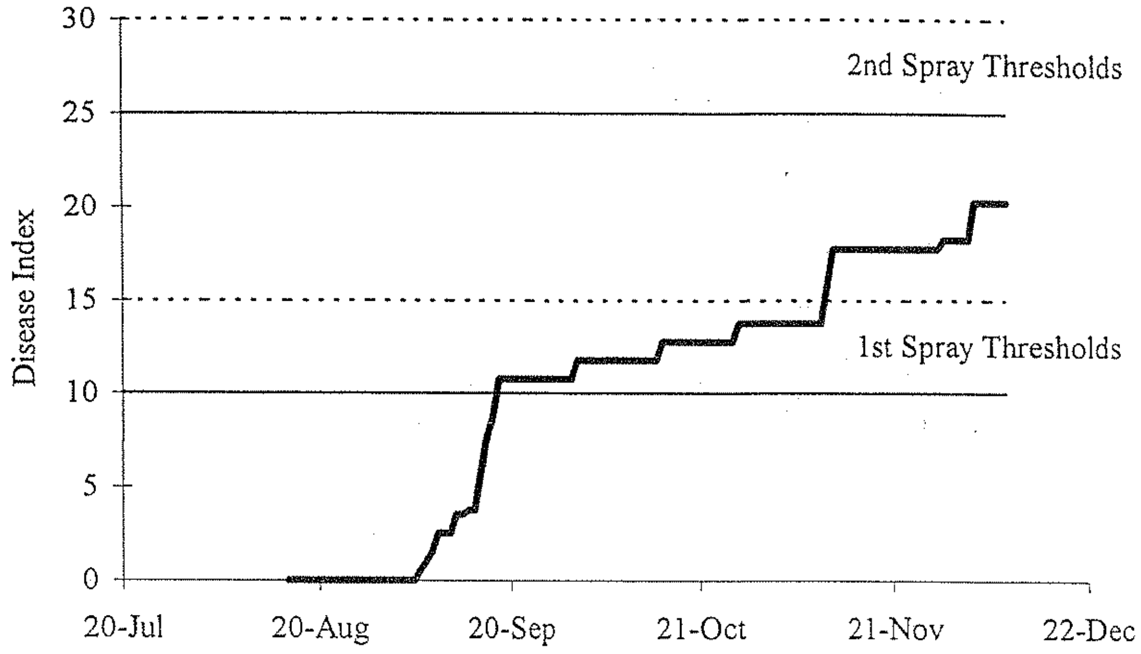


Table 8 **Disease at harvest, Wellesbourne 7.12.95 - (a) Severity, (b) Incidence**

(a) Mean number of lesions on 27 buttons, back-transformed from log_{10} values for three replicates.

	Routine Spray	Treatment Spray Timing System Spray Threshold 10	Unsprayed Control
Lower Stem	97	182	317
Middle Stem	38	57	138
Upper Stem	19	18	53

(b) Mean percentage of buttons infected, three replicates. Data angular transformed for T-test and analysis of variance.

	Routine Spray	Treatment Spray Timing System Spray Threshold 10	Unsprayed Control
Lower Stem	85	91	98
Middle Stem	62	69	91
Upper Stem	42	43	76

4.1.3 Investigation of light leaf spot latent /incubation period

Results from the series of experiments investigating the effect of temperature on latent/incubation period of light leaf spot are shown in Table 9 Predicted dates of symptom expression varied over the duration of the observations particularly during December 1995. However, the observed date of symptom expression was identical for all sets of plants (11th January) although plants had been inoculated at differing times. Observations on plants exposed to glasshouse temperatures after light leaf spot inoculation are shown in Table 10. Observed latent periods were of longer duration than predicted through use of the model although symptom expression on different sets of plants occurred at approximately the same time despite some differences in inoculation date. All isolates of *Pyrenopeziza brassicae* were similar in the duration of latent/incubation period regardless of environment used (glasshouse or frame).

The severity of disease on the plants in this experiment varied widely. Brussels sprouts plants were more severely affected than the oilseed rape plants, however, some plants had little infection. No conclusions can be drawn from these results except that symptom expression would appear to be related to several factors only one of which is temperature. Assessments of disease symptoms prior to 11th January when symptoms appeared on plants had not shown any disease present. Host phenology may be important in the determination of symptom expression. This may explain the observation that Brussels sprout buttons display light leaf spot lesions late in the growing season when no symptoms are seen on the leaves. Infected leaf material may have disappeared however infection on the buttons may remain latent and symptomless until button development.

