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DECISION MODELS FOR THE INTEGRATED USE OF FUNGICIDES ON WHEAT

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Edited
by

N D PAVELEY
(on behalf of the collaborating group)

ADAS High Mowthorpe, Duggleby, Malton,
North Yorkshire YO17 8BP

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Project co-ordinator

Dr N D Paveley
ADAS High Mowthorpe, Duggleby, Malton, North Yorkshire, YO17 8BP

Research collaborators

Bayer plc, Eastern Way, Bury St Edmunds, Suffolk, IP32 7AH

Dr H Schramm
Dr H Schmeer
Mr D Morris

CSL, Sand Hutton, York, YO4 1LZ

Dr M J Hims
Mr R Leach
Dr D Anderson

IACR Long Ashton, Long Ashton, Bristol, BS18 9AF

Dr D Royle
Mr D Lovell
Mr R Coker

Morley Research Centre, Morley, Wymondham, Norfolk, NR18 9DB

Mr R J Cook
Mr M Nuttall
Mr R Hindley

SAC Aberdeen, The Ferguson Building, Craibstone Estate, Bucksburn, Aberdeen, AB21 9YA.

Dr S Wale
Mrs K Sutherland

Technical University of Munich, Department of Phytopathology, Weihenstephan, 85350, Freising, Germany.

Dr U Schoefl

Abstract

Downward pressure on the unit cost of wheat production requires that fungicides should be applied only where an economic return will result. Several decision models have been devised, in the UK and Europe, to allow growers to assess the risk of disease development and hence, tailor fungicide inputs to disease pressure. Field experiments, at six sites in three seasons, tested decision models on varieties of contrasting resistance, under varying pressure from *Septoria tritici* and powdery mildew. The models tested were: the Bayer Cereal Diagnostic System, the Long Ashton Splashmeter, ADAS Managed Disease Control and a developmental Integrated Disease Risk (IDR) system (the last, designed to the support the use of appropriate fungicide doses). Untreated controls and prophylactic one- and three-spray programmes were also included. Measures of disease control, yield, grain quality and fungicide input costs allowed the performance of systems to be assessed. The main findings of the project are summarised below.

- Disease control and fungicide input costs achieved by the decision models were compared against those achieved in commercial practice, using disease survey data. The results suggest substantial potential for improvement in unit cost, if decisions could be based on better intelligence of disease risk.
- Prophylactic programmes can be devised, which produce a net benefit across a range of sites and seasons. However, such programmes have to over-apply on average, in order to prevent occasional severe losses under high disease pressure.
- Combining assessments of inoculum, weather, host resistance and the sensitivity of the crop to disease, provided a robust quantification of disease risk which could be used to guide fungicide dose decisions. However, the complexity of combining risk factors in order to improve precision, conflicts with the need for simplicity of operation on-farm.
- Decision models for individual diseases are inappropriate for commercial use and need to be combined, so that decisions are optimised simultaneously for all the major foliar diseases. Interactions with stem-base and ear diseases also need to be taken into account. Furthermore, disease control decisions form only part of the crop management complex.

It was concluded that disease control decision models would be implemented most effectively as a component of a computer-based modular system, covering a range of cropping decisions. Such a system should be implemented as a support to, rather than a replacement for, current methods of technology transfer and decision making, and could act as a direct route for transfer of future improvements in disease risk assessment to the industry.

CONTENTS

OBJECTIVES

To evaluate decision models for the integrated use of fungicides against foliar pathogens of wheat.

To identify and integrate the most valuable elements from each system in order to derive and test improved decision systems.

To generate in-crop weather and disease progress data to aid development and validation of improved decision models.

INTRODUCTION

Economic pressures require new knowledge to be effectively exploited in industry practice, in order to reduce the unit cost of cereal production. Rationalising the use of variable inputs such as foliar fungicides could make an important contribution to this process and, in so doing, lessen the concern about their real or perceived environmental effects. During the past decades, research on the epidemiology of cereal foliar pathogens has increased understanding of the factors determining disease progress and the effects of disease on yield. Similarly, the development of new, more active, fungicides has been accompanied by research to quantify their eradicant and protectant properties, and their interactions with crop and epidemic development (Griffin, 1994). This research, more recently, has indicated that, if timed accurately to coincide with critical stages in host and epidemic development, fungicidal sprays can be effective when the active ingredient is delivered at a dose smaller than that recommended by the manufacturer (Paveley et al., 1995).

Several systems have been devised to support cereal disease control decisions. Many of these claim to have improved the level of technical expertise of those growers and advisers who have used them; but their sustained impact within EU cereal production remains small (Forrer, 1992). The work described here was commissioned by the Home-Grown Cereals Authority, Bayer plc and the Ministry of Agriculture, Fisheries and Food in order to evaluate leading decision support systems used in the UK for cereal disease control, to quantify the potential benefits from their use and to further inform the evaluation and development of improved systems.

METHODS

Experiments were completed in the seasons 91/92, 92/93 and 93/94 on crops of winter wheat. The target diseases chosen to test the systems were mildew (*Erysiphe graminis)* and leaf blotch caused by *Septoria tritici*, the two most economically damaging foliar diseases of wheat (Polley and Thomas, 1991). Combinations of varieties and locations were designed to achieve a range of levels of host resistance and disease pressure sufficient to test the ability of the decision models to match fungicide inputs to disease risk. (Table 1). The susceptible cultivar Riband was used to test the *S. tritici* models in trials at Morley Research Centre (MRC), Long Ashton Research Station (LARS) and Bayer Elm Farm Development Station (EFDS) in 91/92. In 92/93 the more resistant cultivar Beaver was included together with a fourth site at ADAS Terrington. These *S. tritici* trials were repeated in 93/94 at Terrington, Morley and Long Ashton. Mildew trials were completed on the susceptible cultivar Apollo in 91/92 at Terrington, Bayer Elm Farm and at a site managed by the Central Science Laboratory, Harpenden (CSL). The mildew-resistant cultivar Hereward was included in 92/93 at Terrington, CSL, Elm Farm and also at the Scottish Agricultural College, Aberdeen (SAC). In 93/94 these mildew trials were repeated at Terrington, CSL and SAC.

Table 1. Summary of cultivars and sites

	ADAS			MRC			LARS			EFDS	
	91/92	92/93	93/94	91/92	92/93	93/94	91/92	92/93	93/94	91/92	92/93
Riband		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Beaver		✓	✓		✓	✓		✓	✓		✓
					CSL			SAC			
Apollo	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓
Hereward		✓	✓		✓	✓		✓	✓		✓

Treatments

Four decision support models were used to determine the need for fungicide sprays to field-plots. These models were:-

(i) ADAS Managed Disease Control (MDC); a decision tree system based on disease severity at particular critical growth stages, weather records, cultivar and the time elapsed since previous sprays were applied; used for both mildew and *S. tritici* (Anon., 1986)

(ii) Bayer Cereal Diagnostic System (CDS); based on disease threshold values; used for both mildew and *S. tritici* (Anon., 1991; Vereet, 1995).

(iii) LARS Splashmeter; *S. tritici* only. The system monitors rainfall for its ability to distribute spores from the lower to the upper leaves and integrates such dispersal events into a decision tree system based on inoculum, growth stage and dew (Royle 1990).

(iv) Integrated Disease Risk (IDR); mildew and *S. tritici*; a developmental system to estimate a variable threshold of disease risk based on cultivar susceptibility, inoculum, weather and crop sensitivity, using these factors to recommend an appropriate dose of fungicide (Paveley, 1993). Further development of the system is ongoing using data from experiments started in 1994.

Details of these four models are summarised in Appendix 1. The models were tested against prophylactic treatments, namely a single spray of fungicide applied on 20 May or GS39, (Tottman, 1987) whichever was the later, a three-spray programme based on a spray applied at GS32/33, 39 and 59, untreated plots and plots treated according to a combination of some of the components of each of the four main decision models. The range of treatments was further expanded for *S. tritici* and mildew experiments respectively by using sprays of chlorothalonil and fenpropidin to artificially reduce inoculum levels on otherwise untreated plots, the Bayer CDS mildew and *S. tritici* treatments and the ADAS MDC mildew treatment. The aim of these treatments was to investigate the effect of variation in initial inoculum on subsequent disease development and to test the system's responses to the potentially reduced risk. All experiments where the target disease was mildew were oversprayed with the fungicide UK152 at the rate of 1 l ha^{-1} at GS37 and GS59, to suppress *S. tritici*.

Consequently, a second control without the UK152 overspray was incorporated to measure the effect of the overspray, to ensure that it did not interfere with the natural development of the mildew epidemics. The fungicides used to control the target diseases were the conazole tebuconazole (as the c.p. 'Folicur') in the case of *S. tritici* ,and the morpholine fenpropidin (as the c.p. 'Patrol') in the case of mildew. The Bayer CDS treatment was duplicated to allow a comparison of the triazole spray alone, and a spray incorporating both the triazole and the morpholine. All spray applications were made in approximately 250 l ha^{-1} of water using 110° flat fan nozzles with a medium spray quality as defined by the British Crop Protection Council. Tables 2 and 3 summarise the treatments applied in the *S. tritici* and mildew experiments respectively.

Table 2. Treatments applied at *S. tritici* target sites.

Treatment number Riband	Beaver	Spray criteria/fungicide treatment	Abbreviated title
1	1	Untreated	Unt
2	2	Untreated + inoculum suppression	Unt/sup
3	3	ADAS MDC (*S. tritici* elements only)	MDC
4	4	Bayer CDS (*S. tritici* elements only)	CDS
5	5	Bayer CDS + low inoculum	CDS/sup
6	6	LARS splashmeter based system	LARS
7	7	Single spray daylength/GS related*	1 spray
8	8	Three spray programme GS32 + 39 + 59	3 sprays
9	9	CDS + retrospective MDC splash criteria	CDS + MDC
10	10	CDS + MDC splash criteria for 2nd spray in 92/93 & 93/94 CDA + LARS splash criteria in 1991/92	CDS + splash
11	11	IDR developmental spray	IDR

* Single spray applied on 20 May or GS39, whichever was the later.
low inoculum = inoculum level artificially reduced by four applications of chlorothalonil (as the c.p. 'Bravo 500')from the beginning of February to the end of March.
Fungicide - Tebuconazole as the c.p. 'Folicur' at 1.0 l ha^{-1}.

In 1991/92, plots were laid out in randomised blocks with four replicates. In 1992/93 and 1993/94, when resistant cultivars were introduced, effectively doubling the number of treatments, the two cultivars were in adjacent randomised blocks, replicated three times. Statistical analysis was by analysis of variance with treatment means distinguished by LSD with 95% confidence. Plots were a minimum of 3 m wide and 12 m long.

Table 3. Treatments applied at mildew target sites.

Treatment number			Abbreviated
Apollo	Hereward	Spray criteria/fungicide treatment	title
1	1	Untreated	Unt
2	2	Untreated without UK152 overspray	Unt/minus
3	3	Untreated + inoculum suppression	Unt/sup
4	4	ADAS MDC (mildew elements only)	MDC
5	5	ADAS MDC + inoculum suppression (mildew elements only)	MDC/sup
6	6	BAYER CDS (mildew elements only)	CDS
7	7	BAYER CDS + IOI based second spray (mildew elements only) [BAYER CDS + inoculum suppression in 1991/92]	CDS mod
8	8	BAYER CDS with triazole additional to morpholine (mildew elements only)	CDS + triaz
9	9	BAYER CDS with triazole additional to morpholine + IOI based second spray (mildew elements only) [BAYER CDS + inoculum suppressionin 1991/92]	CDS mod + triaz
10	10	Single spray daylength/GS related*	1 spray
11	11	Three spray programme GS32/33 + 39 + 59	3 sprays
12	12	MDC low threshold **	MDC/low
13	13	MDC high threshold **	MDC/high
14	14	IDR developmental system	IDR

* single spray applied on 20 May or GS38 whichever is the later.
** Defined in Appendix 1.

Low inoculum - inoculum level artificially reduced by a single spray of fenpropidin (as the c.p. 'Patrol')at the end of March.

