Project Title: Carrots: forecasting and integrated control of sclerotinia disease

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Commercial crops of carrots in North East Scotland

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‘The results and conclusions in this report are based on an investigation conducted over one year. The conditions under which the experiment was carried out and the results obtained have been reported with detail and accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results especially if they are used as the basis for commercial product recommendations.’

CONTENTS

Grower Summary

Headlines

- Canopy development rate, weather conditions and availability of soil-borne inoculum determine the onset, duration and severity of sclerotinia epidemics. Lush, rapidly growing main crop carrots with early leaf senescence in fields with a history of the disease have the highest risk.
- Over the three years of the project, under conditions in east central Scotland, crops which reached 100% canopy ground cover within the bed later than the third week of July tended to have a lower risk of sclerotinia foliar blight.
- Combining the results for all thee years indicated that yields of marketable roots increased, foliar blight severity decreased and the incidence of sclerotinia root rot decreased, when fungicides were used to control sclerotinia foliar blight.
- It was estimated that each 1% increase in the percentage of roots diseased resulted in a loss of approximately 1t/ha in marketable yield (the estimated disease-free marketable yield for these trials was 118t/ha).
- Fruiting bodies of sclerotinia were observed when canopy ground cover was 80-85% within the beds (i.e. before canopy closure) indicating the need for fungicide programmes to start well before canopy closure.
- Fruiting bodies can germinate throughout the crop growth season from June to September and that conditions favourable for infection occur frequently throughout that period.
- The onset of foliar blight epidemics, and large increases in foliar blight severity in on-going epidemics, were found to follow periods either when there were 3 to 4 days of measurable rain per week, or sharp increases in the intensity of rainfall over periods of 1 to 2 days.
- A week-ahead risk prediction tool was constructed from an index of canopy development, number of rain days per week and mean daily rainfall intensity (mm/day). The tool correctly predicted the change in risk (of disease either increasing or not) in 73% of weeks across the data from all locations and three years.

Background and expected deliverables

Sclerotinia disease, caused by the fungus *Sclerotinia sclerotiorum*, is one of the most economically important diseases that threaten UK carrot (*Daucus carota*). It infects both the foliage and the roots, and yield losses appear to be increasing as a result of poor control. The financial losses are serious, and it has been estimated that the disease causes annual crop losses to UK growers in excess of £5 million. The fungus survives in soil as small, black resting bodies (sclerotia), which germinate under moist soil conditions to produce tan-coloured fruiting bodies (apothecia). These fruiting bodies release millions of microscopic spores (ascospores), which spread in air currents, and are the major source of infection. Optimum timing of fungicide sprays is currently unknown and several sprays are often applied. A simple forecasting system, based on crop growth stage and environmental factors affecting fruiting body production, is needed to predict the optimum time to spray and save costs by reducing unnecessary fungicide applications.

The overall aim of this project is to develop an effective integrated control system, based on a simple predictive forecasting model and rational use of fungicides. Such an integrated control system could reduce production losses to carrot growers by 75%, an annual saving of approximately £4 million, less the cost of implementing control.

The expected deliverables from this work include:

- An understanding of the environmental conditions that promote infection of carrots in relation to crop growth stage and senescence
- The identification of periods of high sclerotinia risk
- Development of a simple predictive model, based on crop growth stage and environmental factors affecting fruiting body production and spore infection
- An evaluation of new and existing fungicides against sclerotinia
- An evaluation and validation of a developed simple forecasting system.

Summary of the project and main conclusions

Environmental factors affecting carrot foliage infection

Results from controlled environment experiments examining the conditions required for infection were reported fully in last year's annual report for this project and are given in summary only here:

- Optimum conditions for foliage infection were greater than 4 days (0-8 hours minimum) of continuous leaf wetness, ≥90% (60% minimum) relative humidity (RH) and air temperatures of 10-18^{0}C (5-10^{0}C minimum).

Because infection can occur at temperatures from 5 to 25^{0}C and at RHs from 60 to 100%, suitable periods for infection are likely to be regularly available during the main carrot growing season except under periods of very hot, dry weather.

Development of sclerotinia disease and fruiting production in carrot crops

In the 2006 growing season two field trial sites were established in carrot crops at Cleeves and Hall Hole (both in Perthshire). Both crops were sown with the variety *Nairobi*, on 22/04/07 at Cleeves and 11/05/07 at Hall Hole. As in previous years, crop development, disease severity (foliar blight) and fruiting body production were recorded at 50 points in an unsprayed area of each crop; observations were made at 7 day intervals.

Field observations made during the 2006 season were similar to those observed during the 2005 season which was also relatively dry (see Year 2 Annual Report 2005). The main points of interest were:

- The first appearance of fruiting bodies occurred in the crops when canopy cover was 85% within the beds at Cleeves (on 14/07/06) and 80% at Hall Hole (on 04.08/06). This was 6 weeks before full canopy closure at Cleeves and 2 weeks before closure at Hall Hole. The last recorded flush of fruiting bodies at Cleeves was on 15/09/06 and 08/09/06 at Hall Hole.
- Leaf senescence and lodging were first noted on 17/08/06 at both Cleeves and Hall Hole.
- Foliar blight was first recorded on 11/08/06 at Cleeves but not until 08/09/06 at Hall Hole.

- Overall, foliar blight severities at both sites were low (generally less than 1%) throughout the trial as a result of a combination of late crop development and above average temperatures and below average rainfall during the growing season.

Evaluation of fungicide spray programmes & timings

Fungicide/yield response trials were established at both Cleeves and Hall Hole using the same design at both trial sites. There were two main objectives in these trials. First, to evaluate the potential for using weather and crop development information to target fungicide applications to high risk periods of infection; particularly to evaluate the scope for delaying second and subsequent applications. Secondly, to examine yield responses to fungicide treatment in crops lifted later than the previous January harvest dates used in the trial.

Table 1. Fungicide trial 2006 – details of fungicides evaluated

Trade name	Active ingredient	Application Rate (product/ha)	Application volume (l water/ha)	Approval status
Folicur	tebuconazole	1 L/ha	200-300	On-label
Signum	boscalid + pyraclostrobin	1 kg/ha	200-300	On-label
A9219B[b]	Experimental	0.8 kg/ha	200-300	Exp.[a]
A137036	Experimental	1 L/ha	200-300	Exp.

[a] Used under Automatic Experimental Approval for the trial. Inclusion in the trial funded by Syngenta

[b] Also evaluated in 2005

Table 2. Fungicide trial 2006 – details of fungicide spray programme treatments and timings

Spray programme	Timings[a]			
	T1	T2	T3	T4
Control	-[b]	-	-	-
Folicur	Folicur	Folicur	Folicur	Folicur
BASF	Signum	Folicur	Signum	Folicur
CPP[d]	Signum	Folicur/Amistar	Signum	Folicur/Amistar
Predict	Signum	Folicur	?	?[c]
A9219B	A9219B	A9219B	A9219B	A9219B
A137036	A137036	A137036	A137036	A137036

[a] The four fungicide timings were:

T1	14 Jul, Cleeves; 4 Aug, Hall Hole
T2	28 Jul, Cleeves; 18 Aug, Hall Hole
T3	11 Aug, Cleeves; 1 Sep, Hall Hole
T4	25 Aug, Cleeves; 15 Sep, Hall Hole

[b] -, No fungicide applied.

[c] ? fungicide application dependent on week-ahead prediction of risk

[d] Commercial production practice

Foliage disease severity was assessed on 25 August and 15 September at Cleeves and 8 and 15 September at Hall Hole. The trials were protected against frost using straw in early October 2006. Roots were harvested subsequently on 15th January 2007 and 15th February 2007 at Hall Hole. The Cleeves trial site was partially destroyed during flooding in early December 2006 and the field was cleared in late December 2006 in order to salvage the remaining commercial production. No experimental yield data are available from this site. As in previous years the trial at Hall Hole was assessed for yield, and incidence and severity of sclerotinia on roots post harvest.

Week-ahead risk predictor

The week-ahead risk predictor was developed with the aim of using crop development and weather data to provide a short-term forecast of the likely behaviour of sclerotinia based on the conditions during the seven days leading up to the prediction. In the initial predictor, used in the 2006 trials, the data from 2004 and 2005 observations (six field sites in all) was used to obtain a simple set of rules relating rainfall (number of days with rain and average mm/day) to foliar blight dynamics. The predictor was subsequently modified after the 2006 season to include canopy development and its predictive accuracy assessed by making weekly predictions for all 8 data sets from 2004, 2005 and 2006 and testing them against the observed disease progress.

Results for the severity of sclerotinia foliage blight at Cleeves are given in Table 3. Yield data from Hall Hole are given in Table 4.

Table 3. Mean disease severity (%) observed at Cleeves averaged over two observation dates.

Treatment						
Control	Folicur	BASF	CPP	Predictor	A9129B	A137036
0.63	0.02	0.12	0.21	0.01	0.01	0.01
s.e.d. = 0.144[1]						

[1] To be significantly different from one another, treatments need to differ by more than twice this value

Table 4. Mean marketable yield data (t/ha) for hand-dug plots at Hall Hole averaged over two harvest dates.