Table 9 **Light leaf spot latent/incubation period experiments in open frames**

Host Type	Inoculation date	Symptom development	Lesions * plant^{-1}	Predicted date of symptom expression
Oilseed Rape	27 Oct	11 Jan	2	25 Nov
	31 Oct	-	0	29 Nov
	03 Nov	-	0	02 Dec
	07 Nov	"	18	04 Dec
	10 Nov	-	0	11 Dec
	14 Dec	"	13	18 Dec
	21 Nov	"	16	31 Dec
Brussel sprouts	27 Oct	"	12	25 Nov
	31 Oct	"	14	29 Nov
	03 Nov	"	16	02 Dec
	07 Nov	"	7	04 Dec
	10 Nov	"	3	11 Dec
	14 Nov	"	21	18 Dec
	21 Nov	"	5	31 Dec

* normalised for differences in inoculum

Table 10 **Light leaf spot latent/incubation period experiments under glasshouse conditions**

Host Type	Inoculation date	Symptom development	Lesions * plant^{-1}	Predicted date of symptom expression
Oilseed rape	12 Jan	-	0	29 Jan
	22 Jan	-	0	08 Feb
	26 Jan	20 Feb	19	12 Feb
Brussels sprout	12 Jan	20 Feb	40	29 Jan
	22 Jan	20 Feb	19	08 Feb
	26 Jan	20 Feb	51	12 Feb

* normalised for differences in inoculum

4.2 Validation of the dark leaf spot spray timing system in commercial crops

4.2.1 1994 Lincolnshire

4.2.1.1 Predicted dark leaf spot disease development

During the 1994 growing season spray timing predictions did not differ significantly between sites in Lincolnshire. Disease was first noted at low levels in the canopy at the end of July 1994 at all three sites. Tabulation of disease index commenced when symptoms first appeared in the crop and was based on subsequent predictions of dark leaf spot infection and sporulation (Fig. 10). The dark leaf spot forecast system predicted the need for two applications of fungicide against dark leaf spot due to favourable disease conditions which occurred at all trial sites in 1994. Sprays were applied in the forecast treatment on 23rd September and 12th November 1994 when the disease index was approximately 10 and 25 respectively.

4.2.1.2 Observed dark leaf spot disease development

Control of leaf spot pathogens on the buttons, other than dark leaf spot, was satisfactory at all three sites. Buttons from all treatments were marketable with only low levels of disease present (Univeg, *pers comm.*).

Algakirk

Dark leaf spot on the samples of buttons taken at harvest (Table 11) from the grower's practice plot had significantly higher disease severity than buttons from the spray timing ($p<0.05$) and routine ($p<0.01$) treatments. The routine treatment had a significantly lower button disease severity ($p<0.05$) than the spray timing treatment (Table 11a). There were significantly higher numbers of dark leaf spot lesions on those buttons removed from the bottom of the stem. Significantly higher percentages of buttons were infected with dark leaf spot in plots sprayed according to the grower's practice than on those sprayed according to forecast predictions ($p<0.01$) and routine ($p<0.001$) treatments (Table 9b). The routine treatment had a significantly lower ($p<0.01$) percentage of buttons with dark leaf spot in comparison with the forecast treatment.

Fig. 10 Predicted disease progress, Lincolnshire 1994, and the disease thresholds used to time sprays.