IOI - incidence of infection

Fungicide - 1.0 l ha^{-1} fenpropidin (as the c.p. 'Patrol'). Treatments 8 and 9 received 0.5 l ha^{-1} Patrol with additional tebuconazole (as the c.p. 'Folicur') at 0.75 l ha^{-1}.

All plots except treatment 2 were oversprayed with UK152 at 2.0 l ha^{-1} at GS37 and GS59 to suppress *S. tritici*.

Treatment decisions

To ensure that the various models under test were consistently interpreted and decisions consistently applied across sites, each site manager provided an ADAS and Bayer co-ordinator, by FAX, each week during the growing season, with a spreadsheet of the latest week's disease assessment, crop development and meteorological data. Co-ordinators interpreted these data according to the criteria demanded by their decision support models and, by return FAX, communicated the required treatments to site managers. Decisions for the LARS splashmeter system were made each week by site managers according to the guidelines at Appendix 1.

Disease assessments

All foliar diseases and green leaf area were assessed weekly on each of ten randomly selected tillers per plot in all replicates from GS31 to GS85. Early in the season, to conserve resources, single treatments representative of treatments dealt with identically up to the date of assessment were assessed. After GS39, or when >50% of plots of any cultivar in a trial had received different treatments, all plots in the trial were assessed on each assessment date.

In trials targeted at *S. tritici*, all leaves from the leaf layer below the lowest layer assessable for severity were assessed for incidence and those from treatments 1, 2, 12 and 13 in 92/93, and treatment 1 only in 93/94, were sampled for pycnidia counts. *S. tritici* inoculum was assessed by washing leaves from treatments 2 and 5 at the time of first application and after the final application of chlorothalonil; treatment 6 (LARS splashmeter) was also sampled for inoculum after the final chlorothalonil spray. In 92/93 and 93/94, leaves bearing lesions were taken from treatment 1 for *S. tritici* ecotype analysis at IACR Long Ashton.

At the mildew target sites, the first threshold in the Bayer CDS decision system demanded that infection of plants as well as tillers be recorded on each assessment date until all of the four CDS treatments had been applied.

Diseases on the ear at GS85 and the stem base at GS31 and 75 were also recorded, to enable any incidental effects of treatments on ear and stem base diseases to be accounted for in the interpretation of yield responses.

Protocols for all disease assessments, leaf number determination, chlorothalonil analysis (92/93 only), tiller counts, soil sampling, meteorological data and data-presentation are detailed in Appendix 2.

Leaf numbers are referred to numbered down the plant from the flag leaf (F), down to leaf 2 (F-1), leaf 3 (F-2), etc.

RESULTS

Details of treatment dates generated by the decision support models under test, assessment dates, growth stages, yield components, meteorological data and disease development are given in the annual site reports in Appendix 3. The main body of the report below contains summarised information, extracted from the appendices for ease of reference.

Target disease *Septoria tritici*

Dates of sprays recommended by the models under test are summarised in table 4.

<u>ADAS Terrington</u>

At the 92/93 harvest, on both Riband and Beaver, high yields were recorded for treatments 3, 8 and 11 (MDC, 3-spray programme and IDR respectively) with treatment 6 (LARS splashmeter) also being high for Beaver (Table 5). In 93/94, all treatments except treatment 5 (CDS low inoculum) produced higher yields than the two unsprayed treatments with MDC and the three-spray programme again being the best on Riband. Neither of the seasons provided a particularly severe epidemic of *S. tritici* (Table 6) so it is perhaps not surprising that, in 93/94, the spray treatments produced, on average, a yield only about 8% better than the controls. In 92/93, when the yields of treated plots were, on average, 35% better than the unsprayed, the gains were attributable less to the control of *S. tritici* than to the control of brown rust which began epidemic development after all the decision models had been run and all the required sprays had been applied, affecting 45-70% of the area of leaf F-1 on the unsprayed plots by growth stage 81 (Table 7). The apparently poor performance of the CDS model (treatments 4, 5 and 9) in 92/93 was partly a consequence of the fact that the model, being based on incidence of leaves affected by *S. tritici*, did not trigger any spray applications in a season when the disease was not severe, leaving those treatments to the depredations of brown rust. Treatment 10 (CDS + LARS splashmeter) yielded significantly better than the appropriate control (treatment 1), probably because of a spray required on 8 June. The fact that brown rust had been well-controlled at GS81 in plots sprayed some three weeks earlier points to a strong fungicidal effect of the chemical applied, tebuconazole, against this disease.

<u>Elm Farm Development Station</u>

There were no interacting non-target diseases on Riband or Beaver at this site in either 91/92 or 92/93.

In the 91/92 season on Riband, the ADAS MDC system (treatment 3) was among the best three in terms of yield (Table 8), the other two being the LARS splashmeter (treatment 6) and the three-spray programme (treatment 8). In this season, when a relatively severe epidemic of *S. tritici* occurred (Table 9), the CDS system resulted in significantly better yields on treatments 4 and 5 than on the respective untreated controls (treatments 1 and 2) although disease control was poorer than that engendered by the other systems. In 92/93, the target disease was slightly less severe on Riband and markedly so on Beaver, thus perhaps presenting a greater challenge to the decision support systems. Nevertheless, the CDS system resulted in significantly increased yields on both the susceptible and the resistant cultivar where inoculum levels had not been suppressed, although it was no better than either MDC on Riband or any of the systems on Beaver, and did not result in particularly good disease control when used in conjunction with other systems on the susceptible variety. None of the systems outyielded the prophylactic three-spray programme on Riband in 92/93.

<u>Long Ashton Research Station</u>

All systems at Long Ashton except for the LARS splashmeter in 91/92, the CDS low inoculum treatment on Riband in 92/93 and all the CDS systems together with the single prophylactic spray on Beaver in 93/94 (treatments 5, 7, 9 and 10), resulted in yields significantly greater than the controls. The best systems in terms of yield were the ADAS MDC (treatment 3) on Riband in 91/92, and the CDS splash criteria (treatment 10) together with IDR (treatment 11) on this cultivar in 93/94 (Table 10). All other treatment yields were not significantly different within seasons. This is probably a reflection of the relatively low severity of late-season disease (Table 11) which was slow to develop in spite of relatively high levels of inoculum on leaves F-4 and F-5 both in 92/93 and 93/94.

No non-target diseases appeared to interact with treatment effects.

Morley Research Centre

Only in 91/92 did the untreated low inoculum control (treatment 2) significantly out-yield the control where inoculum had not been artificially reduced (treatment 1) (Table 12), in spite of the fact that, in all years on both cultivars, there had been a clear depressant effect of the sprays of chlorothalonil on *S. tritici* infection of leaves F-4 and F-5 in late April to early May, and this depressant effect had persisted to the grain-filling period most markedly in 93/94 on Riband (Table 13). In all three experiments on Riband, all the decision models and prophylactic treatments, except for the CDS low inoculum treatment in 93/94, induced yields significantly greater than the appropriate controls. On Riband in 93/94, and on Beaver in 92/93, the highest yielding treatment was the prophylactic three-spray programme. Of the decision support treatments, CDS produced the highest yield on Beaver in 93/94 and, on Riband, was among the best being equal to MDC and IDR in 91/92, and in 93/94, but worse than both of them in 92/93.

In 92/93, an epidemic of brown rust began in early June and developed to significant levels in control plots of both cultivars as the season progressed. In 93/94 mildew, another non-target disease, was observed in early May. The epidemics of both these diseases were retarded by the spray treatments which the various models required (Table 14). It is probable therefore, that the increases in yield associated with treatments are due partly to the control of these non-target diseases.

Table 4. Target disease *S. tritici*. Dates of spray applications recommended by decision models

Year/site/cv		Treatment									
		3	4	5	6	7	8	9	10	11	IDR Dose
<u>91/92</u>											
MRC	R	20/5	15/5	28/5	20/5	28/5	6/5	20/5	20/5	11/5	0.25
		9/6	9/6		23/6		28/5	15/6	23/6	20/5	0.25
							15/6			1/6	0.75
										15/6	0.25
LARS	R	12/5	15/5	2/6	21/5	2/6	23/4	21/5	21/5	12/5	0.5
		2/6	11/6				2/6	9/6	9/6	28/5	0.75
		18/6					18/6			9/6	0.25
EFDS	R	1/5	13/5	9/6	13/5	20/5	1/5	13/5	13/5	1/5	0.25
		20/5			9/6		20/5			15/5	0.50
		9/6					3/6			3/6	0.75
										15/6	0.25
<u>92/93</u>											
ADAS	R	5/5	-	-	18/5	29/5	5/5	-	8/6	5/5	0.25
		29/5			15/6		29/5			18/5	0.5
		21/6					15/6			1/6	0.75
										15/6	0.25
	B	29/5	-	-	18/5	29/5	5/5	-	8/6	18/5	0.25
		21/6			15/6		29/5			15/6	0.75
							15/6			15/6	0.25
MRC	R	21/5	21/5	21/5	19/5	29/5	6/5	29/5	29/5	19/5	0.5
		21/6			15/6		29/5		21/6	1/6	1.0
							15/6				
	B	21/5	21/5	21/5	19/5	29/5	10/5	29/5	29/5	19/5	0.25
		21/6			15/6		29/5		21/6	1/6	0.75
							15/6			21/6	0.25
LARS	R	13/5	20/5	21/6	20/5	28/5	30/4	28/5	28/5	13/5	0.5
		9/6	21/6		21/6		28/5	17/6	17/6	28/6	0.75
							15/6			15/6	0.25
	B	13/5	20/5	21/6	20/5	28/5	30/4	28/5	28/5	13/5	0.25
		9/6	21/6		21/6		28/5	21/6	17/6	28/5	0.75
							15/6			15/6	0.25
EFDS	R	29/4	14/5	25/5	19/5	20/5	29/4	25/5	25/5	29/4	0.25
		22/5	10/6		13/6		22/5		15/6	12/5	0.25
		13/6					4/6			23/5	1.0
										13/6	0.25

Table 4 continued

	B	22/5	22/5	22/5	19/5	22/5	29/4	25/5	25/5	29/4	0.25
		13/6			13/6		22/5			18/5	0.75
							4/6			9/6	0.25
93/94											
ADAS	R	16/5	23/5	23/6	31/5	31/5	5/5	23/5	23/5	16/5	0.5
		7/6			13/6		31/5			31/5	1.0
										13/6	0.25
	B	16/5	17/6	-	31/5	31/5	5/5	17/6	17/6	16/5	0.5
		7/6			13/6		31/5			31/5	0.75
							13/6			13/6	0.25
MRC	R	16/5	18/5	6/6	6/5	20/5	29/4	18/5	18/5	6/5	0.5
		6/6	13/6		6/6		20/5	13/6	13/6	23/5	1.0
							13/6			13/6	0.25
	B	16/5	18/5	6/6	6/5	23/5	30/4	18/5	18/5	6/5	0.25
		6/6			6/6		23/5		13/6	23/5	0.75
							17/6			6/6	0.25
LARS	R	19/5	19/5	19/5	19/5	8/6	5/5	19/5	19/5	9/5	0.5
		8/6	14/6	14/6	23/6		27/5	14/6	27/5	27/5	1.0
							14/6		14/6	14/6	0.25
	B	19/5	19/5	19/5	19/5	8/6	5/5	19/5	19/5	9/5	0.25
		8/6	30/6		23/6		27/5		14/6	27/5	0.75
							14/6			14/6	0.25

Table 5. ADAS Terrington. Target Disease *S. tritici*
Annual mean yields per treatment (t ha^{-1}at 85% dm)

Treatment		Riband		Beaver	
		92/93	93/94	92/93	93/94
1	Unt	6.36	10.56	7.11	10.34
2	Unt/sup	6.53	10.52	7.32	10.50
3	MDC	10.49	11.58	10.64	11.31
4	CDS	6.36	11.08*	7.24	11.15*
5	CDS/sup	6.58	11.29	7.35	10.65
6	LARS	10.13	11.45	10.75	11.16
7	1 spray	9.75	11.21	10.30	11.26
8	3 sprays	10.55	11.55	10.71	11.25
9	CDS + MDC	6.37	11.34*	7.40	11.24*
10	CDS + splash	9.09	11.49*	10.23	11.09*
11	IDR	10.74	11.35	10.84	11.33
SED		0.19	0.19	0.12	0.16
df		20	20	20	20
LSD (5%)		0.39	0.39	0.26	0.33

* treatments received identical spray regimes within cultivar/year.