Treatment						
Control	Folicur	BASF	CPP	Predictor	A9129B	A137036
113.9	118.3	123.2	118.2	119.4	120.2	131.1
s.e.d. = 6.81[1]						

[1] To be significantly different from one another, treatments need to differ by more than twice this value

The key findings from the fungicide/yield trials were:

- Low levels of foliar blight occurred at both sites. The severity of disease at Hall Hole was so low that statistical analysis of the data was not conducted.

- At Cleeves, all treatments reduced disease in comparison with the control, but there was no evidence of statistically significant differences among treatments. The Predictor treatment, using week-ahead risk predictions, used only three fungicide applications instead of the four applied in the other treatments because low disease risk was predicted for the weeks 11 and 18 August.
- Carrot yields estimated at Hall Hole did not differ among treatments and only one treatment (A137036 – Syngenta experimental product) produced a yield greater than the unsprayed control.
- These results are similar to those obtained in 2005 (another low disease pressure year) and suggest that for crops lifted in Jan/Feb the benefits of fungicide application may be marginal. However an overview analysis of all three years' data (see below) indicates the overall trend in yield response to treatment and also highlights the danger of assuming that crops with little or no apparent foliar blight will be free from sclerotinia root rot.

Week-ahead risk predictor

The predictor was used to determine spray timings and fungicide choice at Cleeves and Hall Hole in the Predictor treatment in the fungicide trials. The predictor was based on two different measures of rainfall over a 7 day period: the number of days with measurable rain and the average mm/hour rainfall. By examining the weather and disease development data for the 2004 and 2005 epidemics a three point risk scale for each of these variables was established as shown below:

Number of rain days		Average rain per hour (mm)	
From 0 to 1	Low	Less than 0.3	Low
From 1 to 2	Moderate	From 0.3 to 0.6	Moderate
More than 2	High	More than 0.6	High

The main findings in evaluating the predictor were:

- In all, including both 2006 trials (i.e. Cleeves and Hall Hole) the predictor was used to predict the risk of foliar blight increase/decrease for the week ahead on 22 occasions.

- In total, 64% of these predictions were correct and 36% were false.
- The false predictions were all cases where a high risk was predicted (on the basis of weather data) but no increase in foliar blight was observed.
- Examination of the weeks with false predictions suggested that they were mainly associated with weeks in which the crop was not at risk from infection because the canopy had not reached sufficient maturity to allow infection.
- The link between canopy development rate and disease severity was reported in the 2004 annual report. The predictor was extended by including a rule based on a canopy risk index described in the 2004 annual report; the canopy risk index combines ground cover, senescence and lodging measurements into a single index of disease risk. The final version of the predictor added the following rules to the rain-based rules noted above:
    - If canopy risk index is less than 1 on July 14th, disease risk is 0 until 11th August irrespective of rain-based risk predictions.
    - If canopy risk index is 1 or more on July 14th, disease risk predictions are as suggested by the rain-based predictor.
    - After August 11th disease risk predictions are as suggested by the rain-based predictor.
- The modified predictor was tested using the available data from all three years of the project (110 predictions). The percentage of correct predictions was 72%.
- Of the 28% false predictions, the majority (27 out of 30) were cases where high risk was predicted but disease did not increase, while only 10% (3 out of 30) were cases where a low risk was predicted but disease increased.
- The trigger date of July 14th may need to be adjusted to account for differences in typical crop maturity dates across the UK.

Overview of disease and yield responses 2004-2006

Despite the fact that yield responses were difficult to demonstrate in 2005 and 2006 in individual experiments, combining the data from all available experiments from 2004 to 2006 provided a view of the relationships between foliar blight, root disease incidence and yield. Table 5 summarises the results of this comparison.

Table 5. Overall comparison of disease and yield results in field trials from 2004-2006.

Foliar blight (%)		Root rot incidence (%)		Marketable yield[a] (t/ha)	
Untreated	Treated[b]	Untreated	Treated	Untreated	Treated
25.2	6.3	29.4	14.1	88.4	111.1

[a]results from hand-dug trials harvested in January or February

[b]averaged over all fungicide treatments used

The main findings of the yield response analysis were:

- Both the severity of foliar blight (percentage leaf area diseased) and the incidence of sclerotinia root rot (percentage of roots infected) were significantly correlated with loss in marketable yield, but the severity of foliar blight was a better predictor of yield loss than the incidence of root disease.
- The relationship between marketable yield and root rot incidence was linear with and estimated loss in marketable yield of 1.08t/ha for each 1% increase in roots diseased
- The relationship between marketable yield and foliar blight severity was nonlinear, with proportionally greater yield loss from small levels of disease than large levels. For example an increase in disease severity from 0 to 1% caused a predicted decrease of 2.5 t/ha, but an increase in severity from 10% to 11% caused a predicted decrease of only 1.4 t/ha.
- The shape of the predicted yield loss relationship emphasises the benefit of preventing low levels of disease.
- Significant levels of root disease can occur even when foliar blight severity is 0 or close to 0. For example, the average incidence of root rot in treatments with 0% foliar blight was 17% and in treatments with less than 1% foliar blight it was 14%.

Financial benefits

The results from the fungicide trials and field artificial inoculation experiments conducted from 2004 to 2006 illustrate the benefits, which arise from controlling sclerotinia disease in carrot crops. Marketable yields in untreated plots were, across the three years, 20% lower than in treated plots. The Table below (Table 7) shows the predicted losses in yield at four different levels of foliar blight severity. The predicted financial cost (£/ha) of these losses can be calculated by multiplying the figures by the expected price per tonne of marketable yield. Finally, the overall benefit/cost of spraying can be estimated by calculating the cost of spraying (£/ha) by assuming a 4 spray programme and supplying a value for the average cost of a spray (which should by multiplied by 4 and subtracted from the predicted loss).

Table 7. Empty pro-forma to allow relative costs/benefits from preventative fungicide programmes for sclerotinia to be calculated based on users' own estimates of carrot prices and spray costs.

A Disease severity (%)	**B** Predicted yield loss (t/ha)	**C** Carrot price (£/t)	**D** Predicted loss (£/ha) [=**B**×**C**]	**E** Average spray cost (£/ha)	**F** Net cost/benefit (£/ha) [=**D**-(4×**E**)]
1%	2.5				
5%	11				
10%	19.5				
25%	34				

Action points for growers

These action points are modifications and additions to the actions suggested in the 2005 annual report, all of which remain relevant.

- Action should be taken to prevent foliage infection via spores, limit production of resting bodies and prevent the long-term build up of resting bodies in the soil. Growing varieties with upright, open canopies and incorporating Contans WP pre-planting may contribute to short and long term disease control.
- A preventative fungicide spray programme should remain the main defence against foliage infection. It is important to apply the first fungicide early, before canopy closes, to ensure protection of senescing leaves at the base of the canopy. For a standard protection programme for main crops carrots, apply further sprays at recommended intervals and rates.
- Observations of fungal fruiting bodies well before canopy closure suggest that erring on the side of being early with the first spray application rather than late may be advisable.

- Some potential might exist for reducing fungicide inputs depending on a number of factors which reduce the risk of severe infection. In these situations it might be possible to use risk forecasting to determine fungicide applications after the first pre-canopy closure spray. The suitability of a crop to be managed in this way depends upon:
    - Field history of sclerotinia (preferably this should be low);
    - Canopy risk index in relation to timing of sclerotinia infection period (the risk index should be less than 1 on a date corresponding to the onset of fruiting body appearance);
    - General weather conditions for the field allowing for possibility of low risk periods for infection (continual high risk periods are likely to result in substantial infection even when the background level of inoculum is low).

Science Section

Introduction

Sclerotinia disease, caused by the soil-borne pathogen *Sclerotinia sclerotiorum*, is one of the most economically important diseases that threaten UK carrot (*Daucus carota*) production. The disease causes plant and root death, and renders carrots unmarketable or often causes down-grading. Although disease incidence varies greatly among years, regions and fields, yield losses are increasing as a result of poor control. The financial losses are serious, and it has been estimated that the disease causes annual crop losses to UK growers in excess of £5 million. Preliminary observations reveal that infection is more common in later growth stages once leaf senescence or crop lodging is advanced.

Periods of high Sclerotinia risk in UK carrot crops are unknown. Many growers rely on routine use of Folicur (tebuconazole; on-label), Compass (iprodione + thiophanate-methyl; SOLA) and Amistar (azoxystrobin; on-label) for sclerotinia control. However, control is often inadequate because fungicide use is based on a poor understanding of disease epidemiology, and sprays are often applied at the incorrect time. By identifying the optimum time to spray, disease control could be improved, and yield losses as well as unnecessary fungicide applications avoided.

The pathogen survives in soil as resting bodies (sclerotia), which germinate to produce fruiting bodies (apothecia). Air-borne spores (ascospores) released from fruiting bodies are the major source of infection in the majority of hosts, including carrots (Phillips, 1987). Consequently, there is an urgent need to be able to predict the appearance of fruiting bodies and identify periods of high disease risk. Such a reliable forecasting system would identify the optimum time to spray and enable rational, economic and effective use of fungicides. Previous studies have shown that soil temperature and moisture are key factors affecting fruiting body production in the field (Phillips, 1987; Hao *et al*., 2003; Clarkson *et al*., 2004). Temperature, relative humidity (RH) and leaf wetness duration also affect ascospore survival and infection of plants by the pathogen (Grogan & Abawi, 1975; Caesar & Pearson, 1983). However, none of these studies were conducted using an UK *S. sclerotiorum* isolate, originally derived from a diseased carrot.