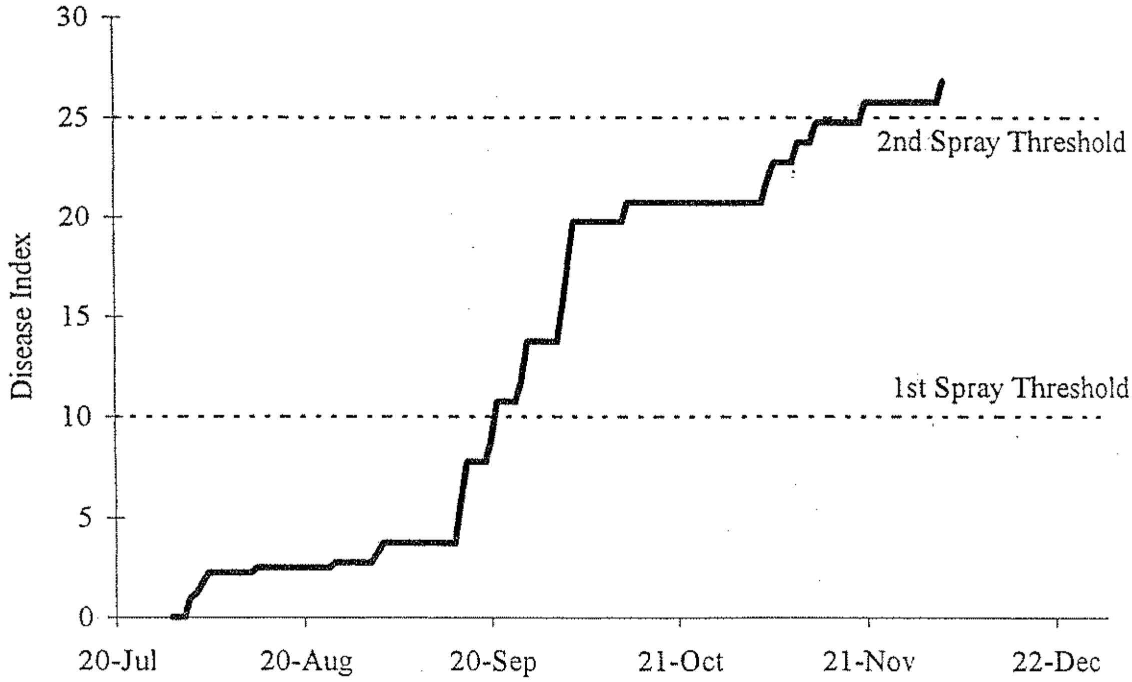


Table 11 **Disease at harvest, Algakirk 28.11.94 - (a) Severity, (b) Incidence**

(a) Mean number of lesions on 50 buttons, back-transformed from $\log_{10}$ values for three replicates.

	Treatment		
	Routine Spray	Spray Timing System	Grower's Practice
Lower Stem	25	58	69
Middle Stem	17	30	60
Upper Stem	11	10	19

(b) Mean percentage of buttons infected, three replicates. Data angular transformed for T-test and analysis of variance.

	Treatment		
	Routine Spray	Spray Timing System	Grower's Practice
Lower Stem	22	48	60
Middle Stem	25	36	51
Upper Stem	20	18	29

Use of the dark leaf spot forecasting system reduced the number of fungicide applications to the crop compared to both grower's practice and the routine spray treatment (Table 12). One fewer application of iprodione and two fewer applications of fungicide in general were made to the spray timing treatment in comparison to the growers control practice. Control of dark leaf spot however, was better on buttons in the spray timing treatment than in the grower's practice treatment. The routine treatment achieved better control but two more applications of iprodione and other fungicides were applied in this treatment.

Donington

Buttons from the grower's practice had significantly higher dark leaf spot disease severity than those from both the spray timing and routine treatments ($p<0.05$). Generally, higher disease levels occurred on those buttons at the base of the plant in all treatments. However, at all stem levels there were no significant differences in dark leaf spot severity between the routine and the spray timing treatments (Table 13). Significantly higher percentage infection of buttons by dark leaf spot was observed on the grower's practice treatment than on the spray timing and routine treatments ($p<0.05$). There were no significant differences in dark leaf spot incidence between the routine and spray timing treatments.

Fewer applications of fungicide were made to plots sprayed in accordance with the spray timing regime compared to both the grower's practice and the routine spray treatment (Table 14). The control of dark leaf spot was considerably better using the forecasting system with one less application of iprodione and fewer applications of other fungicides in comparison to the grower's practice. Control of dark leaf spot was not significantly better in the plots routinely treated with fungicide despite two additional applications of iprodione and other fungicides.

Freiston

Brussels sprouts buttons from plots sprayed according to the grower's practice had significantly higher numbers of dark leaf spot lesions per button than those from the spray timing and routine treatments ($p<0.01$). However, there was no significant difference in dark leaf spot disease severity between buttons harvested from routinely sprayed plots and those sprayed according to disease predictions (Table 15). The severity of disease was significantly different on buttons removed from different stem levels with higher amounts on those removed from the base of the stem. A significantly higher percentage of buttons were infected with dark leaf spot (Table 15) in plots sprayed according to the growers practice than in either the spray timing or the routinely treated plots ($p<0.01$). No significant differences in disease incidence were observed between the routine and forecast treatments.

Table 12 Fungicide Treatments at Lincolnshire field sites 1994 - Algakirk

Growers Practice	05.08 - chlorothalonil 28.08 - iprodione, chlorothalonil 22.09 - triadimenol, fenpropimorph, mancozeb + metalaxyl 13.10 - iprodione, triadimenol 17.11 - chlorothalonil
Routine Spray Treatment	31.08 - iprodione 23.09 - iprodione, triadimenol, mancozeb + metalaxyl 24.10 - iprodione, triadimenol, mancozeb + metalaxyl 15.11 - triadimenol, fenpropimorph
Spray Timing System	23.09 - iprodione, triadimenol, mancozeb + metalaxyl 24.10 - mancozeb + metalaxyl 15.11 - triadimenol, fenpropimorph

Table 13 **Disease at harvest, Donington 28.11.94 - (a) Severity, (b) Incidence**

(a) Mean number of lesions on 50 buttons,
back-transformed from $\log_{10}$ values for three replicates.