Table 6. ADAS Terrington. Target Disease *S. tritici*
Annual mean disease severity (%) (and incidence) on leaf F-1 at growth stage 75

Treatment		Riband		Beaver	
		92/93	93/94	92/93	93/94
1	Unt	8.0 (32.6)	0.5 (10.0)	9.9 (40.0)	0.4 (13.3)
2	Unt/sup	8.9 (47.8)	1.4 (26.7)	2.8 (30.0)	0.5 (13.3)
3	MDC	0.1 (6.7)	0.0 (0.0)	0.2 (3.3)	0.0 (0.0)
4	CDS	8.8 (40.0)	0.1 (10.0)	3.1 (18.3)	0.1 (6.7)
5	CDS/sup	5.6 (26.7)	1.2 (20.0)	4.9 (43.3)	0.3 (6.7)
6	LARS	0.1 (10.0)	0.0 (0.0)	<0.1 (3.3)	0.0 (0.0)
7	1 spray	0.6 (30.0)	0.0 (0.0)	0.1 (6.7)	0.0 (0.0)
8	3 sprays	0.1 (10.0)	0.5 (3.3)	0.0 (0.0)	0.0 (0.0)
9	CDS + MDC	7.3 (38.3)	0.0 (0.0)	3.6 (25.0)	0.2 (6.7)
10	CDS + splash	0.3 (16.7)	0.0 (0.0)	0.0 (0.0)	0.4 (10.0)
11	IDR	0.0 (0.0)	2.0 (23.3)	0.0 (0.0)	0.0 (0.0)

Table 7. ADAS Terrington 92/93. Non-target diseases on leaf F-1
Mean disease severity (%)

Treatment		Brown rust at GS81	
		Riband	Beaver
1	Unt	65.0	45.0
2	Unt/sup	51.3	70.0
3	MDC	0.0	1.7
4	CDS	55.4	56.7
5	CDS/sup	53.3	51.7
6	LARS	0.1	1.1
7	1 spray	0.2	1.1
8	3 sprays	0.0	0.1
9	CDS + MDC	45.0	56.7
10	CDS + splash	5.2	3.7
11	IDR	0.0	0.1

Table 8. Elm Farm Development Station. Target disease *S. tritici*
Annual mean yields per treatment (t ha^{-1} at 85% DM).

Treatment		Riband		Beaver
		91/92	92/93	92/93
1	Unt	8.78	6.70	7.41
2	Unt/sup	8.56	7.33	7.72
3	MDC	10.32	8.34	7.95
4	CDS	9.62*	8.24	8.17*
5	CDS/sup	9.50	7.78*	7.68*
6	LARS	10.04	7.94	7.66
7	1 spray	9.91	7.53	7.73*
8	3 sprays	10.30	8.83	8.26
9	CDS + MDC	9.66*	8.11*	8.07*
10	CDS + splash	9.58*	8.08	8.01*
11	IDR	9.99	8.04	8.20
SED		0.22	0.31	0.20
df		20	20	20
LSD (5%)		0.46	0.64	0.41

* treatments received identical spray regimes within cultivar/year.

Table 9. Elm Farm Development Station. Target Disease *S. tritici*
Annual mean disease severity (%) (and incidence) on leaf F-1 at growth stage 75

Treatment		Riband		Beaver
		91/92	92/93	92/93
1	Unt	35.5 (100.0)	17.7 (100.0)	3.1 (96.7)
2	Unt/sup	30.8 (100.0)	8.6 (100.0)	2.2 (80.0)
3	MDC	0.4 (40.0)	0.2 (20.0)	0.3 (0.2)
4	CDS	7.2 (90.0)	0.6 (40.0)	0.1 (10.0)
5	CDS/sup	6.8 (100.0)	0.2 (20.0)	0.0 (0.0)
6	LARS	0.6 (50.0)	1.6 (66.7)	0.0 (0.0)
7	1 spray	1.3 (86.7)	1.2 (60.0)	0.0 (0.0)
8	3 sprays	0.3 (30.0)	0.1 (6.7)	0.0 (0.0)
9	CDS + MDC	4.8 (93.3)	20.5 (96.7)	0.1 (13.3)
10	CDS + splash	4.2 (96.7)	15.4 (100.0)	0.5 (30.0)
11	IDR	1.0 (76.7)	0.2 (23.3)	0.2 (16.7)

Table 10. Long Ashton Research Station. Target disease *S. tritici*
Annual mean yields per treatment (t ha^{-1} at 85% DM).

Treatment		Riband			Beaver	
		91/92	92/93	93/94	92/93	93/94
1	Unt	4.48	5.34	5.25	7.42	7.41
2	Unt/sup	4.79	5.70	5.61	7.49	7.47
3	MDC	6.19	9.88	9.71	10.41	10.32
4	CDS	5.36	10.04*	9.86*	9.81*	9.77
5	CDS/sup	5.46*	6.74	6.63*	8.96	8.93*
6	LARS	5.08	10.06*	9.88	10.36*	10.22
7	1 spray	5.16*	9.24	9.11	9.90	9.87
8	3 sprays	5.60	9.11	10.35	10.51	10.45
9	CDS + MDC	5.69†	9.91	9.73*	10.09	10.01*
10	CDS + splash	5.61†	9.68	9.49	10.10	10.06
11	IDR	5.22	9.56	9.38	9.83	9.80
SED		0.32	0.68	0.41	0.35	0.40
df		30	20	20	20	20
LSD (5%)		0.65	1.42	0.86	0.71	0.83

* † treatments marked by the same symbol received the same spray regime, as determined by the decision models under test on that cultivar/year.

Table 11. Long Ashton Research Station. Target disease *S. tritici*
Annual mean disease severity (%) (and incidence) on leaf F-1 at growth stage 75

Treatment		Riband			Beaver	
		91/92	92/93	93/94	92/93	93/94
1	Unt	1.9 (93.7)	1.6 (100.0)	6.6 (100.0)	-	13.5 (100.0)
2	Unt/sup	0.2 (67.5)	1.3 (100.0)	5.1 (100.0)	1.9 (100.0)	5.1 (100.0)
3	MDC	0.1 (13.3)	0.8 (77.0)	2.6 (96.7)	0.1 (23.3)	1.2 (87.1)
4	CDS	0.1 (32.6)	1.3 (80.0)	2.5 (100.0)	0.03 (26.7)	2.9 (100.0)
5	CDS/sup	0.1 (23.6)	1.7 (100.0)	1.1 (76.4)	0.7 (93.3)	0.9 (55.2)
6	LARS	0.1 (38.3)	1.2 (86.7)	4.6 (95.8)	0.2 (36.7)	2.2 (89.4)
7	1 spray	0.3 (49.0)	1.5 (80.0)	5.4 (100.0)	0.1 (16.7)	3.4 (88.9)
8	3 sprays	0.2 (51.8)	0.4 (80.0)	0.8 (66.7)	0.01 (20.0)	0.3 (43.2)
9	CDS + MDC	0.1 (8.8)	1.8 (86.7)	2.8 (92.5)	-	6.0 (100.0)
10	CDS + splash	0.1 (20.6)	2.5 (100.0)	1.7 (93.3)	0.1 (23.3)	1.6 (88.9)
11	IDR	0.1 (12.5)	0.8 (63.3)	0.9 (81.7)	0.1 (23.3)	1.6 (93.0)

Table 12. Morley Research Centre. Target disease *S. tritici*
Annual mean yields per treatment (t ha^{-1} at 85% DM).

Treatment		Riband			Beaver	
		91/92	92/93	93/94	92/93	93/94
1	Unt	6.56	7.70	8.23	7.63	9.70
2	Unt/sup	7.65	7.73	8.12	7.84	9.86
3	MDC	9.08	10.01	9.77	9.63	10.38
4	CDS	8.92	9.48*	9.62	9.08*	10.61
5	CDS/sup	8.55*	9.73*	9.08	9.32*	10.40
6	LARS	8.81†	9.86	9.47	9.81	9.91
7	1 spray	8.43*	9.51†	9.27	9.22†	10.22
8	3 sprays	8.82	10.06	10.09	10.05	10.15
9	CDS + MDC	8.89	9.52†	9.66*	9.19†	10.15
10	CDS + splash	8.76†	9.83	9.32*	9.45	10.69
11	IDR	9.09	9.96	9.28	9.75	10.10
SED		0.23	0.12	0.34	0.14	0.28
df		30	20	20	20	20
LSD (5%)		0.48	0.25	0.71	0.30	0.59

* † treatments marked by the same symbol received the same spray regime, as determined by the decision models under test on that cultivar/year.

Table 13. Morley Research Centre. Target disease *S. tritici*
Annual mean disease severity (%)(and incidence) on leaf F-1 at growth stage 71-75

Treatment		Riband			Beaver	
		91/92	92/93	93/94	92/93	93/94
1	Unt	6.1 (88.9)	4.1 (76.7)	13.1 (100.0)	1.3 (43.3)	1.6 (80.0)
2	Unt/sup	4.1 (92.5)	4.7 (66.7)	3.6 (66.7)	0.9 (53.3)	1.1 (83.3)
3	MDC	0.4 (25.0)	0.8 (33.3)	0.3 (30.0)	0.0 (0.0)	0.0 (0.0)
4	CDS	1.0 (32.5)	0.1 (16.7)	0.4 (26.7)	0.0 (10.0)	0.0 (3.3)
5	CDS/sup	0.4 (35.0)	0.1 (6.7)	1.5 (70.0)	0.0 (3.3)	0.4 (50.0)
6	LARS	0.1 (12.5)	0.3 (16.7)	1.0 (50.0)	0.0 (10.0)	0.5 (46.7)
7	1 spray	2.6 (57.5)	0.1 (16.7)	2.1 (60.0)	0.0 (10.0)	0.0 (0.0)
8	3 sprays	0.4 (27.5)	0.0 (0.0)	0.3 (16.7)	0.0 (6.7)	0.0 (3.5)
9	CDS + MDC	0.4 (27.5)	0.4 (26.7)	1.0 (26.7)	0.0 (3.3)	0.0 (3.3)
10	CDS + splash	0.3 (22.5)	0.4 (13.3)	0.9 (33.3)	0.0 (10.0)	0.2 (6.7)
11	IDR	0.9 (37.5)	0.0 (0.0)	0.4 (30.0)	0.0 (6.7)	0.0 (6.7)

Table 14. Morley Research Centre. Non-target diseases on leaf F-1
Mean disease severity (%)

Treatment		92/93 Brown rust GS 83		93/94 Mildew GS 75
		Riband	Beaver	Riband
1	Unt	3.6	4.2	0.4
2	Unt/sup	5.7	4.3	1.6
3	MDC	0.0	0.0	0.2
4	CDS	-	0.0	0.0
5	CDS/sup	-	0.1	0.2
6	LARS	-	0.0	0.1
7	1 spray	0.0	0.0	0.2
8	3 sprays	0.0	0.0	0.2
9	CDS + MDC	0.0	0.0	0.1
10	CDS + splash	0.0	0.0	0.0
11	IDR	0.0	0.0	0.1

Target disease mildew

At all sites in all seasons, sprays of UK152 had been applied across the entire experiment, except treatment 2, to suppress the non-target *S. tritici*. Treatment 2 was left unsprayed in order to estimate the effect of UK152 on the natural development of mildew epidemics. There were no apparent effects of UK152 on mildew but, in 13 out of 17 comparisons, yield was reduced when the spray was omitted, significantly so at Terrington in all experiments except for that on Apollo in 93/94. Dates of sprays recommended by the decision support systems under test are summarised in Table 15.