The overall aim of this project was to develop an effective integrated control system for Sclerotinia disease in carrots, based on a simple predictive model and rational use of fungicides. The work was undertaken with the following specific objectives: (1) to identify key environmental factors affecting fruiting body production, ascospore survival and infection; (2) to develop and evaluate a simple disease predictive model, based on crop growth stage and environmental factors; (4) to evaluate current and novel fungicides; (5) to devise and evaluate an integrated control programme, using the simple disease predictive model and fungicide spray programmes.

The majority of the work reported in this final report concerns data analysis and modelling of field data from all three years of the project. Specific results from the 2006 fungicide evaluation/yield experiments are also reported briefly.

Materials and Methods

General

Details of the general design, treatment protocols, experimental design, layout and assessment procedures for evaluation of sclerotinia development and fungicide evaluation are identical to those given in the Annual Report for 2005 except that disease and pathogen development assessments were made weekly and no assessments of sclerotium population densities were conducted in 2006. The fungicides included in the 2006 trial are listed in Table 1; details of the treatment programmes used are given in Table 2. The main difference between the fungicide evaluation experiments carried out in 2006 and those done in 2004 or 2005 was the inclusion of a treatment in which sprays applied after the second spray were determined by a weekly evaluation of the risk of infection based on weather data and disease levels in the crop. The crops used in 2006 were grown at Cleeves and Hall Hole (both Perthshire) and sown on dd/mm/yy and dd/mm/yy respectively, both with variety Nairobi.

Week-ahead disease risk predictor

One of the main objectives of this project was to evaluate the potential for using crop and weather data to produce a predictive system for predicting the optimum timing for fungicide applications.

Table 1. Fungicide trial 2006 – details of fungicides evaluated

Trade name	Active ingredient	Application Rate (product/ha)	Application volume (l water/ha)	Approval status
Folicur	tebuconazole	1 L/ha	200-300	On-label
Signum	boscalid + pyraclostrobin	1 kg/ha	200-300	On-label
A9219B[b]	Experimental	1 kg/ha	200-300	Exp.[a]
A137036	Experimental	1 L/ha	200-300	Exp.

[a] Used under Automatic Experimental Approval for the trial. Inclusion in the trial funded by Syngenta

[b] Also evaluated in 2005

Comparison of the observed temperature data from the 2004 and 2005 trials sites with results from growth chamber experiments in carried out in 2005 (see 2005 Annual Report) suggested that temperatures would rarely be a limiting factor in sclerotinia infection in carrots. Consequently the derivation of a risk prediction system focussed on rainfall. The aim was to develop a simple predictive system, using basic weather data, which would allow a simple short-term forecast of disease risk to be calculated. The basic idea of the prediction system is to use the weather in one week to predict the risk status of the crop for the next week. In making decisions about the need for treatment, the information on risk needs to be combined with knowledge of the development stage of the crop and the current disease status.

Table 2. Fungicide trial 2006 – details of fungicide spray programme treatments and timings

	Timings[a]			
Spray programme	T1	T2	T3	T4
Control	-[b]	-	-	-
Folicur	Folicur	Folicur	Folicur	Folicur
BASF	Signum	Folicur	Signum	Folicur
CPP[d]	Signum	Folicur/Amistar	Signum	Folicur/Amistar
Predict	Signum	Folicur	?	?[c]
A9219B	A9219B	A9219B	A9219B	A9219B
A137036	A137036	A137036	A137036	A137036

[a] The four fungicide timings were:

T1	14 Jul, Cleeves; 4 Aug, Hall Hole
T2	28 Jul, Cleeves; 18 Aug, Hall Hole
T3	11 Aug, Cleeves; 1 Sep, Hall Hole
T4	25 Aug, Cleeves; 15 Sep, Hall Hole

[b] -, No fungicide applied.

[c] ? fungicide application dependent on week-ahead prediction of risk

[d] Commercial production practice

Data for rainfall (mm/hour) and disease progress from the six trial sites used in 2004 and 2005 were examined to identify correlations between rainfall events and increases in disease severity. Two rainfall variables were considered: (1) the number of days with measurable rain per week; (2) the mean rainfall intensity (mm/hour) per week. Time series graphs of weekly values for these variables and observations of foliar blight severity were plotted for the six sets of field data . From inspection of these time series a rule base was developed for each rain variable which related its values in one week to the change in disease severity observed in the following week. The derived rules are listed in Table 3.

Table 3. Derived rule base relating rain variables to predicted risk of disease increase in the week ahead.

Number of rain days		Average rain per hour (mm)	
Observed values	Week-ahead risk	Observed values	Week-ahead risk
From 0 to 1	Low (=1)	Less than 0.3	Low (=1)
From 1 to 2	Moderate (=2)	From 0.3 to 0.6	Moderate (=2)
More than 2	High (=3)	More than 0.6	High (=3)

In order to use the rule base to control spray decisions in the Predict treatment in the fungicide/yield trial, an Excel spreadsheet was written to produce the values of the risk scores automatically from the weekly logged weather data. The data were collected each week at both sites starting in the week 7 days after the second fungicide treatment had been applied to all treated plots *(i.e.* 7 days before the date of the next (third) fungicide application in a standard 14-day interval 4-spray programme. The spreadsheet was set up to generate two blocks of coloured cells corresponding to the calculated risk values for the rain variables to allow the user easily to interpret the risk calculation. The coloured block formed a traffic light system with green corresponding to low risk; amber, moderate risk; and red, high risk.

Testing the predictor against the observed changes in foliar blight severity at Cleeves and Hall Hole for 2006 provided a total of 26 weekly predictions. At the end of the 2006 growing season the data 2006 data were added to those for 2004 and 2005. This produced a database of 111 site/week combinations spread over 8 site/year combinations. Risk predictions were produced for all 111 observations and compared with the observed values for foliar blight dynamics.

Inspection of the performance of the risk predictor on both the 2006 data alone and on the larger data set suggested that it tended to produce a relatively high proportion of false positive predictions. That is, there was a high proportion of weeks in which the risk scores were high and suggested that disease would occur or increase, but no increase was observed. Further inspection of the data indicated that the majority of these false positive predictions occurred early in the growing season, suggesting that they arose under conditions where there was suitable weather for infection but either no inoculum present or (and) no available infection sites on senescing leaves. In order to improve the predictive accuracy of the system, and on the basis of the observed disease progress data, a further set of rules was introduced to modify the risk prediction from the original weather-based system. These new rules were based on the quantitative risk factor described in the 2005 Annual Report. This Sclerotinia Development Risk Factor (SDRF, referred to as SRF in the 2005 Annual Report) combines canopy ground cover and indices for leaf senescence and crop lodging into a single index which is positively correlated with disease risk:

> SDRF = (proportion ground cover)+[(proportion ground cover)×(senescence index+lodging index)]

SDRF is essentially an index of crop development. It was noted that in crops in which SDRF was less than 1 in mid July no disease developed, while in crops in which SDRF reached or exceed 1 by mid July foliar blight could become severe. The observed data suggested that under conditions in which SDRF was less than 1 by July 14th no disease would occur the following 4 weeks. On this basis, an additional set of SDRF-based rules was added to the predictor to moderate the rain-based risk prediction described above. The SDRF-based rules are:

If SDRF<1 on July 14th then disease risk = 0 until after August 11th and then disease risk determined by rain-based week-ahead prediction
If SDRF ≥1 on July 14th disease risk determined by rain-based week-ahead prediction

The initial predictor was labelled –SDRF and the new predictor labelled +SDRF. +SDRF was tested against the 111 site/week data points and its performance compared with that of –SDRF using case/control methods which have recently been adapted from medical diagnostic scales evaluation into plant disease epidemiology (Yuen & Hughes, 2002; McRoberts *et al.*, 2003).

The rule base in +SDRF for predicting disease risk was incorporated in an expert system shell together with information derived from the 2005 trials in which a comparison of varietal resistance was conducted (see 2006 Annual Report). The expert system shell was constructed using the DEXi expert system shell software (http:/www.sji.si).

Disease-yield loss relationships 2004-2006.

Data from all three years of the project were used to examine the relationships between observed disease (both severity of foliar blight and incidence of root rot) on marketable yield. Combining all experiments in which disease and yield were measured, there were 35 different separate treatments available to derive the yield loss relationships. The analyses are conducted on the mean values for these 35 treatments. A straightforward data modelling exercise was carried out using Genstat interactively to model the relationships between marketable yield (yld, t/ha), sclerotinia foliar blight severity (sfb%), and sclerotinia root rot incidence (srr%).

Results and Discussion

2006 Fungicide/yield trials

Numbers of apothecia observed per quadrat and mean percentage foliar blight at both sites over time are shown in Figure 1 together with the percentage ground cover within the bed. It can be seen that disease occurred at a low level at both sites and never exceeding 1% diseased leaf area. Apothecia were more abundant and detected earlier at Cleeves than at Hall Hole. At Cleeves the peak mean density of apothecia was 0.5 apothecia per quadrat (or 1 apothecium every other quadrat on average) which was observed on July 28th. At Hall Hole the highest abundance of apothecia was observed on the 4th of August when the mean number per quadrat was 0.18 (or just under one for every five quadrats sampled. Note that in both crops the bulk of apothecia were produced before the crop canopy had reach 100% cover within the beds and was well short of full closure. However, disease symptoms were not observed until full canopy cover was reached.