	Treatment		
	Routine Spray	Spray Timing System	Grower's Practice
Lower Stem	41	47	104
Middle Stem	23	25	120
Upper Stem	10	10	41

(b) Mean percentage of buttons infected, three replicates.
Data angular transformed for T-test and analysis of variance.

	Treatment		
	Routine Spray	Spray Timing System	Grower's Practice
Lower Stem	31	39	71
Middle Stem	26	32	69
Upper Stem	17	19	52

Table 14 Fungicide Treatments at Lincolnshire field sites 1994 - Donington

Growers Practice	15.08 - iprodione 13.09 - triadimenol, mancozeb + metalaxyl 07.10 - iprodione, triadimenol 23.10 - triadimenol, chlorothalonil
Routine Spray Treatment	31.08 - iprodione 23.09 - iprodione, triadimenol, mancozeb + metalaxyl 24.10 - iprodione, triadimenol, mancozeb + metalaxyl 15.11 - triadimenol, fenpropimorph
Spray Timing System	23.09 - iprodione, triadimenol, mancozeb + metalaxyl 24.10 - mancozeb + metalaxyl 15.11 - triadimenol, fenpropimorph

Table 15 **Disease at harvest, Freiston 29.11.94 - (a) Severity, (b) Incidence**

(a) Mean number of lesions on 50 buttons, back-transformed from $\log_{10}$ values for three replicates.

	Treatment		
	Routine Spray	Spray Timing System	Grower's Practice
Lower Stem	45	47	112
Middle Stem	36	40	86
Upper Stem	19	18	38

(b) Mean percentage of buttons infected, three replicates. Data angular transformed for T-test and analysis of variance.

	Treatment		
	Routine Spray	Spray Timing System	Grower's Practice
Lower Stem	43	48	73
Middle Stem	42	39	61
Upper Stem	27	27	45

Numbers of fungicide applications were reduced in plots treated according to disease forecasts in comparison to both the grower's practice and the routine treatments (Table 16). The control of dark leaf spot was considerably better using disease predictions with reduced fungicide applications in comparison to the "growers practice" treatment.

Table 16 Fungicide Treatments at Lincolnshire field sites 1994 - Freiston

Growers Practice	28.06 - chlorothalonil *
	09.08 - triadimenol
	26.08 - triadimenol
	23.09 - triadimenol, chlorothalonil + metalaxyl
	01.11 - iprodione, triadimenol
Routine Spray Treatment	28.06 - chlorothalonil *
	31.08 - iprodione
	23.09 - iprodione, triadimenol, mancozeb + metalaxyl
	24.10 - iprodione, triadimenol, mancozeb + metalaxyl
	15.11 - triadimenol, fenpropimorph
Spray Timing System	28.06 - chlorothalonil *
	23.09 - iprodione, triadimenol, mancozeb + metalaxyl
	24.10 - mancozeb + metalaxyl
	15.11 - triadimenol, fenpropimorph

(* applied before start of experiment)

4.2.2 1995 Bedfordshire, Lancashire, Lincolnshire

4.2.2.1 Disease development by other leaf spot pathogens

Infection by a number different types of foliar pathogen occurred at all three sites despite the dry conditions (see Table 6). Consequently regular applications of fungicides were used at all sites by the growers, including applications of the recently approved eradicant tebuconazole (folicur) in Lancashire and Lincolnshire. There were low levels of ringspot infection on the buttons in all three treatment regimes in Lancashire. Larger lesions were observed in both the routine and forecast spray timing plots. Aphid transmitted virus (turnip mosaic virus) was a problem, particularly in Bedfordshire where some of the crop was unmarketable due to this disease.

4.2.2.2 Predicted dark leaf spot disease development

Spray timing predictions differed between sites in Lincolnshire, Lancashire and Bedfordshire in 1995 (Fig. 11). Predictions of dark leaf spot disease development commenced when disease was first noted in the crop canopy on 13th, 16th and 9th September respectively in Lancashire, Bedfordshire and Lincolnshire. Sprays, of iprodione, were applied in the forecast treatments when the predicted disease index reached 10. A second spray was not applied as the predicted disease index did not reach 25 at any site.