ADAS Terrington

At ADAS Terrington, there were no effects of inoculum suppression on yields (Table 16). On the inoculum suppression plots on Apollo in 92/93, both the MDC (treatment 5) and CDS (treatment 7) systems resulted in increased yields compared to the appropriate control (treatment 3). The CDS system also resulted in improved yields when the spray used included a triazole in addition to the morpholine, both in 91/92 when it was a low inoculum treatment and in 92/93 when any second spray required by the model was based on incidence of infection (treatment 9).

Where inoculum had not been suppressed in 91/92 and 92/93, CDS again improved yields relative to the untreated (treatment 1) when using either a morpholine alone (treatment 6) or the morpholine and triazole mixture (treatment 8). In all experiments except those of 93/94, the three-spray programme (treatment 11) resulted in the highest yields, with comparable increases arising from the MDC low threshold system.. The IDR model was among the best performers on Apollo but not in the more resistant cultivar Hereward.

Disease control apparent at grain-filling (Table 17) was not spectacular in any of the experiments, particularly on Hereward. In 92/93, Apollo was affected by brown rust (Table 7) and control of this non-target disease must have contributed to yield increases arising from sprays applied for mildew control.

Elm Farm Development Station

At this site, none of the untreated low inoculum treatments (treatment 3) produced a yield significantly different from the untreated without inoculum suppression (treatment 1) (Table 18). This is consistent with the similarity in late-season mildew levels for those treatments (Table 19) but, perhaps, is surprising in view of the possible suppression of the non-target disease *S. tritici* on treatment 3 (Table 20) for which confirmatory evidence is lacking but which, like treatment 1, received no sprays for late-season control of any disease. Of the low inoculum treatments (5, 7 and 9 in 91/92; 5 in 92/93), only MDC (treatment 5) on Apollo in 92/93 resulted in sprays which gave a yield increase relative to the appropriate control (treatment 3).

Only on Apollo in 92/93 did any of the treatments yield better than the control in plots which had not been oversprayed to control the non-target disease *S. tritici*. In this experiment, brown rust was as severe as mildew on untreated plots (Tale 20) and it is likely that the significant yield increase promoted by the CDS treatment involving additional triazole (treatment 9) was attributable, at least in part, to the control of brown rust which was reduced to a zero infection score on leaf F-1 at growth stage 75.

The increased levels of both *S. tritici* and brown rust in treatment 2 where the UK152 overspray had been omitted suggest that this chemical was, to a degree, effective in controlling both of these non-target diseases in the other treatments (Table 20).

Scottish Agricultural College

Only in 92/93 on Apollo did any significant differences in yield between treatments occur. In that experiment, all treatments where inoculum suppression had not been applied yielded better than the appropriate control but none of the systems differed from any other (Table 21). Where inoculum had been suppressed, MDC (treatment 5) was not significantly better than its control (treatment 3) in spite of the fact that sprays had resulted in partial control of mildew (Table 22). Mildew levels on the resistant cultivar Hereward were low and, apart from the MDC low inoculum treatment and IDR, only the prophylactic treatments required to be applied. Similarly, no mildew occurred in 93/94 and only the prophylactic treatments and IDR required sprays to be applied.

Low levels of the non-target *S. tritici* and *S. nodorum* at growth stage 75 occurred on both cultivars in 92/93 (Table 23). On Apollo, the partial control of *S. nodorum* probably contributed to yield increases.

Central Science Laboratory

Only on Apollo, in all three years, were yields increased as a result of spray applications (Table 24). The yields of the low inoculum control (treatment 3) and the plots from which suppression of *S. tritici* had been omitted (treatment 2) yielded similarly to the untreated control (treatment 1) in all five experiments. In 91/92, when mildew was relatively severe on the control plots (Table 25), the MDC (treatment 5) and both the CDS systems (treatments 7 and 9) yielded significantly better than the control (treatment 3) but were not different from each other. Similar yield increases on treatments without inoculum suppression followed the implementation of CDS where triazole was incorporated (treatment 8), the three-spray prophylactic programme (treatment 11), the MDC low threshold system (treatment 12) and IDR (treatment 14).

In 92/93 a severe epidemic of brown rust occurred on Apollo (Table 26) which apparently out-competed mildew. Consequently, the yield increases recorded on both CDS triazole treatments (treatments 8 and 9), both prophylactic treatments (treatments 10 and 11) and IDR (treatment 14) were probably a result of the control of brown rust indicated in Table 26. Mildew levels on Hereward were zero and no non-target disease was recorded. Consequently, all yields were similar.

In 93/94, yellow rust was the predominant disease and treatment yields were all similar except for the three-spray prophylactic programme (treatment 11) on Apollo. None of the decision models which were primarily threshold based (treatments 4 to 9, 11 and 12) triggered spray applications. The IDR model resulted in two spray applications and was associated with reduced yellow rust levels but without significant yield effects on either cultivar.

Table 15. Target disease mildew. Dates of spray applications recommended by models

Year/site/cv		Treatment 4	5	6	7	8	9	10	11	12	13	14	IDR dose
<u>91/92</u>													
ADAS	A	2/6	-	13/5	2/6	13/5	2/6	2/6	13/5	2/6	-	6/5	0.25
									2/6			20/5	0.25
									15/6			2/6	0.5
EFDS	A	9/6	9/6	9/6	9/6	9/6	9/6	20/5	23/4	9/6	9/6	1/5	0.25
									13/5			15/5	0.25
									3/6			3/6	0.25
CSL	A	5/5	13/5	5/5	13/5	5/5	13/5	29/5	5/5	5/5	5/5	5/5	0.5
		29/5	9/6	29/5	29/5	19/5	29/5		29/5	29/5	29/5	20/5	0.5
									12/6			29/5	0.5
												18/6	0.25
<u>92/93</u>													
ADAS	A	4/5	4/5	6/5	6/5	6/5	6/5	29/5	4/5	4/5	4/5	4/5	0.5
		29/5	29/5				15/6		29/5	29/5	15/6	18/5	0.5
									15/6			1/6	0.5
	H	4/5	18/5	11/5	11/5	11/5	11/5	29/5	4/5	4/5	-	4/5	0.25
									29/5			18/5	0.25
									15/6			1/6	0.25
EFDS	A	29/4	29/4	27/4	27/4	27/4	27/4	22/5	27/4	29/4	12/5	29/4	0.25
		22/5	9/6	25/5	22/5	22/5	4/6		22/5	22/5		12/5	0.25
									4/6			23/5	0.5
												9/6	0.25
	H	-	-	27/4	27/4	27/4	27/4	22/5	27/4	12/5	-	29/4	0.25
									22/5			18/5	0.25
									4/6				
SAC	A	23/6	28/6	28/6	28/6	28/6	28/6	23/6	1/6	23/6	28/6	1/6	0.25
		21/7	21/7	20/7	20/7	20/7	20/7		23/6	21/7	21/7	14/6	0.5
									20/7			28/6	0.25
												7/7	0.25
	H	-	14/6	-	-	-	-	23/6	1/6	-	-	23/6	0.25
									23/6				
									20/7				
CSL	A	15/6	22/6	18/5	18/5	18/5	18/5	24/5	30/4	15/6	-	30/4	0.5
									24/5			20/5	0.5
									8/6			8/6	0.5
												18/6	0.5

Table 15 continued

	H	-	-	-	-	-	-	24/5	4/5 24/5 8/6	-	-	24/5	0.5
<u>93/94</u> ADAS	A	28/6	-	28/6	-	28/6	-	12/6	25/5 12/6 28/6	28/6	-	25/5 12/6 28/6	0.5 0.5 0.5
	H	-	-	-	-	-	-	12/6	25/5 12/6 27/6	-	-	12/6	0.5
SAC	A	-	-	-	-	-	-	15/6	24/5 15/6 8/7	-	-	24/5 16/6 8/7	0.25 0.25 0.25
	H	-	-	-	-	-	-	15/6	24/5 15/6 8/7	-	-	16/6	0.25
CSL	A	-	-	-	-	-	-	31/5	10/5 31/5 23/6	-	-	23/5 8/6	0.25 0.25
	H	-	-	-	-	-	-	31/5	10/5 31/5 23/6	-	-	23/5 8/6	0.25 0.25

Table 16. ADAS Terrington. Target disease mildew
Annual mean yields per treatment (t ha^{-1} at 85% DM).

Treatment		Apollo			Hereward	
		91/92	92/93	93/94	92/93	93/94
1	Unt	8.21	8.16	6.2	9.37	9.4
2	Unt minus	7.88	7.05	7.1	8.79	8.8
3	Unt/sup	8.16	8.40	8.4	9.26	9.3
4	MDC	8.48*	9.60*	9.6*	9.63*	9.6*
5	MDC/sup	8.11	9.68*	9.7†	9.58	9.6*
6	CDS	8.62†	8.58†	8.6*	9.66†	9.7*
7	CDS mod	8.50*	9.29†	9.3†	9.64†	9.6*
8	CDS + triaz	8.63†	9.16†	9.2*	9.63†	9.6*
9	CDS mod + tria	8.71*	9.83	9.8†	9.68†	9.7*
10	1 spray	8.38*	9.07	9.1	9.87	9.9
11	3 sprays	8.64	9.66	9.6	9.84	9.8
12	MDC low	8.45*	9.60*	9.6*	9.57*	9.6*
13	MDC high	8.19	9.31	9.3†	9.31	9.3*
14	IDR	8.51	9.42	9.4	9.51	9.6
SED		0.07	0.14	0.20	0.12	
df		39	26	26	26	
LSD (5%)		0.15	0.29	0.41	0.25	NS

* † treatments marked by the same symbol received the same spray regime, as determined by the decision models under test on that cultivar/year.

Table 17. ADAS Terrington. Target disease mildew
Annual mean disease severity (%) (and incidence) on leaf F-1 at growth stage 71-75

Treatment		Apollo			Hereward	
		91/92	92/93	93/94	92/93	93/94
1	Unt	0.4 (57.5)	1.9 (86.7)	3.8 (100.0)	0.2 (43.3)	0.0 (0.0)
2	Unt minus	0.2 (24.8)	1.1 (63.3)	1.6 (80.0)	0.3 (53.3)	0.0 (0.0)
3	Unt/sup	0.2 (60.0)	1.7 (66.7)	4.0 (66.7)	0.2 (43.3)	0.0 (0.0)
4	MDC	0.1 (22.5)	0.2 (26.7)	3.0 (63.3)	0.2 (33.3)	0.0 (0.0)
5	MDC/sup	0.2 (65.0)	0.1 (16.7)	2.4 (76.7)	0.1 (10.0)	0.0 (0.0)
6	CDS	0.1 (7.5)	1.6 (86.7)	1.1 (73.3)	0.1 (13.3)	0.0 (0.0)
7	CDS mod	0.1 (5.0)	0.7 (70.0)	2.5 (66.7)	0.1 (13.3)	0.0 (0.0)
8	CDS + triaz	0.1 (7.5)	1.3 (80.0)	2.0 (70.0)	0.1 (0.0)	0.0 (0.0)
9	CDS mod + tria	0.1 (12.5)	0.4 (60.0)	5.5 (96.7)	0.1 (16.7)	0.0 (0.0)
10	1 spray	0.1 (22.5)	0.3 (36.7)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
11	3 sprays	0.1 (2.5)	0.1 (30.0)	0.1 (6.7)	0.0 (0.0)	0.0 (0.0)
12	MDC low	0.1 (20.0)	0.2 (40.0)	2.3 (60.0)	0.1 (3.3)	0.0 (0.0)
13	MDC high	0.1 (17.5)	0.7 (83.3)	3.7 (93.3)	0.3 (46.7)	0.0 (0.0)
14	IDR	0.0 (0.0)	0.1 (26.7)	0.2 (16.7)	0.1 (6.7)	0.0 (0.0)

Table 18. Elm Farm Development Station. Target disease mildew
Annual mean yields per treatment (t ha^{-1} at 85% DM)/

Treatment	Apollo		Hereward
	91/92	92/93	92/93
1 Unt	9.80	7.03	8.25
2 Unt minus	9.27	6.72	7.81
3 Unt/sup	9.38	7.14	8.24
4 MDC	9.60*	7.64*	7.76*
5 MDC/sup	9.35*	7.93*	8.15*
6 CDS	9.38*	7.48†	7.90†
7 CDS mod	9.60*	7.42†	8.20†
8 CDS + triaz	10.04*	7.65†	8.19†
9 CDS mod + tria	9.98*	8.27	8.23†
10 1 spray	9.33	6.95	8.22
11 3 sprays	10.17	8.08	8.55
12 MDC low	9.85*	7.41*	7.97
13 MDC high	9.80*	7.08	8.14*
14 IDR	9.69	7.05	8.21
SED	0.34	0.30	0.24
df	26	26	26
LSD (5%)	0.69	0.62	0.49

* † treatments marked by the same symbol received the same spray regime, as required by the support systems under test on that cultivar/year.