The first fungicides were applied to the crops of either 14/07/06 (Cleeves) or 04/08/06 (Hall Hole). The timing of these applications in relation to canopy ground cover is indicated in Figure 2. At Cleeves the first application was made 6 weeks before full canopy closure, while at Hall Hole it was made 3 weeks before.

The initial analysis of the trial data indicated that there was a significant difference in disease levels between the two sites and that disease levels at Hall Hole were too low to allow differences between treatments to be detected. As a result the data for Cleeves were re-analysed separately and the results presented here refer to Cleeves only. Because of the low levels of disease in the trials, the data for disease severity were translated into disease incidence (*i.e.* presence/absence) and an additional analysis using an appropriate technique was used. Disease incidence (presence/absence) values were calculated from the severity assessments using a simple binary classification: incidence = 0 when severity = 0, incidence = 1 when severity > 0.

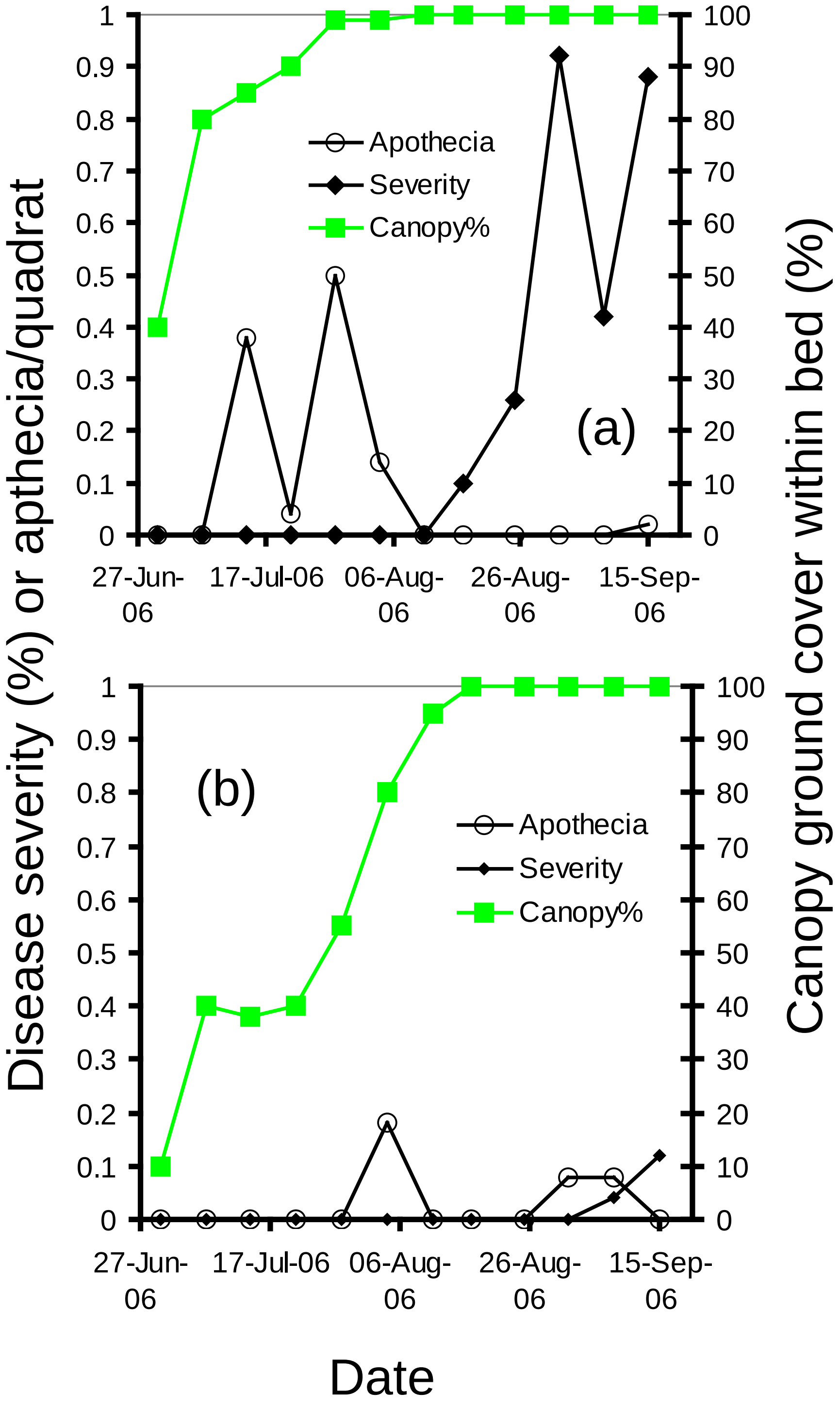

Figure 1. Apothecial abundance, disease severity and canopy development over time at (a) Cleeves and (b) Hall Hole (both Perthshire) in 2006.

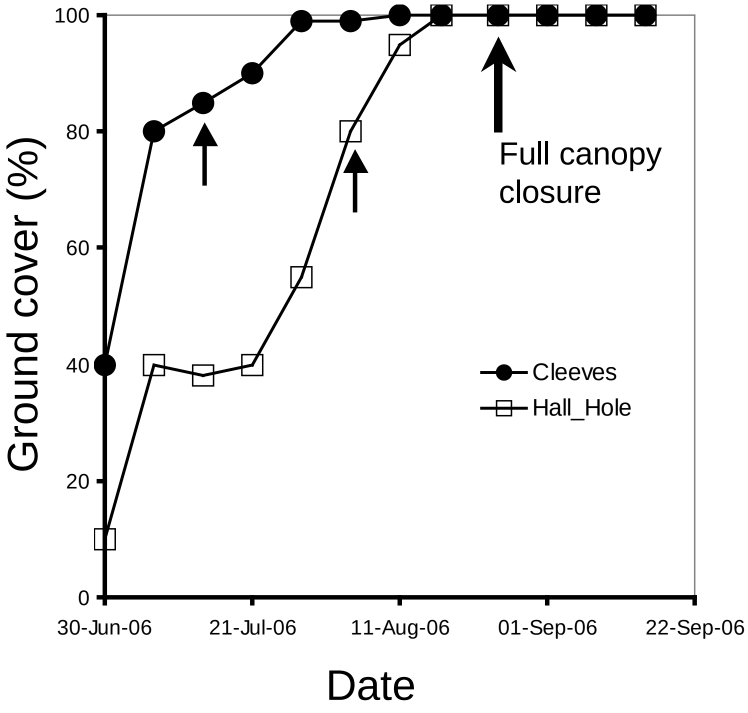

Figure 2. Canopy development and fungicide application programme initiation at Cleeves and Hall Hole in 2006. The smaller arrows indicate the dates of first fungicide application date at both sites, the larger arrow shows the date of full canopy closure.

Disease severity

Table 4 gives the observed average disease severity for each treatment at Cleeves, taking the average over two observation dates (25/08/06 and 15/09/06). The observed disease severity was significantly higher in the control treatment than in the fungicide treated controls, but there was no significant difference between the fungicide treatments.

Table 6. Mean disease severity (%) observed at Cleeves averaged over two observation dates.

Treatment						
Untreated	Folicur	BASF	KP	Predict	A9129B	A137036
0.63	0.02	0.12	0.21	0.01	0.01	0.01
s.e.d. = 0.144[1]						

[1] To be significantly different from one another, treatments need to differ by more than twice this value

Disease incidence

Table 6 gives the results of an analysis of the effect of fungicide treatment on the presence of disease incidence. The results of this analysis largely confirmed the analysis of the disease severity data. That is, there was evidence that disease was more likely to occur in the untreated plots than treated ones, but there was no evidence that the probability of finding disease differed among the various treatments.

Table 6 gives the marketable yields of roots from the trial plots at Hall Hole. Note that direct comparisons between the values in Tables 4 and 5 (disease) and Table 6 (yield) are not possible because the disease data were collected at Cleeves, while the yield data are from Hall Hole. Yield data could not be collected from Cleeves because the trial site was destroyed by flooding on December 2006. The data from Hall Hole are included in the yield loss analysis reported below.

Table 5. Foliar blight incidence (presence/absence) in plots of different fungicide treatments at Cleeves in 2006.

	Treatment						
	Untreated	Folicur	BASF	KP	Predict	A9129B	A137036
Logit	2.94	1.21	2.10	1.85	0.75	0.00	-2.94
s.e. (logit)[1]	1.12	1.20	1.85	1.14	1.27	1.45	1.02
Incidence[2] (%)	19.0	3.5	8.1	6.3	2.1	1.0	0.05

[1] The standard error (s.e.) of the logit value gives an idea of how accurately the effect of the fungicide has been estimated. Logits which differ by more than +/- their respective standard errors may indicate a significant effect.

[2] The incidence values back-transformed from the logits are the percentage of plots of each treatment in which disease was observed (e.g. diseased was observed in 19% or just less than one fifth of the untreated control plots).

Table 6. Mean marketable yield data (t/ha) for hand-dug plots at Hall Hole averaged over two harvest dates.