4.2.2.3 Observed dark leaf spot disease development

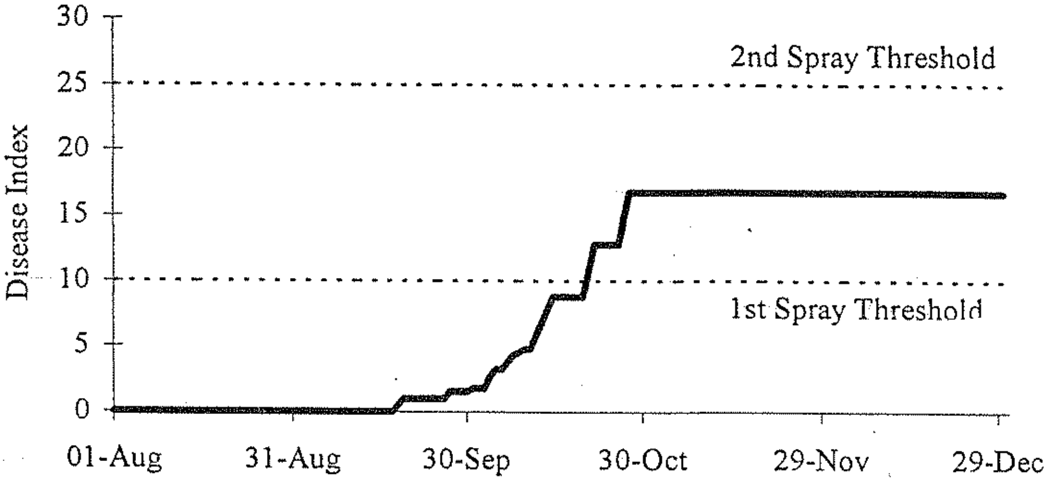
Dark leaf spot incidence at all sites was lower than in Lincolnshire in 1994, but still had potential to increase to damaging levels.

Bedfordshire

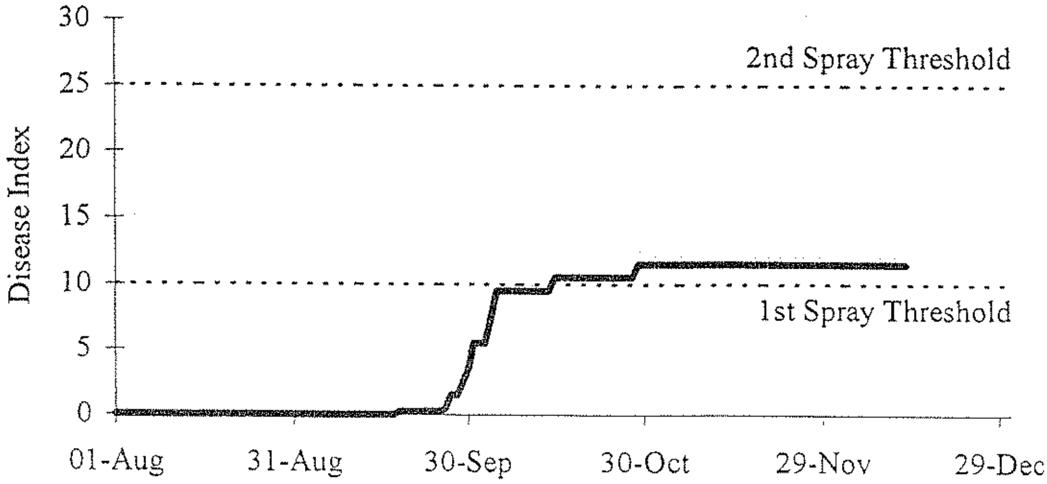
Dark leaf spot incidence on the buttons did not differ significantly between any of the three treatments (Table 17b). However, buttons harvested from plots treated according to the growers disease control regime had significantly higher numbers of dark leaf spot lesions per button ($p<0.05$) than plots treated with fungicide routinely or those sprayed according to the disease forecasting system (Table 17a). The routine and forecast treatments did not differ significantly in disease severity levels. There were no differences in the level of button infection at different heights in the canopy were found. Plots sprayed according to disease predictions had two fewer applications of fungicides than those treated according to the grower's practice and the routine treatment (Table 18). All buttons harvested from within the trial were marketable.

Fig. 11 Predicted Disease Progress at trial sites 1995
a) Bedfordshire, b) Lancashire, c) Lincolnshire

a)



b)



c)