Table 19. Elm Farm Development Station. Target disease mildew
Annual mean disease severity (%) (and incidence) on leaf F-1 at growth stage 75

Treatment		Apollo		Hereward
		91/92	92/93	92/93
1	Unt	1.1 (76.6)	6.7 (100.0)	0.5 (46.7)
2	Unt minus	1.5 (80.0)	5.7 (100.0)	0.4 (43.3)
3	Unt/sup	1.4 (80.0)	5.2 (100.0)	0.4 (40.0)
4	MDC	0.4 (36.7)	0.8 (63.3)	0.5 (46.7)
5	MDC/sup	0.3 (30.0)	1.0 (93.3)	0.4 (40.0)
6	CDS	0.4 (36.7)	1.0 (80.0)	0.2 (16.7)
7	CDS mod	0.3 (30.0)	0.6 (50.0)	0.2 (16.7)
8	CDS + triaz	0.4 (40.0)	0.7 (63.3)	0.2 (30.0)
9	CDS mod + tria	0.3 (26.7)	1.1 (80.0)	0.2 (30.0)
10	1 spray	0.1 (6.7)	1.5 (80.0)	0.0 (0.0)
11	3 sprays	0.0 (0.0)	0.1 (10.0)	0.0 (0.0)
12	MDC low	0.4 (36.7)	0.4 (33.3)	0.0 (0.0)
13	MDC high	0.4 (36.7)	0.8 (66.7)	0.5 (46.7)
14	IDR	0.2 (16.7)	0.8 (66.7)	0.4 (36.7)

Table 20. Elm Farm Development Station. Non-target diseases on Apollo in 91/92 and 92/93

Treatment		91/92 *Septoria tritici* F-1, GS 79 Pycnidia leaf[1]	92/93 Brown rust F-1, GS 75 severity (%)
1	Unt	54.7	6.2
2	Unt minus	186.7	11.1
3	Unt/sup	**	5.3
4	MDC	*	1.5
5	MDC/sup	*	1.2
6	CDS	*	1.8
7	CDS mod	*	2.3
8	CDS + triaz	4.0	0.1
9	CDS mod + tria	*	0.0
10	1 spray	*	2.7
11	3 sprays	44.3	0.6
12	MDC low	*	0.6
13	MDC high	*	2.9
14	IDR		2.3

Other non-target diseases:- low levels of eyespot in 91/92 and 92/93, *S. tritici* on Apollo in 92/93, *S. nodorum* on Riband and Beaver in 92/93; no disease associated with treatment.

* Assume same, or lesser, disease severity than treatment 8.

** Assume similar or lesser disease severity than treatment 1.

Table 21. Scottish Agricultural College. Target disease mildew Annual mean yields per treatment (t ha^{-1} at 85% DM).

Treatment		Apollo		Hereward	
		92/93	93/94	92/93	93/94
1	Unt	3.90	9.54	4.60	8.26
2	Unt minus	3.54	9.51	4.47	8.52
3	Unt/sup	4.43	10.25	4.72	8.36
4	MDC	4.62*	9.08*	4.59*	8.32*
5	MDC/sup	4.72†	9.85*	4.35	8.55*
6	CDS	4.81#	9.50*	4.67*	8.08*
7	CDS mod	4.65#	9.42*	4.61*	8.26*
8	CDS + triaz	4.45#	9.85*	4.74*	8.35*
9	CDS mod + tria	4.69#	9.48*	4.55*	8.91*
10	1 spray	4.05	9.03	4.89	8.53
11	3 sprays	4.67	9.36	4.80	8.48
12	MDC low	4.73*	9.50*	4.49*	9.39*
13	MDC high	4.72†	9.46*	4.56*	8.48*
14	IDR	4.77	9.46	4.49	9.33
SED		0.22	0.45	0.20	0.50
df		26	26	26	26
LSD (5%)		0.45	0.93	0.41	1.03

* † # treatments indicated by the same symbol received the same spray regime, as determined by the support models under test on that cultivar/year.

Table 22. Scottish Agricultural College. Target disease mildew
Annual disease severity (%) (and incidence) on leaf F-1 at growth stage 71 (92/93) and 75 (93/94)

Treatment		Apollo		Hereward	
		92/93	93/94	92/93	93/94
1	Unt	10.6 (90.0)	0.0 (0.0)	1.4 (30.0)	0.0 (0.0)
2	Unt minus	9.4 (96.3)	0.0 (0.0)	0.4 (26.7)	0.0 (0.0)
3	Unt/sup	8.7 (83.3)	0.0 (0.0)	0.4 (30.0)	0.0 (0.0)
4	MDC	0.8 (50.0)	0.0 (0.0)	0.1 (6.7)	0.0 (0.0)
5	MDC/sup	1.3 (60.0)	0.0 (0.0)	0.9 (6.7)	0.0 (0.0)
6	CDS	4.6 (73.3)	0.0 (0.0)	0.7 (26.7)	0.0 (0.0)
7	CDS mod	2.1 (80.0)	0.0 (0.0)	0.5 (16.7)	0.0 (0.0)
8	CDS + triaz	5.5 (93.3)	0.0 (0.0)	0.7 (23.3)	0.0 (0.0)
9	CDS mod + tria	5.5 (90.0)	0.0 (0.0)	1.3 (46.7)	0.0 (0.0)
10	I spray	1.7 (53.3)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
11	3 sprays	1.2 (56.7)	0.0 (0.0)	0.1 (6.7)	0.0 (0.0)
12	MDC low	6.5 (96.7)	0.0 (0.0)	0.4 (26.7)	0.0 (0.0)
13	MDC high	2.5 (80.0)	0.0 (0.0)	0.8 (30.0)	0.0 (0.0)
14	IDR	0.3 (20.0)	0.0 (0.0)	4.8 (53.3)	0.0 (0.0)

Table 23. Scottish Agricultural College. Non-target diseases on Apollo and Hereward in 92/93. Mean disease severity (%)

Treatment		*Septoria tritici*		*Septoria nodorum*	
		Apollo	Hereward	Apollo	Hereward
1	Unt	0.1	0.3	8.1	2.0
2	Unt minus	0.1	3.5	21.0	7.2
3	Unt/sup	0.1	0.7	6.1	1.2
4	MDC	0.5	1.2	4.0	3.1
5	MDC/sup	0.2	0.0	2.7	3.0
6	CDS	0.5	2.2	6.3	6.8
7	CDS mod	1.5	0.7	4.3	3.7
8	CDS + triaz	0.1	0.4	2.0	3.5
9	CDS mod + tria	0.0	2.7	2.5	4.8
10	1 spray	0.2	3.3	6.5	5.2
11	3 sprays	0.0	0.4	2.3	1.6
12	MDC low	0.5	0.9	4.8	4.9
13	MDC high	0.3	1.8	4.1	5.2
14	IDR	0.2	1.5	4.2	5.0

Other non-target diseases: sooty moulds and fusarium on ears at GS 83 in 92.93

Table 24. Central Science Laboratory. Target disease mildew
Annual mean yields per treatment (t ha^{-1} at 85% DM)

Treatment		Apollo		Hereward	
	91/92	92/93	93/94	92/93	93/94
1 Unt	4.81	7.98	8.0	9.73	8.97
2 Unt minus	4.32	7.87	7.97	10.39	9.46
3 Unt/sup	4.54	8.07	8.37	10.00	8.67
4 MDC	5.11*	8.46*	8.32*	10.17*	8.80*
5 MDC/sup	5.45	8.49	8.08*	10.14*	8.82*
6 CDS	5.31*	8.46*	7.99*	9.65*	9.20*
7 CDS mod	5.84†	8.75†	8.11*	9.72*	8.99*
8 CDS + triaz	5.82	9.42†	8.28*	9.61*	9.21*
9 CDS mod + tria	5.84†	9.25†	7.96*	10.44*	8.51*
10 1 spray	5.36	8.86	8.76	9.95	9.21
11 3 sprays	5.80	9.49	9.88	10.44	8.71
12 MDC low	5.56*	8.27*	8.05*	10.16*	9.05*
13 MDC high	5.36*	7.83	7.88*	10.04*	7.91*
14 IDR	5.43	9.20	8.55	10.35	8.70
SED	0.29	0.32	0.32	0.40	
df	39	26	26	26	
LSD (5%)	0.58	0.66	0.66	0.83	NS

* † treatments marked by the same symbol received the same spray regime, as required by the support models under test on that cultivar/year.

Table 25. Central Science Laboratory. Target disease mildew
Annual mean disease severity (%) (and incidence) on leaf F-1 at growth stage 75

Treatment		Apollo			Hereward	
		91/92	92/93	93/94	92/93	93/94
1	Unt	19.2 (100.0)	2.4 (26)	<0.1 (6.7)	0.0 (0)	0.0 (0.0)
2	Unt minus	19.5 (100.0)	0.5 (30)	<0.1 (33.3)	0.0 (3)	<0.1 (3.3)
3	Unt/sup	22.6 (95.0)	0.7 (17)	<0.1 (6.7)	0.0 (0)	0.0 (0.0)
4	MDC	3.8 (70.0)	3.2 (36)	0.0 (0.0)	0.0 (0)	0.0 (0.0)
5	MDC/sup	2.0 (55.0)	1.3 (23)	0.0 (0.0)	0.0 (0)	0.0 (0.0)
6	CDS	1.8 (67.5)	0.2 (10)	0.0 (0.0)	0.0 (0)	0.0 (0.0)
7	CDS mod	4.1 (55.0)	0.6 (13)	0.0 (0.0)	0.0 (0)	0.0 (0.0)
8	CDS + triaz	6.8 (87.5)	0.2 (10)	0.0 (0.0)	0.0 (0)	0.0 (0.0)
9	CDS mod + tria	2.1 (62.5)	0.6 (20)	0.0 (0.0)	0.0 (0)	0.0 (0.0)
10	1 spray	7.9 (100.0)	<0.1 (3)	<0.1 (10.0)	0.0 (0)	0.0 (0.0)
11	3 sprays	1.2 (50.0)	<0.1 (3)	<0.1 (3.3)	0.0 (0)	0.0 (0.0)
12	MDC low	1.5 (60.0)	0.8 (23)	0.0 (0.0)	0.0 (0)	0.0 (0.0)
13	MDC high	3.4 (87.5)	1.3 (20)	0.0 (0.0)	0.0 (0)	0.0 (0.0)
14	IDR	2.0 (55.0)	0.7 (7)	<0.1 (3.3)	0.0 (0)	0.0 (0.0)

Table 26. Central Science Laboratory. Non-target diseases on Apollo and Hereward.
Mean disease severity (%) Leaf F-1 at GS 75.

Treatment		92/93	93/94	
		Brown rust	Yellow rust	
		Apollo	Apollo	Hereward
1	Unt	39.6	28.6	1.5
2	Unt minus	41.5	7.7	0.4
3	Unt/sup	40.2	17.4	1.4
4	MDC	29.4	*	*
5	MDC/sup	29.6	*	*
6	CDS	15.4	*	*
7	CDS mod	19.9	*	*
8	CDS + triaz	1.3	*	*
9	CDS mod + tria	1.3	*	*
10	1 spray	11.6	6.6	0.3
11	3 sprays	3.4	0.2	1.3
12	MDC low	27.5	*	*
13	MDC high	34.5	*	*
14	IDR	5.6	8.5	0.6

* Assumes same, or lesser, disease severity than treatment 1.