Treatment						
Control	Folicur	BASF	CPP	Predictor	A9129B	A137036
113.9	118.3	123.2	118.2	119.4	120.2	131.1
			s.e.d. = 6.81[1]			

[1] To be significantly different from one another, treatments need to differ by more than twice this value

The disease predictor treatment (-SDRF)

There was a problem with the beginning of the predictor treatment programme at Cleeves which resulted in two consecutive applications of Signum being made (on 14/07/06 and again on 28/07/06). The second of these treatments should have been a Folicur application. However, since we know that disease was absent from the crop until early August even in the untreated monitoring blocks (see Figure 1a) it is not likely that this mistake had a major effect on the subsequent relationship between the risk indicator scores and the dynamics of disease. Figure 3 shows the disease progress curve for Cleeves repeated from Figure 1, but with the risk categories recorded each week indicated by coloured blocks for each week.

Figure 3a shows the risk categories identified on the basis of the 5-day moving average rainfall intensity during the week in question using a “traffic light” system, where green = low, amber = moderate, and red = high. The sequence of risk levels starting on August 4th was low, moderate, moderate, moderate, high. The corresponding sequence (shown in Figure 3b) based only on the number of rain days was: moderate, high, high, high, high. Fungicide use decisions were based on the risk categories identified in Figure 3a. On the basis of the low and moderate risk categories recorded between August 4th and 25th, and the low level of disease present, no fungicide was applied to the predictor treatment during this period; other treatments received an application on August 25th. It can be seen that if the second risk score (based on rain days had been used) the sequence of risk scores would have been suggested the need for an application on August 25th.

Development of +SDRF

Figure 4 shows the values for number of rain days, rain intensity, SDRF and severity of foliar blight for the 8 field trials from 2004 to 2006. The trials in which severe blight developed are in the left-hand column of graphs, those in which severe blight did not develop are on the right. It can be seen that the values of SDRF increase faster and generally reach higher values in the graphs on the left than on those on the right indicating the correlation between severe disease and SDRF. It can also be seen that in the right-hand graphs the values of SDRF generally increase slowly over the early part of the season.

Based on the data sets from all three years, (111 weekly predictions) -SDRF produced 69% correct predictions while +SDRF produced 74% correct predictions. For the 2006 data alone (22 predictions), -SDRF produced 64% correct predictions and +SDRF produced 82% correct predictions. Figure 5 shows the relative performance of each predictor in a likelihood ratios graph (Biggerstaff, 1999). In figure 5a the true positive proportion [TPP] (*i.e.* the fraction of predictions that disease would increase in which disease was observed to increase) is plotted on the vertical axis while the horizontal axis plots the false positive proportion [FPP] (*i.e.* the proportion of predictions of disease increase which subsequently turned out to be wrong). Comparing the graphs for +SDRF and –SDRF it can be seen that +SDRF has a slightly lower TPP than –SDRF (0.92 versus 0.95) but a substantially lower FPP (0.48 versus 0.62).

The graphs for +SDRF and -SDRF in Figure 5a are composed of 2 sections. From the point (0,0) to the corner point on each graph, the gradient of the line section is given by TPP/FPP, and is the positive likelihood ratio (LR+) of the predictor. The gradient of the section of each graph from the corner point to the top right point (1,1) is given by (1-TPP)/(1-FPP) and is negative likelihood ratio of the predictor (LR-).

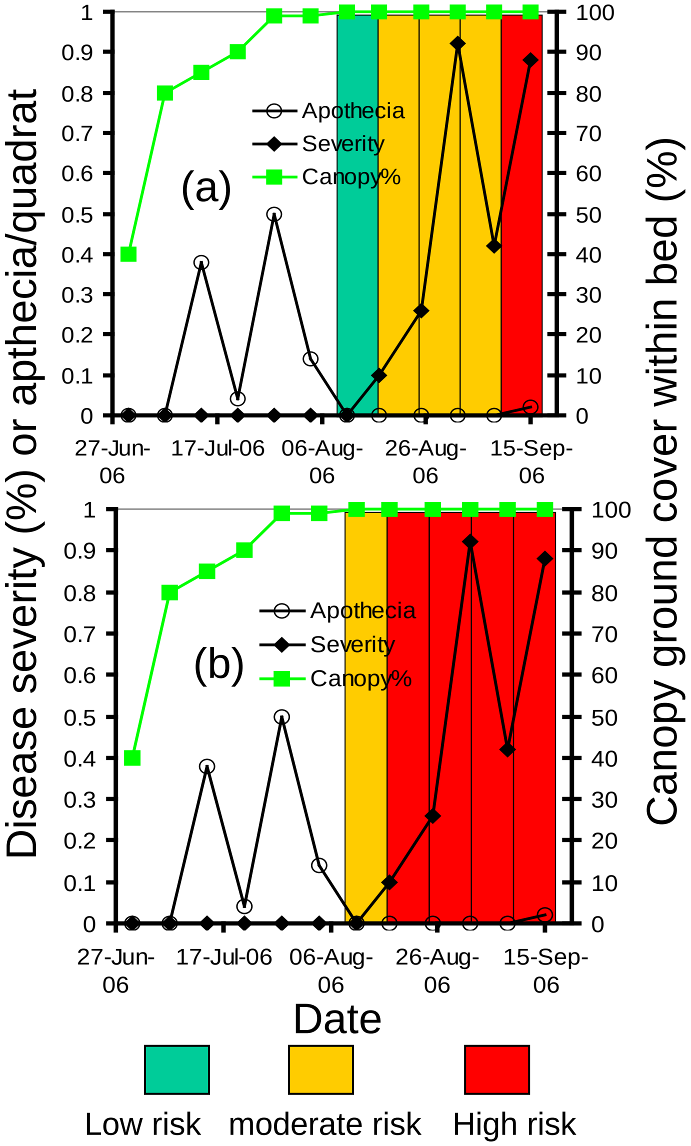

Figure 3. Disease risk scores in relation to disease progress at Cleeves. (a) Risk based on the moving average of daily rainfall intensity; (b) risk based on the number of rain days per week.

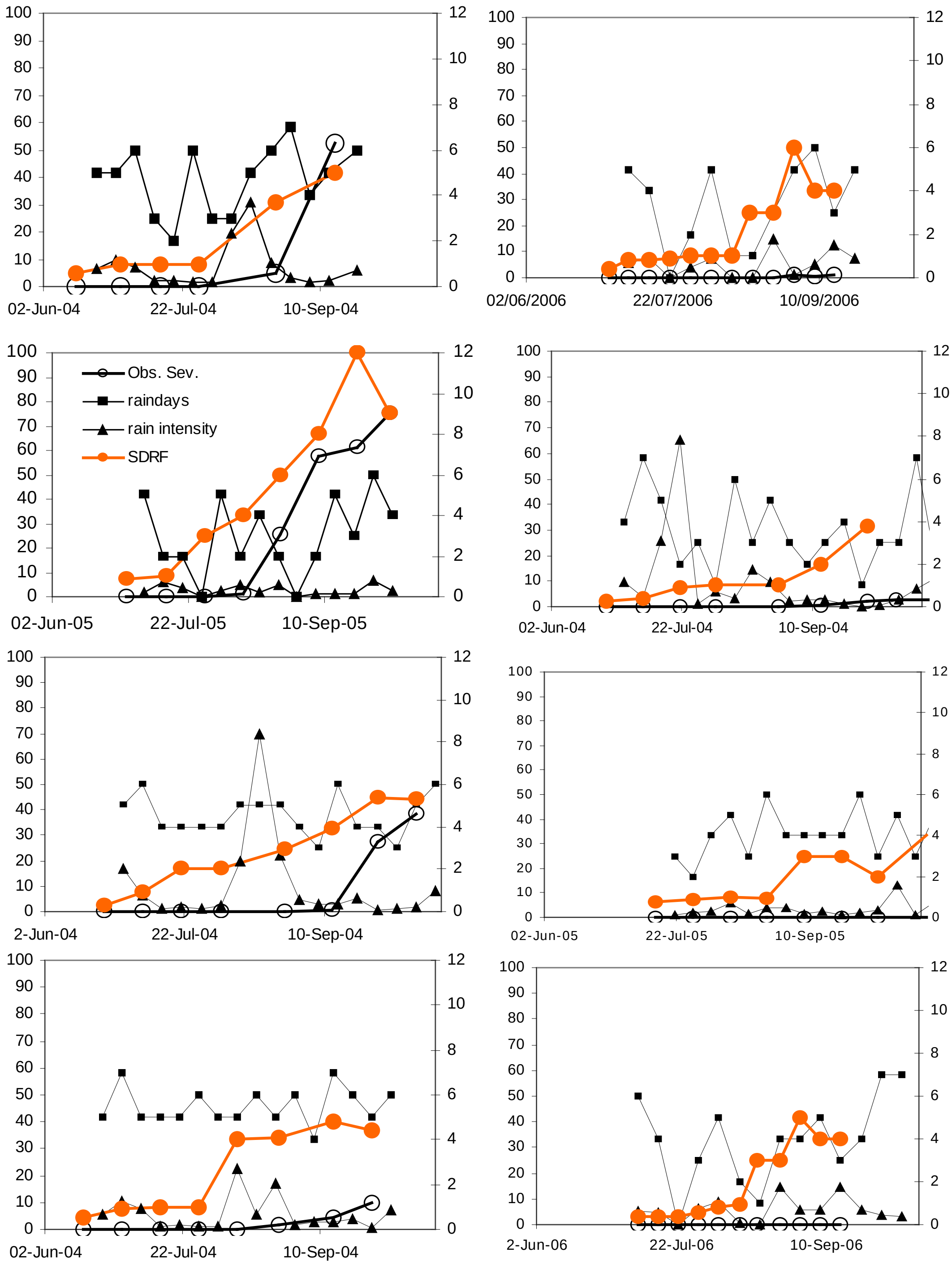

Figure 4. Values of variables in derived risk predictors and sclerotinia foliar blight severity for 8 trial sites used between 2004 and 2006. Disease severity is measured on the left hand scale and values for the number of rain days, the mean rain intensity per hour and the crop-related risk factor SDRF are measured on the right hand scale in each graph.