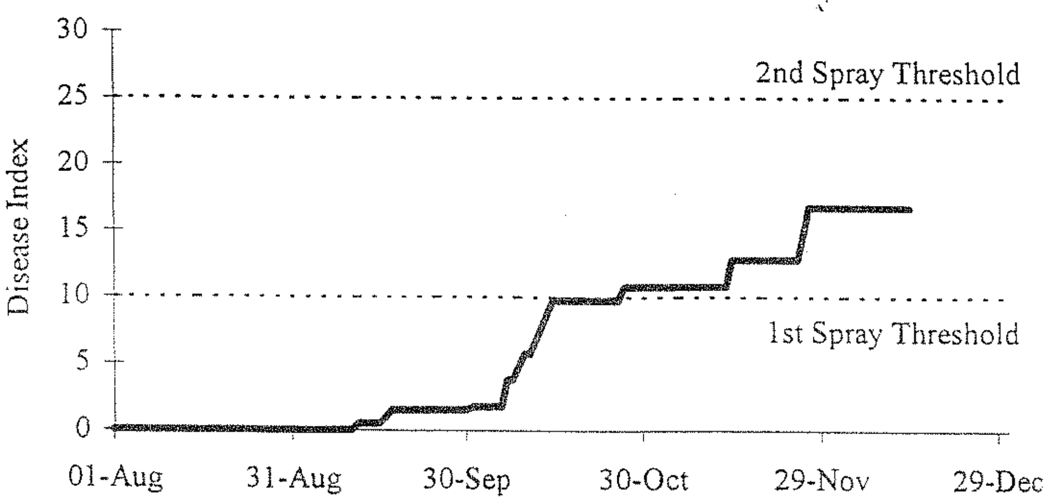


Table 17 **Dark leaf spot present at harvest, Bedfordshire, 1.2.96**
(a) Severity, (b) Incidence

(a) Mean number of lesions on 50 buttons,
back-transformed from $\log_{10}$ values for three replicates.

	Treatment		
	Routine Spray	Spray Timing System	Grower's Practice
Lower Stem	6	10	20
Middle Stem	5	6	13
Upper Stem	17	9	20

(b) Mean percentage of buttons infected, three replicates.
Data angular transformed for T-test and analysis of variance.

	Treatment		
	Routine Spray	Spray Timing System	Grower's Practice
Lower Stem	9	13	20
Middle Stem	7	11	19
Upper Stem	23	15	26

Table 18 Fungicide Treatments at field sites 1995 - Bedfordshire

Growers Practice	28.07 - triadimenol, chlorothalonil 18.08 - mancozeb + metalaxyl 01.09 - triadimenol, chlorothalonil
Routine Spray Treatment	01.09 - iprodione 11.10 - iprodione 20.11 - iprodione, mancozeb + metalaxyl
Spray Timing System	27.10 - iprodione, mancozeb + metalaxyl

Lancashire

No significant differences were observed between treatments in either the number of lesions per button or the percentage of harvested buttons infected with dark leaf spot (Table 19). As in Bedfordshire differences in disease on buttons at different canopy heights were not observed. Ringspot was a problem within the trial site (see Table 6). However addition of ringspot infected buttons at harvest to assessments gave no further significant differences between treatments in the total disease present on button (Table 20). Two fewer fungicide applications were applied to plots sprayed according to predictions from the dark leaf spot disease forecaster than those sprayed routinely (Table 21). Plots sprayed using the growers disease control regime had three additional fungicidal applications in comparison to the forecast treatment. Ringspot lesions on buttons harvested from the routine and forecast treatments were larger than those on buttons harvest from plots sprayed according the growers practice.

Lincolnshire

No significant differences were observed between treatments in either the number of lesions per button or the percentage of buttons infected with dark leaf spot (Table 22). Higher numbers of dark leaf spot lesions were observed on buttons harvested from the lower canopy levels in comparison to buttons harvested from the upper stem canopy. Plots sprayed according to forecast predictions of dark leaf spot received two fewer fungicide sprays than routinely treated plots (Table 23). Plots sprayed using the growers disease control regime had three additional fungicidal applications in comparison to forecast treatments.

Table 19 **Dark leaf spot present at harvest, Lancashire, 12.12.95**
(a) Severity, (b) Incidence

(a) Mean number of lesions on 50 buttons,
back-transformed from log_{10} values for three replicates.

	Treatment		
	Routine Spray	Spray Timing System	Grower's Practice
Lower Stem	15	17	23
Middle Stem	24	27	17
Upper Stem	12	13	8

(b) Mean percentage of buttons infected, three replicates.
Data angular transformed for T-test and analysis of variance.

	Treatment		
	Routine Spray	Spray Timing System	Grower's Practice
Lower Stem	20	19	21
Middle Stem	21	23	16
Upper Stem	21	15	13

Table 20 **Total Disease at harvest, Lancashire, 12.12.95**
(a) Severity, (b) Incidence

(a) Mean number of lesions on 50 buttons, back-transformed from log_{10} values for three replicates.

	Treatment		
	Routine Spray	Spray Timing System	Grower's Practice
Lower Stem	22	30	32
Middle Stem	34	32	18
Upper Stem	12	13	9

(b) Mean percentage of buttons infected, three replicates. Data angular transformed for T-test and analysis of variance.