DECISION MODEL PERFORMANCE SUMMARY

Disease control and fungicide inputs

Effective decision models should provide: (i) a high average level of disease suppression, across a range of sites and seasons, (ii) consistent disease control, so that savings in inputs are not achieved at the expense of occasional severe control failures, and (iii) minimised fungicide input. These requirements will only be achieved if fungicide input responds appropriately to variation in the risk of disease induced loss, both in application timing and total dose applied during the season.

In the summary figures presented here, disease levels on the upper three yield forming leaves are quantified as area under the disease progress curve (AUDPC) values. AUDPC values represent the percentage severity of disease integrated over time, and hence provide a more robust measure of the damage caused to the crop than disease severities at a point in time (Large, 1966; Teng, 1985). As an approximate guide, a leaf with an AUDPC of 300 would typically have 15-30% of its area affected by disease prior to senescence.

Target disease *Septoria tritici*

Figures 1 and 2 show mean, maximum and minimum AUDPC values, on cvs. Riband and Beaver respectively, for all sites in all years. The maximum AUDPC values provide a useful measure of the consistency of control achieved by the main systems evaluated. Fungicide inputs, expressed as total dose units applied, are shown for each system below the appropriate AUDPC bars. Maximum and minimum input values, shown for all sites in all years, provide an indication of the degree of response of the different systems to variation in disease risk.

Under high disease pressure on the susceptible cultivar Riband, all treatments, except the single spray prophylactic, provided a high average level of disease control. The MDC, CDS and LARS systems occasionally had higher levels of disease at some sites, but this was confined to leaf 3. At the ADAS site in 1993, the CDS incidence thresholds were missed by a small margin in a season when the disease subsequently became severe. Such an occurrence would be less likely with assessors more experienced in the use of the system, or making routine use of a binocular microscope to assess the presence or absence of infection.

Mean disease severities on the more resistant cultivar Beaver were lower. All the treatments gave adequate disease control on average, except the single spray prophylactic (on leaves 2 and 3) and occasional sites of the CDS system (on leaf 3 only).

Target disease mildew

Figures 3 and 4 show AUDPC values and fungicide inputs for the main systems evaluated, in the same format as Figures 1 and 2. The upper limits of the y-axis scales have been adjusted to suit the lower levels of powdery mildew experienced, compared to the *Septoria tritici* data. Few sites experienced severe disease and yield responses to control were generally small. The three-spray and IDR treatments provided the most consistent control, however the yield and economic analysis suggests that the modest levels of disease left on leaves 2 and 3 by the other treatments had little effect.

The resistance of cv. Hereward resulted in typically slight or nil disease. All the decision models responded appropriately by reducing the amount of fungicide called for.

Yield and economic analysis

The decision models tested were specific to individual target diseases. Sites and cultivars were selected to minimise the risk of non-target diseases affecting the results, and selective fungicide oversprays were applied as appropriate. However, the requirement not to affect the development of target disease epidemics, limited the scope for oversprays against certain diseases. As a result, non-target diseases did occur on particular cvs. at some sites.

Before analysing yield and economic performance it was important to be rigorous in ensuring that: (i) non-target diseases could not distort the results in favour of those systems where the timing of applications aimed at the target disease, happened to coincide with efficacious timings for control of non-target diseases, (ii) the control of non-target diseases by a range of treatments did not exaggerate the size of the yield responses to fungicide application, and (iii) measurements of both disease and yield were of sufficient accuracy to justify further analysis. Cultivar / site / season combinations were excluded from cross-site analysis if non-target diseases affected more than 5% of any of the upper three leaves in untreated plots at GS 75. To further ensure that control of the target disease was predominantly responsible for yield responses to treatments, yield responses were regressed on total AUDPCs for leaves one, two and three. Cultivar / site / season combinations were excluded where variation in the target disease accounted for less than 50 % of the variation in yield response ($r^2 < 0.5$), unless this appeared to be due to low levels of target disease, rather than high error variation.

Values used in the calculation of economic margins are shown under the appropriate figures. Margins were calculated both with and without the inclusion of application costs, to allow for those growers who consider labour and machinery as part of their fixed costs, rather than ascribing them to individual farm operations.

Target disease *Septoria tritici*

Table 27 shows yields and total fungicide dose inputs for all treatments. Mean data across cvs. Riband and Beaver show yield responses to treatment in the range 1.09 t ha^{-1} to 1.68 t ha^{-1}, with fungicide inputs ranging from 1.0 to 2.2 dose units called for by the various decision models. Responses were generally greater on the more disease susceptible cv. Riband. The MDC, CDS, IDR and combined treatments reduced the mean input on the more resistant cv. Beaver.

Economic margin data in Table 28 showed higher margins for cv. Beaver, reflecting its higher yields in this series of experiments. Mean data across both cvs. show an increase in margin in the range 98 to 74 £ ha^{-1} from disease control, including application costs. This represents a reduction in unit cost of approximately £10 $tonne^{-1}$. When fixed and other variable costs are deducted, such a reduction in unit cost would be critical in ensuring the competitiveness of production. The most effective decision models provided a margin £14 or £20 ha^{-1} higher than the best prophylactic treatments, including and excluding application costs respectively.

Target disease mildew

Table 29 shows yield and fungicide input data for all treatments at the mildew target sites. Mean data across cvs. Apollo and Hereward show small yield responses to treatment in the range 0.01 t ha^{-1} to 0.47 t ha^{-1}, with fungicide inputs ranging from 0.38 to 0.88 dose units called for by the various decision models. Inputs called for by the systems reflected the lower risk of loss from mildew than *S. tritici*, particularly on the more resistant cv. Hereward.

The low risk of loss is illustrated by the margin data in Table 30, showing that fungicide treatment specifically against mildew was generally unprofitable even on the more susceptible cv. Apollo. However, the losses caused by disease at the high mildew sites, suggest that the systems were prudent to call for what were on average, modest fungicide inputs.

Analysis of fungicide dose - yield response relationships

Economic optima for agricultural inputs, such as nitrogen, are often derived by fitting dose-response curves to yield values across a range of levels of input.

Target disease *Septoria tritici*

Figures 5 and 6 (for cvs. Riband and Beaver respectively) show dose response curves fitted through the limited number of total fungicide dose points available from this work. Second order polynomial equations (Table 31) were fitted to the means of yields for treatments at each dose level at each site and forced through the zero response origin. The results should be treated with caution, as the limited number of data points along the x-axis do not justify more sophisticated curve fitting approaches. The apparent decreases in fitted yield seen at high dose levels at some sites, are probably artefacts. Nevertheless, fits (as measured by r^2 values) were good, typically explaining over 90% of yield variation.

Economic optima were calculated from the fitted curves, by determining the point on the dose axis where the slope of increase in yield became less than the slope of increase in fungicide cost. Mean dose optima were 2.3 (range 1.75 to 3) and 1.8 (range 1 to 3) dose units for cvs. Riband and Beaver respectively. Clearly these values can only be approximations, and there is scope for individual treatments within the mean response at a given dose, to perform more or less well, depending on the accuracy of matching spray timing to disease and crop development.

Regressions of yield response to fungicide treatment on yield potential (as represented by the three-spray programme treatment) gave non-significant relationships with r^2 values close to zero.

Target disease mildew

Low disease and small, often inconsistent, yield responses made response curve analysis inappropriate.

Disease - yield loss relationships

Target disease *Septoria tritici*

Disease-yield loss relationships, based on straight line regressions, have been published for a number of diseases, including *S. tritici* (King *et al.*, 1983). Regression fitted lines are shown in Figure 7 for all cultivar / site / season combinations where variation in target disease explained more than 50% of the variation in yield, and where non-target diseases were absent or at low levels (less than 5% on the upper three leaves at GS 75). Mean data points were used for each treatment at each site, but have been omitted from the figure for clarity. The regression equations shown in Table 32 quantify the substantial differences in slope found between sites and season.

Target disease mildew

A substantial mildew epidemic, in the absence of non-target diseases, was experienced at only one site (CSL in 1992 on cv. Apollo). The disease-yield loss regression for this site exhibited a shallow slope (Table 32). Two other sites produced r^2 values greater than 50% along with low levels of non target disease, but the range of mildew values experienced at these sites was limited.

Meteorological data

Meteorological data collected from in-crop data loggers to guide the decision models, will be used, together with disease progress curve data, to aid development and validation of improved weather-disease models, using analytical methods described by Parker *et al.* (1994).

Table 27 Mean yields and total fungicide doses applied (excluding ADAS 93 (Riband and Beaver) and LARS 93 (Riband))

Treatment		Riband		Beaver		Mean for Riband and Beaver	
		Yield ($t\ ha^{-1}$)	Doses (units)	Yield ($t\ ha^{-1}$)	Doses (units)	Yield ($t\ ha^{-1}$)	Doses (units)
1	Unt	7.48	0.00	8.48	0.00	7.90	0.00
2	Unt/sup	7.61	0.00	8.56	0.00	8.01	0.00
3	MDC	9.26	2.38	9.90	2.00	9.54	2.21
4	CDS	8.81	1.63	9.69	1.33	9.19	1.50
5	CDS/sup	8.77	1.13	9.29	0.83	8.99	1.00
6	LARS	8.89	1.88	9.72	2.00	9.25	1.93
7	1 spray	8.63	1.00	9.49	1.00	9.00	1.00
8	3 spray	9.23	3.00	10.05	3.00	9.58	3.00
9	CDS/MDC	8.90	1.50	9.59	1.17	9.19	1.36
10	CDS/splash	8.97	1.88	9.68	1.67	9.27	1.79
11	IDR	9.01	1.66 (3.25)	9.86	1.29 (3.00)	9.37	1.50 (3.14)

The number of fungicide applications made were equal to the dose units applied for all treatments except IDR, where the number of applications is shown in brackets.

Table 28 Mean margins over fungicide cost (excluding ADAS 93 (Riband and Beaver) and LARS 93 (Riband))

		Margin over fungicide cost (£ ha^{-1})					
Treatment		Riband		Beaver		Mean for Riband and Beaver	
		Incl. applic. costs	Excl. applic. costs	Incl. applic. costs	Excl. applic. costs	Incl. applic. costs	Excl. applic. costs
1	Unt	821	821	932	932	869	869
2	Unt/sup	837	837	941	941	881	881
3	MDC	931	950	1015	1031	967	985
4	CDS	909	922	1017	1028	955	967
5	CDS/sup	923	932	991	997	952	960
6	LARS	909	924	995	1011	946	961
7	1 spray	912	920	1007	1015	953	961
8	3 spray	905	929	995	1019	943	967
9	CDS/MDC	923	935	1012	1021	961	972
10	CDS/splash	917	932	1003	1016	951	968
11	IDR	917	943	1023	1047	962	987

Margin = value of grain yield at £110 $tonne^{-1}$ minus fungicide cost (£29 $unit^{-1}$ for Folicur), minus application costs at £8 $application^{-1}$.