The LR+ and LR- for the predictors can be used to calculate how the probability of disease risk changes as a result of the prediction according to Bayes' rule for probability updating (Yuen & Hughes, 2002; McRoberts *et al.*, 2003). The simplest formulation of this rule expresses the updating in terms of odds:

$$\text{Odds(disease)}_{\text{post}} = \text{LR} \times \text{Odds(disease)}_{\text{prior}}$$

What the above equation says is that the odds of disease after (post) prediction are equal to the odds of disease before (prior) prediction multiplied by the appropriate likelihood. If the prediction is negative then LR- should be used and if the prediction is positive LR+ should be used. Since, for any uncertain event, the odds are a simple function of the probability, p, (odds = $p/(1-p)$), the equation can be used to produce a graph showing the extent to which the predictor should update a user's perception of the probability of disease increase given either a positive or negative prediction. These graphs are shown for both +SDRF and –SDRF in Figure 5b.

The example in Figure 5b shows that both predictors supply more information in making negative predictions than positive predictions. This is related to the fact that once foliar blight occurs it tends to increase, so many of the 111 weekly observations are auto-correlated and a positive prediction of disease will not be likely to supply a user with much information. On the other hand negative predictions of disease will tend to relate to rare events, so accurate predictions of low risk weeks supply the user with relatively large amounts of information. The thick diagonal line in Figure 5b shows all the possible values a user might have for the prior probability of disease from 0 (corresponding to a belief that disease increase is impossible) to 1 (disease increase believed to be certain). In the example given in Figure 5b, it is assumed that the user is maximally uncertain about the disease risk for the week and thus has a prior probability of 0.5. The posterior probabilities for the user for each predictor can be obtained by tracing across to the vertical axis from the points where the dashed vertical line crosses the curves for each predictor. The posterior values for negative predictions (i.e predictions of no increase in disease risk) are given by the curves below the diagonal, while those above the diagonal give the values for positive predictions of risk increase. The further the curves are from the diagonal line, the more the predictors ought to change the prior belief of the user.

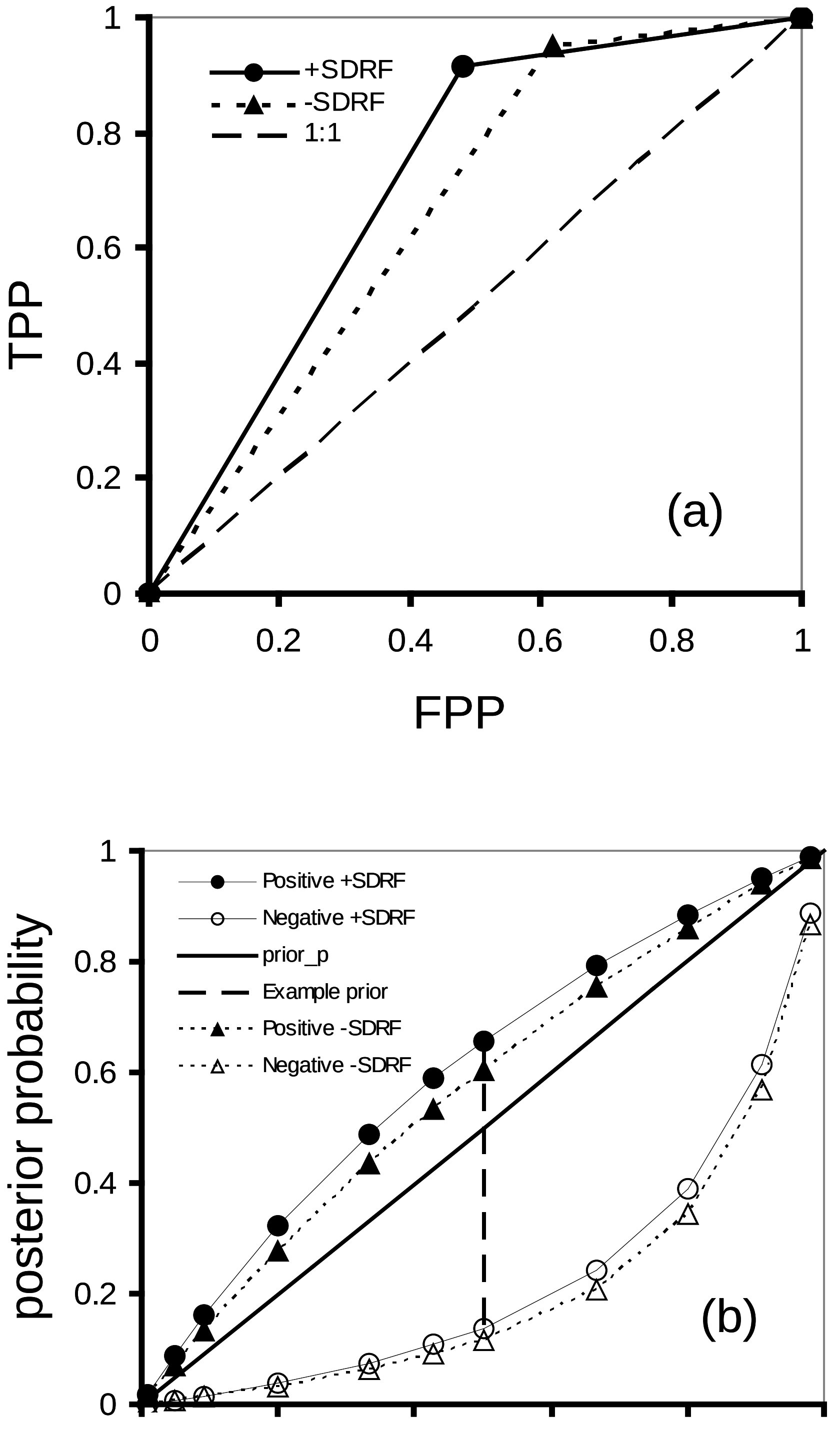

Figure 5. (a) The likelihood ratio graphs for two sclerotinia risk predictors for carrot foliar blight. (b) The probability updating functions of the risk predictors assuming that probability updating occurs according to Bayes' theorem.

To expand on the example, assume that the user is maximally uncertain about the probability that disease risk will increase next week. This is indicated by a prior probability of 0.5 (*i.e.* the probability of increase is equal to the probability of no increase). If we assume that either predictor gives a negative prediction we can see that the posterior probability will be in the region of 0.1 (*i.e.* if the predictors predict no increase in risk, a users whose prior belief was that the probability of disease increase was 0.5, should now consider that the chances of an increase in disease are only one in ten). The exact values for the negative predictions from –SDR and +SDRF in the example are 0.12 and 0.14 respectively.

Implementation of +SDRF in a expert system shell

The rules included in +SDRF were combined with information on the relative effect of varietal canopy variation in an expert system shell using the DEXi software system (http://www-ai.ijs.si/MarkoBohanec/dex.html). Briefly, DEXi allows the model builder to construct hierarchical influence models for a particular feature of the world (in this case risk of sclerotinia foliar blight) by building a rule base. Once constructed, the rule base can be interrogated identify which factors have the biggest influence on the subject of the investigation. A full listing of the model description and the analysis report from the model are given in Appendix 1. A brief summary of the results is given here.

Three basic sets of influences on disease risk were included in the model: (1) crop factors (variety (open or dense canopy) and SDRF); (2) weather factors (rain incidence and intensity); (3) pathogen factors (disease already present/disease absent). Analysis of the rule base in the expert system suggested that the weighting of these factors in determining the risk of disease increase was: Crop factors 57.9%, weather factors 19.3% and pathogen factors 23%. The DEXi model should be viewed as an overall encapsulation of the state of knowledge on factors influencing sclerotinia risk as a result of all three years of work in project FV260.

The rule base in the DEXi model of sclerotinia risk contains 18 possible combinations of the underlying factors determining risk. Interrogation of the model revealed that these 18 combinations specified 7 unique rules for the overall risk of sclerotinia foliar blight development; these are listed in Table 7.

Table 7. Expert system rules specifying the risk of sclerotinia foliar blight based on crop, weather and pathogen factors.