	Treatment		
	Routine Spray	Spray Timing System	Grower's Practice
Lower Stem	30	33	27
Middle Stem	27	29	17
Upper Stem	21	15	14

Table 21 Fungicide Treatments at field sites 1995 - Lancashire

Growers Practice	10.08 - triadimenol, chlorothalonil + metalaxyl
	30.08 - triadimenol, chlorothalonil[1]
	12.09 - triadimenol[2], mancozeb + metalaxyl[3]
	08.10 - tebuconazole[1], mancozeb + metalaxyl[3]
	31.10 - triadimenol, chlorothalonil + metalaxyl[4]
Routine Spray Treatment	05.09 - iprodione, chlorothalonil + metalaxyl
	30.09 - iprodione, mancozeb + metalaxyl
	11.10 - triadimenol, mancozeb + metalaxyl
	28.10- iprodione, triadimenol, mancozeb + metalaxyl
Spray Timing System	11.10 - triadimenol, mancozeb + metalaxyl
	28.10 - iprodione, triadimenol, mancozeb + metalaxyl

[1] 0.5 full rate [2] 0.6 full rate [3] 0.66 full rate [4] 0.75 full rate

Table 22 **Dark leaf spot present at harvest, Lincolnshire, 15.12.96**
(a) Severity, (b) Incidence

(a) Mean number of lesions on 50 buttons,
back-transformed from $\log_{10}$ values for three replicates.

	Treatment		
	Routine Spray	Spray Timing System	Grower's Practice
Lower Stem	31	20	16
Middle Stem	12	14	14
Upper Stem	13	9	11

(b) Mean percentage of buttons infected, three replicates.
Data angular transformed for T-test and analysis of variance.

	Treatment		
	Routine Spray	Spray Timing System	Grower's Practice
Lower Stem	27	19	18
Middle Stem	17	18	17
Upper Stem	21	18	19

Table 23 Fungicide Treatments at field sites 1995 - Lincolnshire

Growers Practice	23.08 - triadimenol 22.09 - tebuconazole 12.10 - iprodione, mancozeb + metalaxyl, fenpropimorph 31.10 - tebuconazole
Routine Spray Treatment	31.08 - iprodione, mancozeb + metalaxyl 25.09 - iprodione 29.10 - iprodione, mancozeb + metalaxyl, fenpropimorph
Spray Timing System	29.10 - iprodione, mancozeb + metalaxyl, fenpropimorph

5. CONCLUSIONS

Forecasting dark leaf spot occurrence

Temperature and leaf wetness conditions necessary for dark leaf spot infection can be used to predict the need for crops to be examined for dark leaf spot occurrence. This aspect of the dark leaf spot forecasting system will be dependant on the location of the crop and its proximity to sources of dark leaf spot in the surrounding area. It has been shown that spores of *A. brassicae* can be transported by wind over a distance of 1.8 km (Humperton Jones & Maude, 1982). It is possible that crops of Brussels sprouts which are within this distance of an over-wintering crop of Brassicas could be designated as "at risk". Crops beyond this limit would have a lower risk of infection from dark leaf spot. In this way it would be possible to predict the need for examination of crops by the degree of risk that is associated with each location. This part of the dark leaf spot forecasting system may be utilised as a locality specific warning system. However further work would be necessary to determine the spatial variation in wetness within crop canopies if predictions were to cover larger localities. In some localities topographic features may make the likelihood of infection greater by extending wetness duration. If these sites are sufficiently close to sources of disease they may act as potential areas where the disease may establish itself within any crop. Extrapolation of forecasts spatially will also determine how these systems will be utilised by the industry.

There are a number of potential dangers in interpreting what would be the limits of areas over which forecasts extend. Firstly the sources of disease (carry over crops) change in location from one year to another. This will greatly influence the risk of disease occurrence at the same point from season to season. Secondly the environmental conditions at any one point will never be the same from season to season. Therefore areas which apparently show similarity in one season may not necessarily yield the same results during another. Wetness duration will also be affected by topography which will increase the need for local measurement of environmental factors. However it is likely that the forecasts could be extrapolated over a certain area without encountering these problems. This distance may, however, only be 1 - 2 km from the point of measurement.

Forecasting the need for dark leaf spot control

The results outlined in this report have shown that use of the dark leaf spot forecaster to predict the timing of control sprays resulted in better disease control than the grower's control regime and equal control in comparison to a routine spray treatment in most cases. The dark leaf spot forecasting system utilised fewer fungicide applications than either the grower's control regime or the routine treatment at all sites and did not require crop walking once the presence of disease had been established within the crop. During 1994 two applications for control of dark leaf spot were predicted as necessary by use of the forecasting system.