Table 29 Mean yields and total fungicide doses applied (excluding ADAS 93 (Apollo), CSL 93 (Apollo), SAC 93 (Apollo), EFDS 93 (Apollo), ADAS 94 (Hereward), CSL 94 (Apollo and Hereward), SAC 94 (Apollo and Hereward))

Treatment		Apollo		Hereward		Mean for Apollo and Hereward	
		Yield ($t\ ha^{-1}$)	Doses (units)	Yield ($t\ ha^{-1}$)	Doses (units)	Yield ($t\ ha^{-1}$)	Doses (units)
1	Unt	7.72	0.00	7.99	0.00	7.85	0.00
2	Unt/minus	7.24	0.00	7.87	0.00	7.55	0.00
3	Unt/sup	7.48	0.00	8.06	0.00	7.77	0.00
4	MDC	7.75	1.25	8.04	0.25	7.89	0.75
5	MDC/sup	7.66	0.75	8.06	0.50	7.86	0.63
6	CDS	7.83	1.25	7.97	0.50	7.90	0.88
7	CDS mod	7.96	1.00	8.04	0.50	8.00	0.75
8	CDS triaz	8.23	1.25	8.04	0.50	8.14	0.88
9	CDS mod + triaz	8.12	1.00	8.23	0.50	8.17	0.75
10	1 spray	7.78	1.00	8.23	1.00	8.01	1.00
11	3 sprays	8.23	3.00	8.41	3.00	8.32	3.00
12	MDC/low	7.95	1.25	8.05	0.50	8.00	0.88
13	MDC/high	7.81	0.75	8.01	0.00	7.91	0.38
14	IDR	7.89	1.25 (3.25)	8.16	0.50	8.03	0.88 (2.5)

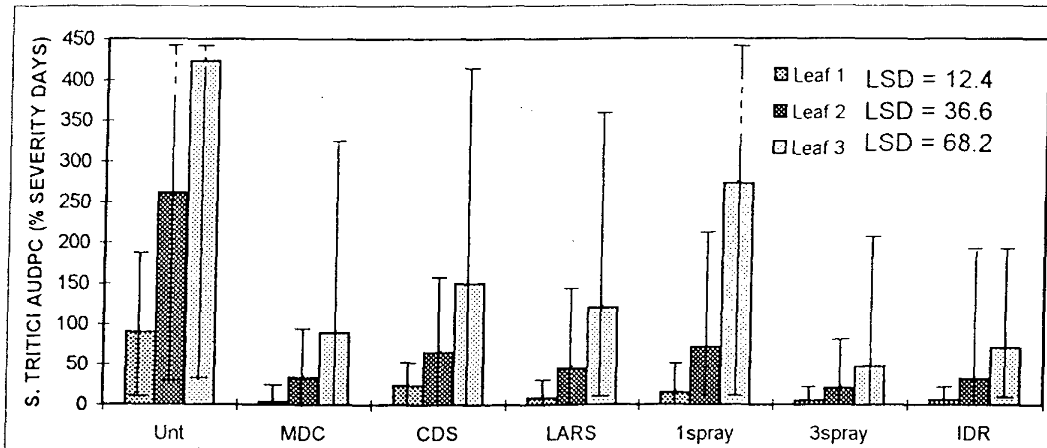
The number of fungicide applications made were equal to the dose units applied for all treatments except IDR, where the number of applications is shown in brackets.

Table 30 Mean margins over fungicide cost (excluding ADAS 93 (Apollo), CSL 93 (Apollo), SAC 93 (Apollo), EFDS 93 (Apollo), ADAS 94 (Hereward), CSL 94 (Apollo and Hereward), SAC 94

		Margin over fungicide cost (£ ha^{-1})					
Treatment		Apollo		Hereward		Mean for Apollo & Hereward	
		Inc.l applic. costs	Excl. applic. costs	Incl. applic. costs	Excl. applic. costs	Incl. applic. costs	Excl. applic. costs
1	Unt	849	849	879	879	864	864
2	Unt/minus	796	796	865	865	831	831
3	Unt/sup	823	823	886	886	854	854
4	MDC	816	826	877	879	847	853
5	MDC/sup	820	826	872	876	846	851
6	CDS	825	835	862	866	844	851
7	CDS mod	847	855	870	874	859	865
8	CDS triaz	855	865	865	869	860	867
9	CDS mod + triaz	853	861	885	889	869	875
10	1 spray	827	835	877	885	852	860
11	3 sprays	818	842	838	862	828	852
12	MDC/low	838	848	871	875	854	861
13	MDC/high	837	843	881	881	859	862
14	IDR	816	842	873	887	844	864

Margin = value of grain yield at £110 $tonne^{-1}$ minus fungicide cost (£21 $unit^{-1}$ for Patrol, £32 $unit^{-1}$ for treatments 8 and 9), minus application costs at £8 $application^{-1}$.

Figure 1. Decision model performance comparison, showing AUDPCs for the upper three leaves and the number of fungicide dose units applied to cv. Riband

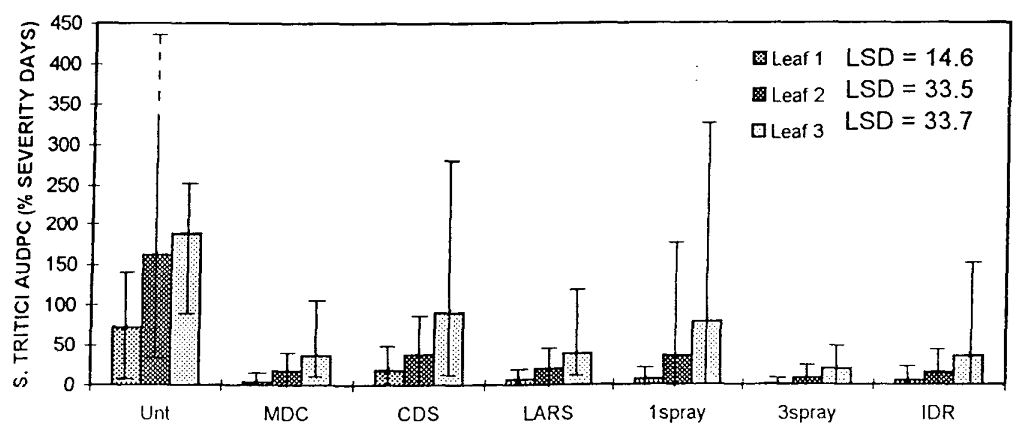


Fungicide units applied

	Unt	MDC	CDS	LARS	1spray	3spray	IDR
Max	0	3	2	2	1	3	1.75 (4)
Mean	0	2.4	1.5	1.9	1	3	1.65 (3.3)
Min	0	2	0	1	1	3	1.5 (2)

Upper and lower limit bars represent the maximum and minimum AUDPC values recorded at any site. The number of fungicide applications was the same as the number of dose units applied, except for IDR where the number of applications is shown in brackets.

Figure 2. Decision model performance comparison, showing AUDPCs for the upper three leaves and the number of fungicide dose units applied to cv. Beaver

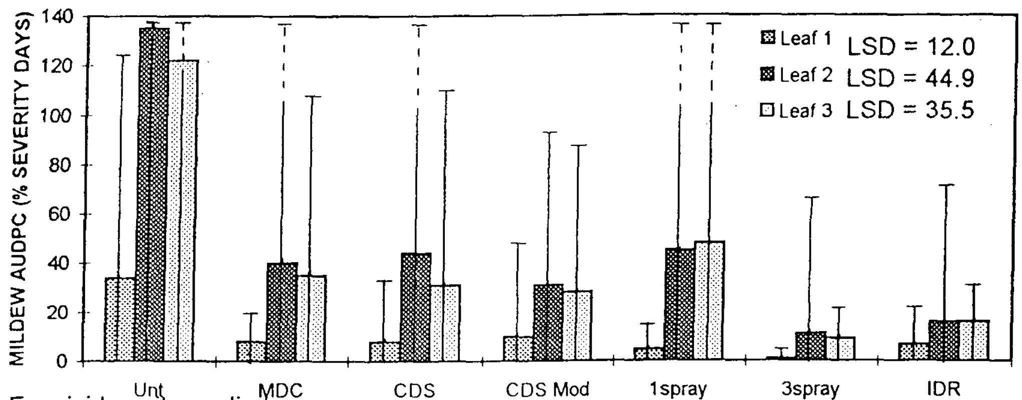


Fungicide units applied

	Unt	MDC	CDS	LARS	1spray	3spray	IDR
Max	0	2	2	2	1	3	1.5 (3)
Mean	0	2	1.1	2.0	1	3	1.3 (3)
Min	0	2	0	2	1	3	1.25 (3)

Upper and lower limit bars represent the maximum and minimum AUDPC values recorded at any site. The number of fungicide applications was the same as the number of dose units applied, except for IDR where the number of applications is shown in brackets.

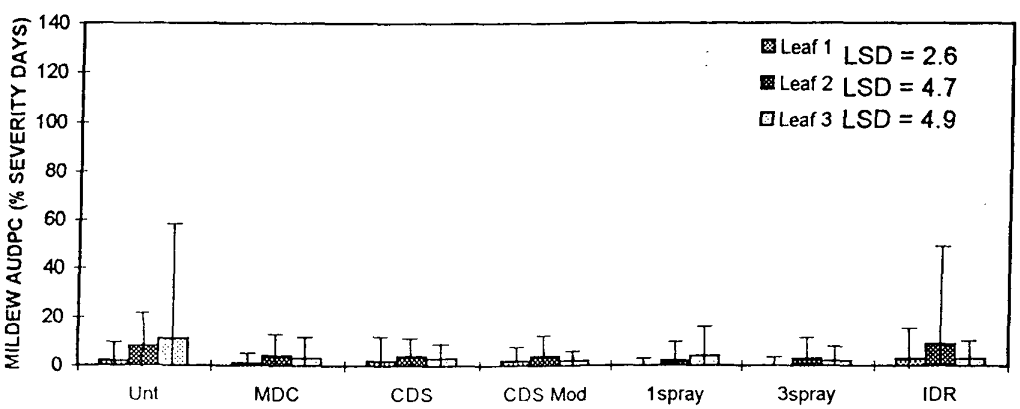
Figure 3. Decision model performance comparison, showing AUDPCs for the upper three leaves and the number of fungicide dose units applied to cv. Apollo



Fungicide units applied	Unt	MDC	CDS	CDS Mod	1spray	3spray	IDR
Max	0	2	2	2	1	3	1.75 (4)
Mean	0	1.2	1.1	1	1	3	1.2 (3.3)
Min	0	0	0	0	1	3	0.5 (2)

Upper and lower limit bars represent the maximum and minimum AUDPC values recorded at any site. The number of fungicide applications was the same as the number of dose units applied, except for IDR where the number of applications is shown in brackets.

Figure 4. Decision model performance comparison, showing AUDPCs for the upper three leaves and the number of fungicide dose units applied to cv. Hereward



Fungicide units applied	Unt	MDC	CDS	CDS Mod	1spray	3spray	IDR
Max	0	1	1	1	1	3	0.75 (3)
Mean	0	0.1	0.3	0.3	1	3	0.5 (1.6)
Min	0	0	0	0	1	3	0.25 (1)

Upper and lower limit bars represent the maximum and minimum AUDPC values recorded at any site. The number of fungicide applications was the same as the number of dose units applied, except for IDR where the number of applications is shown in brackets.