	Crop Factor (52%)	Weather Factor (17%)	Pathogen Factor (31%)	Disease Risk
Rule				
1	Low	≤ Moderate	*Any*	Low
2	Low	High	*Any*	Moderate
3	≤ Moderate	High	Absent	Moderate
4	Moderate	*Any*[1]	Absent	Moderate
5	≥ Moderate	Low	Absent	Moderate
6	≥ Moderate	*Any*	Present	High
7	High	≥ Moderate	*Any*	High

[1] Any value of the factor gives rise to the same value of Disease Risk, given the values of the other factors

When the crop risk factor is low the overall risk of disease is either low or moderate depending on weather but does not depend on the presence/absence of the pathogen. When the crop risk factor is moderate disease risk will be moderate or high depending on the weather and presence/absence of the pathogen: If the pathogen is present in combination with moderate or high crop risk, overall risk is high irrespective of rainfall. Similarly, rainfall generating a moderate or high risk in combination with a high crop risk score will result in an overall high disease risk irrespective of the presence/absence of the pathogen; other combinations of weather and pathogen factors in combination with moderate crop risk result in a moderate overall risk of disease.

Modelling disease-yield loss relationships

Despite inclusive results in the trials in 2006 and 2005, it was possible to derive fairly robust disease-yield loss relationships using the data from all three years of the project. Regression analysis was used to derive these relationships. In the initial analysis both foliar blight severity (sfb%) and root disease incidence (srr%) were used in a multiple linear regression model to explain observed yield loss. The estimated parameters in this model (results not shown) indicated sfb% was a better predictor of yield loss alone than when used in conjunction with srr%. Accordingly, the two disease variables were used separately to model yield loss, resulting in two yield loss models. The best model for sfb% was found to be a negative exponential function, while for srr% was negative and linear. The observed data and fitted models are shown in Figure 6a and 6b. The estimated parameters of the models and information on model fitting are listed in Appendix 2.

The estimated model for yield (Yld, marketable t/ha) as a function of foliar blight was:

$$\text{Yld} = 72.88 + (44.65\times(0.9439^{\text{sfb\%}})$$

For srr% the estimated model was:

$$\text{Yld} = 120.96 - 0.927\times\text{srr\%}$$

The model based on foliar blight severity predicted a marketable yield of 117t/ha when disease was absent, while the model based on root rot predicted a yield of 121t/ha in the absence of disease. However, it should be noted that the model based on sfb% had a higher overall fit to the observed yield data (76% of variance explained versus 39% of variance explained for srr%). Both models indicate that control of disease at low levels is likely to be cost effective and that substantial financial losses will occur even at moderate levels of disease.

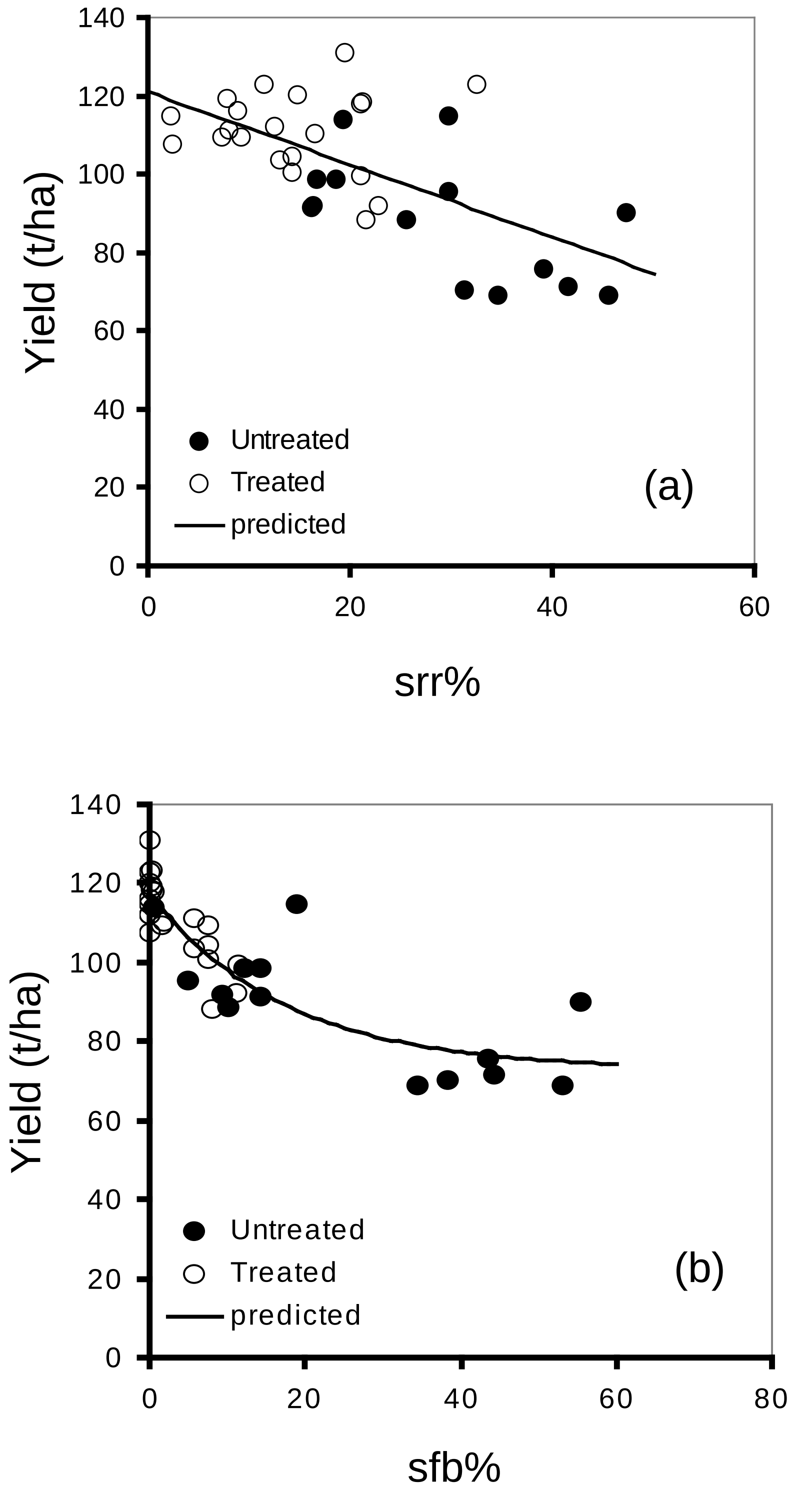

Figure 7 (a) observed data and fitted model for the relationship between sclerotinia root rot incidence and marketable yield based on 35 treatment mean values from 3 years of field experiments. (b) the equivalent disease-yield relationship for sclerotinia foliar blight.

Conclusions

Based on all three years of the project the following key conclusions can be reached:

- The key factor in determining the severity of sclerotinia disease is the relative state of the crop and the behaviour of the pathogen in the key period in the weeks around canopy reaching 100% ground cover within the beds. Note this slightly earlier than the key time point of complete canopy closure which was highlighted in earlier reports.

- Two key factors around this time have a major impact on the probability of severe disease.
    - Canopy development stage
    - Pathogen germination

- The effects of these two factors are then modulated by other variables
    - Weather conditions
    - Fungicide application
    - Cropping history

- If the value of SDRF reaches 1 or more at the time when the main flush of pathogen germination takes place (in the sites used in FV260 this was typically mid July to mid August) the crop is at high risk of disease. Crops with SDRF less than 1 will have a lower risk of disease and may escape significant foliar blight even without fungicide application.
- Protective fungicides applied before full canopy ground cover and followed up with repeat sprays will provide effective protection from sclerotinia foliar blight. Generally in the three years of trials, there was little difference in the performance of the different fungicides tested, although programmes which include either Amistar or Signum in rotation or mixture with other suitable products to reduce the risk of fungicide resistance were routinely effective.

- The relationship between yield loss and foliar blight severity appears to be a negative exponential curve so that proportionally more yield loss occurs for each incremental increase in disease at low disease levels than at high disease levels. This emphasises the desirability for control of disease at low levels.
- The observation that quite high levels of root rot can occur even when foliar blight is at low levels further emphasises the need for good disease management. Further work is needed to understand the relationship between disease levels observed in the crop before strawing down, and root disease levels observed when roots are lifted after different intervals of time.
- Under conditions of relatively low disease pressure and where early season canopy protection has been applied in good time, there may be some scope for determining the timing of subsequent sprays using a risk prediction system.
- The system developed in this project allow the prediction treatment to obtain similar yields to the other treatments with one less spray. However, 2006 was a particularly low disease year until late autumn and further evaluation of the system would be recommended before it is advocated among growers.

Technology Transfer

An article summarising the key findings from the project will be published in the June/July 2006 issue of HDC News. This article will also contain a comparison of the situation in the UK with that in Canada thanks to exchanges between Dr McRoberts and Canadian colleagues. A general overview of the disease, and key findings from the the project was presented at the Carrot growers Technical Briefing, Peterborough in January 2007. The data on sclerotinia germination and weather from 2004 and 2005 have been passed to Dr John Clarkson at Warwick HRI to be used in the development of a predictive system for sclerotinia germination in project FV294.