In 1994 the dark leaf spot forecast predictions were similar at all three sites. However this was coincidental on the prevailing weather for that year and also the time when dark leaf spot was first noted within the crop. If sites which are in proximity to each other have the initial presence of dark leaf spot at increasingly different time periods then the control spray are likely to have different optimal application times. One problem still unresolved in this system is the continued interaction between neighbouring crops that have different levels of disease. However, other difficulties exist, notably the estimation of leaf wetness. The timing of fungicide application at any one site will be determined by differences in the duration of wetness and high humidity conditions. At present leaf wetness is estimated using an electronic wetness sensor, however this estimate may be inaccurate at different levels in the crop canopy and may not reflect leaf surface drying. Also the estimate of leaf surface wetness is at only one point and may be a poor estimate of wetness in other parts of the crop. Despite these potential inaccuracies the disease forecasting system has been shown to predict well the relatively simple dark leaf spot disease cycle.

Forecasting systems for leaf spot pathogens on vegetable brassicas

Dark leaf spot is only one of a number of damaging leaf spot pathogens of Brussels sprouts crops. Commercial trial sites in both 1994 and 1995 were infected with white blister and ringspot. The control of each of these pathogens and other leaf spot pathogens cannot be carried out in isolation from each other. Therefore any disease forecasting system for leaf spot pathogens of Brussels sprouts should include systems for predicting the optimal timing of control applications of fungicides for other pathogens. Information on the effect of environmental factors on life cycle stages of white blister, ringspot and light leaf spot will be required. Some of this information has already been obtained, for example the effect of temperature and wetness on infection of light leaf spot on vegetable brassicas has been successfully investigated. However it will be necessary to combine this information with the effect of temperature and wetness on latent/incubation period for this pathogen, if a more rational system for controlling light leaf spot with fungicides is to be devised. The results of this investigation have shown that the latent/incubation period for light leaf spot on one cultivar of oilseed rape was different from that on one cultivar of Brussels sprouts under identical temperature conditions. These results suggested that temperature alone may not be the only factor controlling duration of latent/incubation period. Further work is required to successfully define the environmental factors determining light leaf spot latent/incubation period. Additional work will also be required to integrate models predicting disease occurrence by other pathogens into a comprehensive forecasting system for foliar pathogens on vegetable brassicas.

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Appendix 1. **Non-fungicidal pesticides applied to trial sites in Lincolnshire 1994**

Algakirk

18.05 -	disulfoton	(aphicide + insecticide)
29.05 -	propachlor	(herbicide)
04.07 -	dimethoate	(insecticide + acaricide)
05.07 -	triazophos	(insecticide)
19.07 -	demeton-S-methyl	(insecticide + acaricide)
	cypermethrin	(insecticide)
05.08 -	demeton-S-methyl	
	cypermethrin	
	metaldehyde	(molluscicide)
08.08 -	disulfoton	
28.08 -	dimethoate	
	cypermethrin	
	metaldehyde	
22.09 -	dimethoate	
	cypermethrin	
	metaldehyde	
13.10 -	cypermethrin	
	metaldehyde	

Donington

25.05 -	propachlor	
01.07 -	demeton-S-methyl	
	cypermethrin	
25.07 -	demeton-S-methyl	
	cypermethrin	
15.08 -	demeton-S-methyl	
	cypermethrin	
	metaldehyde	
13.09 -	demeton-S-methyl	
	cypermethrin	
	metaldehyde	
07.10 -	methiocarb	(molluscicide + insecticide)

Freiston

20.05 -	trifluran	(herbicide)
25.05 -	propachlor	
28.06 -	dimethoate	
	cypermethrin	
12.07 -	demeton-S-methyl	
	cypermethrin	
09.08 -	demeton-S-methyl	
	cypermethrin	
	metaldehyde	
26.08 -	demeton-S-methyl	
	cypermethrin	
23.09 -	demeton-S-methyl	
	cypermethrin	
	metaldehyde	
06.10 -	metaldehyde	

Lincolnshire

30.05 -	disulfoton	
02.06 -	metazachlor	(herbicide)
28.06 -	demeton-S-methyl	
	cypermethrin	
12.07 -	demeton-S-methyl	
	cypermethrin	
31.07 -	desmetryn	
02.08 -	triazophos	
23.08 -	demeton-S-methyl	
	lambda-cyhalothrin	(insecticide)
06.09 -	dimethoate	
	triazophos	
22.09 -	demeton-S-methyl	
	lambda-cyhalothrin	
	metaldehyde	
12.10 -	demeton-S-methyl	
	cypermethrin	
	metaldehyde	
31.10 -	demeton-S-methyl	
	cypermethrin	