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Appendix 1. DEXi expert system model for sclerotinia foliar blight: Model rules and outputs

DEXi 06/07/2007 Page 1

Tree of attributes

Attribute	**Description**
Disease Risk	Overall rating of disease risk status of crop
├**Crop factor**	Combined risk from canopy type and crop development factors
│├Variety	Open or dense canopy type
│└SDRF	Crop develoment risk factor
├**Weather factor**	Combined risk from rain incidence and intensity
│├Raindays	Risk related to frequency of days with rain
│└Rain intensity	Risk related to intensity of rainfall
└Pathogen factor	Risk related to presece/absence of disease in crop

Scales

Attribute	**Scale**
Disease Risk	***low***; moderate; **high**
├**Crop factor**	***low***; moderate; **high**
│├Variety	***open canopy***; **dense canopy**
│└SDRF	***below threshold***; **at/above threshold**
├**Weather factor**	***low***; moderate; **high**
│├Raindays	***low***; moderate; **high**
│└Rain intensity	***low***; moderate; **high**
└Pathogen factor	***absent***; **present**

Disease Risk

Overall rating of disease risk status of crop

1. ***low***
2. moderate
3. **high**

Crop factor

Combined risk from canopy type and crop development factors

1. ***low***
2. moderate
3. **high**

Variety

Open or dense canopy type

1. ***open canopy***
2. **dense canopy**

SDRF

Crop develoment risk factor

1. ***below threshold***
2. **at/above threshold**

Weather factor

Combined risk from rain incidence and intensity

1. ***low***
2. moderate
3. **high**

Raindays

Risk related to frequency of days with rain

1. ***low***
2. moderate
3. **high**

Rain intensity

Risk related to intensity of rainfall

1. ***low***
2. moderate
3. **high**

Pathogen factor

Risk related to presece/absence of disease in crop

1. ***absent***
2. **present**

Decision rules (table)

	Crop factor	Weather factor	Pathogen factor	Disease Risk
	52%	17%	31%	
1	***low***	<=moderate	*	***low***
2	***low***	**high**	*	moderate
3	<=moderate	**high**	***absent***	moderate
4	moderate	*	***absent***	moderate
5	>=moderate	***low***	***absent***	moderate
6	>=moderate	*	**present**	**high**
7	**high**	>=moderate	*	**high**

	Variety	SDRF	Crop factor
	25%	75%	
1	*	***below threshold***	***low***
2	***open canopy***	**at/above threshold**	moderate
3	**dense canopy**	**at/above threshold**	**high**

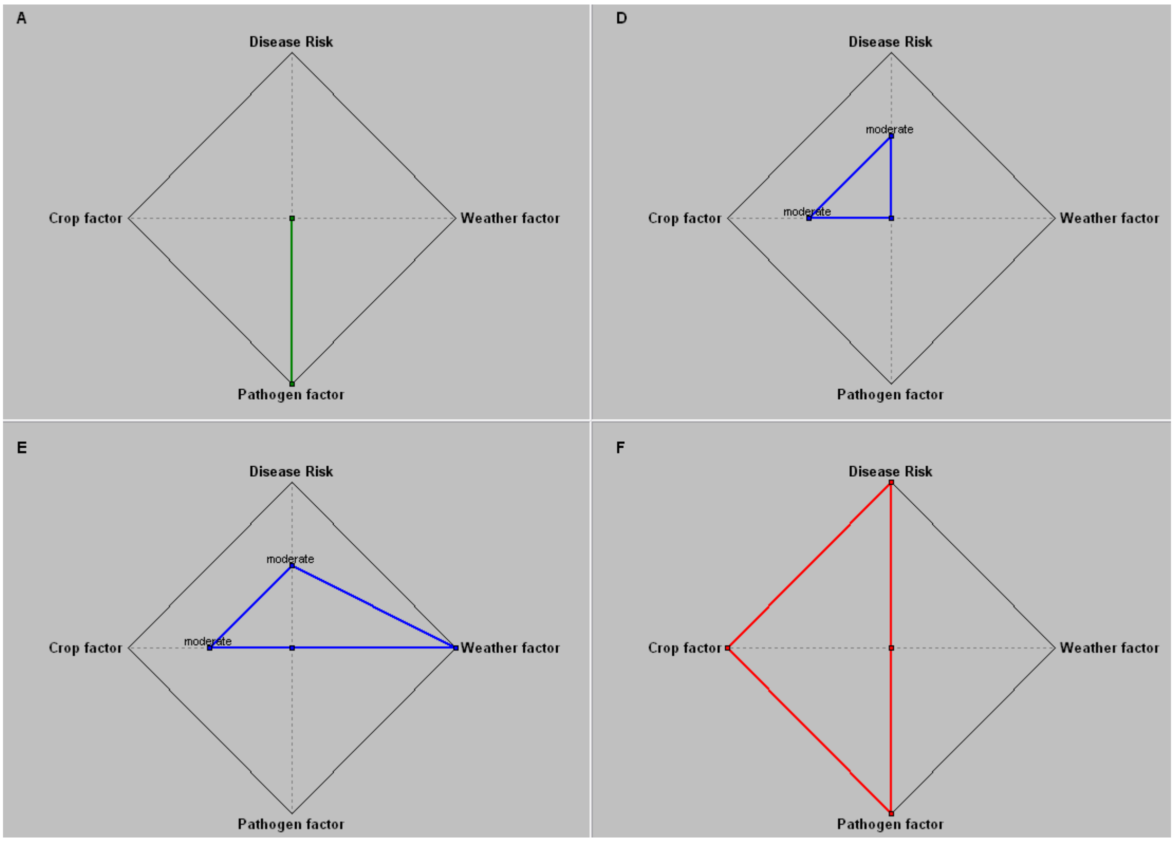
	Raindays	Rain intensity	Weather factor
	43%	57%	
1	<=moderate	***low***	***low***
2	***low***	moderate	moderate
3	*	**high**	**high**
4	>=moderate	>=moderate	**high**
5	**high**	*	**high**

Average weights

Attribute	Local	Global	Loc.norm.	Glob.norm.
Disease Risk				
Crop factor	51.9	51.9	57.9	57.9
Variety	25.0	13.0	25.0	14.5
SDRF	75.0	38.9	75.0	43.4
Weather factor	17.3	17.3	19.3	19.3
Raindays	42.9	7.4	42.9	8.3
Rain intensity	57.1	9.9	57.1	11.0
Pathogen factor	30.8	30.8	22.9	22.9

Evaluation results

Attribute	A	D	E	F
Disease Risk	***low***	***low***	moderate	**high**
Crop factor	***low***	***low***	***low***	**high**
Variety	***open canopy***	**dense canopy**	**dense canopy**	**dense canopy**
SDRF	***below threshold***	***below threshold***	***below threshold***	**at/above threshold**
Weather factor	***low***	***low***	**high**	***low***
Raindays	***low***	***low***	***low***	***low***
Rain intensity	***low***	***low***	**high**	***low***
Pathogen factor	**present**	**present**	***absent***	**present**


A
Disease Risk
Crop factor
Weather factor
Pathogen factor
D
Disease Risk
moderate
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moderate
Crop factor
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Weather factor
Pathogen factor
F
Disease Risk
Crop factor
Weather factor
Pathogen factor

Appendix 2. Results from regression analyses to derive yield loss models

```
Model for sfb%
Nonlinear regression analysis

Response variate:    yld
  Explanatory:  sfb%
 Fitted Curve:  A + B*(R**X)
   Constraints:  R < 1


Summary of analysis

Source    d.f.        s.s.       m.s.     v.r. F pr.
Regression 2     7480.  3740.12  54.18<.001
Residual  32     2209.     69.04
Total       34     9689.   284.98

Percentage variance accounted for 75.8
Standard error of observations is estimated to be 8.31.

Message: the following units have large standardized residuals.
        UnitResponseResidual
            7    114.70      3.37

Message: the following units have high leverage.
        UnitResponseLeverage
          12      68.90     0.226
          13      90.00     0.243


Estimates of parameters

Parameterestimate       s.e.
R              0.9439    0.0165
B                44.65       5.63
A                72.88       5.66


Accumulated analysis of variance

Change       d.f.        s.s.       m.s.      v.r.  F pr.
+ sfb%           2  7480.24  3740.12  54.18<.001
Residual        32  2209.16      69.04
Total           34  9689.40    284.98

                     41                fit [pr=m,s,e,a; fprob=y; tprob=y] src%
```

Model for srr%

Regression analysis

```
Response variate:     yld
  Fitted terms:   Constant, srr%
```

Summary of analysis

```
Source    d.f.        s.s.        m.s.      v.r. F pr.
Regression 1     3946.    3946.3   22.68<.001
Residual  33     5743.     174.0
Total       34     9689.     285.0
```

```
Percentage variance accounted for 38.9
Standard error of observations is estimated to be 13.2.
```

Message: the following units have large standardized residuals.

```
        UnitResponseResidual
          16      123.0       2.51
          22      131.1       2.17
```

Message: the following units have high leverage.

```
        UnitResponseLeverage
            9       71.4     0.125
          12       68.9     0.167
          13       90.0     0.186
```

Estimates of parameters

```
Parameterestimate       s.e.    t(33)  t pr.
Constant   120.96       4.55   26.56<.001
srr%            -0.927      0.195    -4.76<.001
```

Accumulated analysis of variance

```
Change        d.f.         s.s.        m.s.      v.r.  F pr.
+ srr%              1    3946.3    3946.3   22.68<.001
Residual        33    5743.0      174.0
Total     34       9689.4            285.0
```