Figure 5. Fungicide dose response curves for cv. Riband

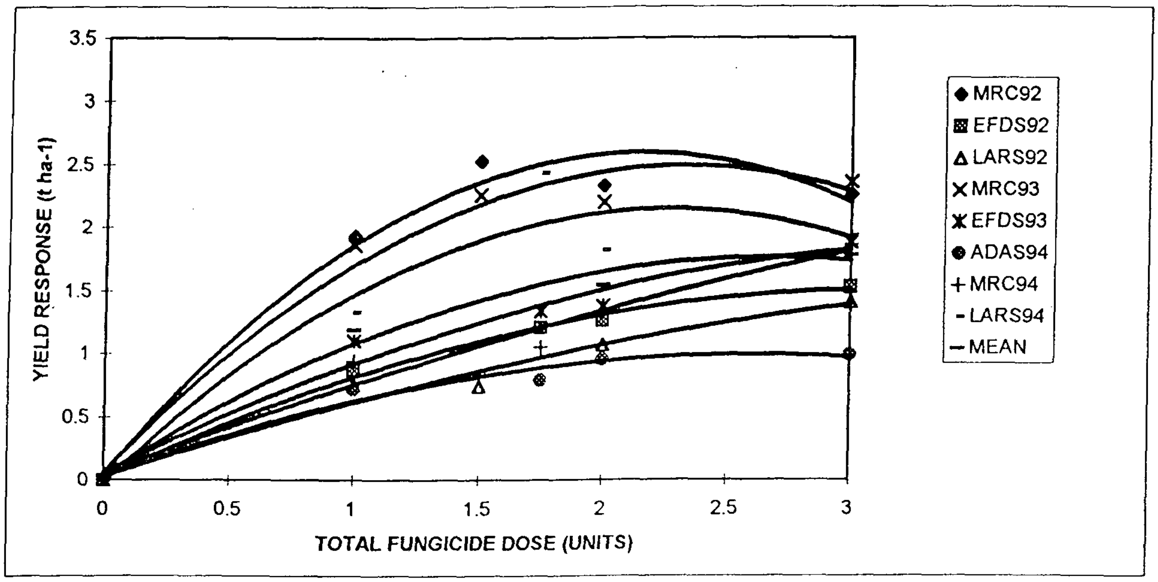


Figure 6. Fungicide dose response curves for cv. Beaver

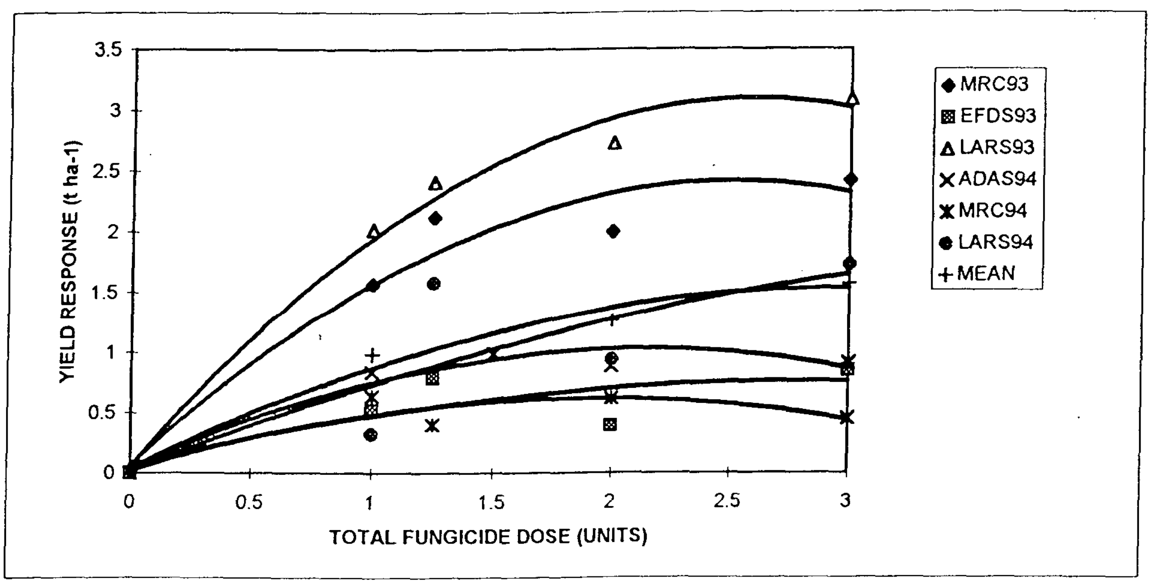


Table 31 Equations and r^2 values for fitted dose reponse curves

Riband

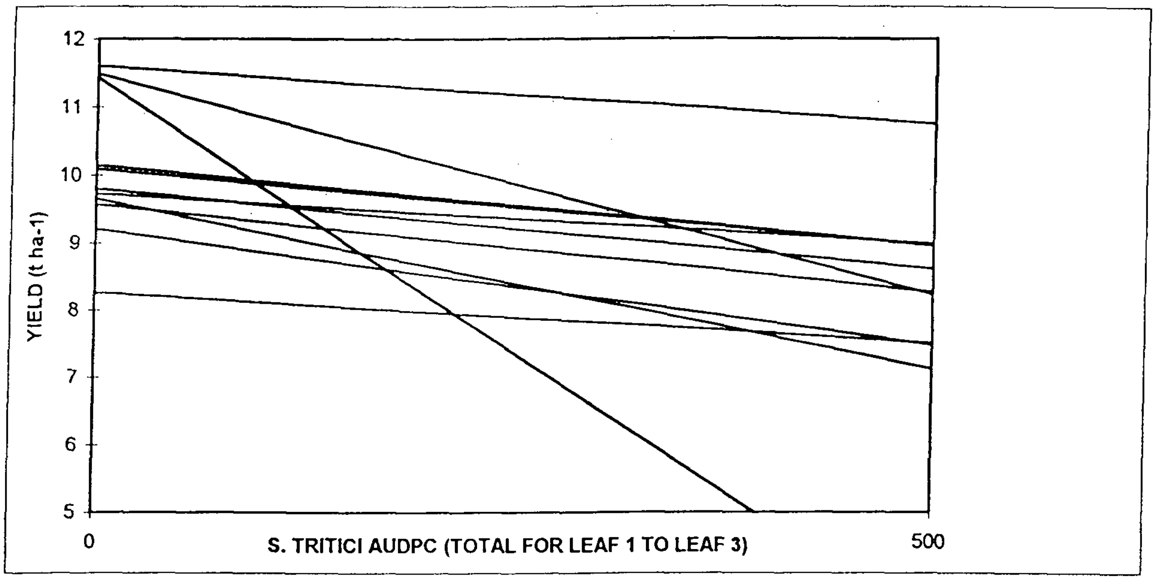
Site	Equation	r^2
MRC 92	$y = -0.5524x^2 + 2.3751x + 0.0425$	0.976
EFDS 92	$y = -0.1486x^2 + 0.9436x + 0.0186$	0.995
LARS 92	$y = -0.0652x^2 + 0.6507x + 0.0300$	0.969
MRC 93	$y = -0.4486x^2 + 2.0877x + 0.0623$	0.974
EFDS 93	$y = -0.1360x^2 + 0.9977x + 0.0577$	0.9701
ADAS 94	$y = -0.1412x^2 + 0.7386x + 0.0268$	0.9694
MRC 94	$y = -0.0559x^2 + 0.7569x + 0.0536$	0.9656
LARS 94	$y = -0.4228x^2 + 1.9162x - 0.0254$	0.9228
MEAN	$y = -0.2381x^2 + 1.2831x + 0.0356$	0.9864

Beaver

Site	Equation	r^2
MRC 93	$y = -0.3745x^2 + 1.8779x + 0.0647$	0.9447
EFDS 93	$y = -0.0872x^2 + 0.4914x + 0.0688$	0.6322
LARS 93	$y = -0.4530x^2 + 2.3506x + 0.0516$	0.9877
ADAS 94	$y = -0.2190x^2 + 0.9351x + 0.0352$	0.952
MRC 94	$y = -0.1594x^2 + 0.6183x + 0.0214$	0.8229
LARS 94	$y = -0.0879x^2 + 0.81x + 0.0130$	0.6623
MEAN	$y = -0.1679x^2 + 1.0039 + 0.0372$	0.9801

y = yield response over untreated (t ha^{-1})
x = total fungicide dose applied (units)

Figure 7. Disease - yield regressions for Riband and Beaver



Regression lines can be related to site, season and cultivar by reference to the regression equations shown in Table 32.

Table 32 Linear regression equations and r^2 values for fitted disease - yield loss relationships

Site	Equation	r^2
Riband		
MRC 92	$y = -0.00344x + 9.21$	0.899
EFDS 92	$y = -0.00223x + 10.09$	0.894
MRC 93	$y = -0.00236x + 10.14$	0.844
EFDS 93	$y = -0.00148x + 8.26$	0.675
ADAS 94	$y = -0.00169x + 11.61$	0.560
MRC 94	$y = -0.00143x + 9.72$	0.504
LARS 94	$y = -0.00258x + 9.57$	0.770
Beaver		
MRC 93	$y = -0.00502x + 9.65$	0.833
LARS 93	$y = -0.01628x + 11.44$	0.662
ADAS 94	$y = -0.00648x + 11.49$	0.757
LARS 94	$y = -0.00234x + 9.80$	0.518
Apollo		
CSL 92	$y = -0.00081x + 5.69$	0.708
ADAS 92	$y = -0.01125x + 8.63$	0.671
Hereward		
ADAS 93	$y = -0.00953x + 9.80$	0.694

y = yield ($t\ ha^{-1}$)
x = total AUDPC for leaves 1 to 3

CONCLUSIONS

Commercial practice

- The results from the first two years (Paveley, *et al.*, 1994) of this project were used to compare the disease control and fungicide input performance achieved by decision models, against that achieved in agricultural practice (Polley, *et al.*,1994). The results suggest that the level of disease control being obtained on-farm is poor in relation to the fungicide inputs being made. The high levels of input to some crops cause concern (five or more fungicide units applied being not uncommon), as do cases of severe disease despite treatment. These latter seem to relate more to poor timing and product choice than to any suggestion of a shift in pathogen sensitivity to fungicides.

- Despite clear evidence of the economic importance of controlling disease on the upper leaves of the crop canopy, 37% and 23% respectively, of Riband and Beaver crops surveyed received no fungicide application between GS 32 and GS 55.

- As the cereals industry becomes more competitive and pressure on the unit cost of production increases, the rate of adoption of technological change must be improved. 1995 cereal disease survey data (Polley pers. comm.) suggests an improvement in the timing of fungicide applications. But this simple improvement has taken more than a decade to implement.

Methodology for decision model evaluation

- The evaluation methodology used in this project, based on weekly fax communication between sites and central co-ordinators, functioned well and applied decision criteria consistently across a wide range of sites and season. Such methods can provide reliable measures of model performance.

- Where the aim is to test user reactions to decision support systems, or their reliability when used on farm, substantially different techniques would be required.

System performance

Septoria tritici

- Results from the prophylactic single- and three-spray treatments reinforce the practical experience that good disease control can be obtained by applying a fixed number of applications, appropriate to the disease susceptibility of the cultivar. However, such prophylactic programmes must consistently over apply on average, to avoid suffering occasional severe losses in high disease risk situations.

- Both the Managed Disease Control (MDC) and LARS Splashmeter systems provided consistently good control. Comparing the former to the latter suggests that, using tebuconazole as the test fungicide, the MDC system tended to apply more material than required. In the form tested, the Splashmeter system applied the same inputs to Riband and

Beaver within each site; suggesting scope for inclusion of a varietal component in the decision process, other than that currently provided via an assessment of inoculum level at GS 30.

- The Cereal Diagnostic System (CDS) was the only system based on the use of disease thresholds (measured by incidence on indicator leaf layers) to determine the need for treatment. At the ADAS site in 1993, the incidence thresholds were missed by a small margin in a season when the disease subsequently became severe. Such an occurrence would be less likely with assessors more experienced in the use of the system, or making routine use of a binocular microscope to assess the presence or absence of infection. A revised system, which takes account of rainfall events (Schoefl *et al.*, 1994), is now in operation in Bavaria.

- The Integrated Disease Risk system (IDR), in its developmental form, used measures of inoculum and weather conduciveness to epidemic development from the CDS, MDC and Splashmeter systems. These were combined with measures of host resistance and sensitivity of the crop to disease induced loss of green leaf area. The system worked in a consistent manner, although the number of applications was typically one more than the number required with 'conventional' full dose systems. Recent data (Paveley, unpublished) suggest that two, or occasionally three, applications are sufficient for an appropriate dose system, even under high disease risk, thus reducing application costs.

Powdery mildew

- In experiments where the target disease was mildew, there was more coincidence of spray recommendations than was the case for *S. tritici* sites, disease levels were lower and more of the sites suffered interference from non-target diseases.

- All of the decision models responded appropriately to the generally low risk of loss, by prompting low or nil levels of fungicide input, particularly on the more resistant cv. Hereward, but did not provide economic benefits.

- There is a shortage of basic epidemiological information for powdery mildew of wheat, compared to that available for *Septoria spp.*, on which to base improved decision systems. The lack of defined weather-disease relationships for powdery mildew may have limited the performance of the IDR model.

Inoculum suppression

- Early season inoculum suppression treatments were included to test the effect of variation in inoculum on subsequent epidemic development, and to test some of the decision models across a wider range of risk conditions.

- The chlorothalonil applications used to suppress inoculum at the *S. tritici* sites, reduced disease severity and the number of spores in basal foliage. At sites where subsequent disease development was slow, the effects of suppression were still apparent on the upper leaves. At other sites, where disease development was more rapid and severe, the effects were generally restricted to the lower leaves.

- Analysis of chlorothalonil residues showed detectable amounts (2 to 9 ng cm^{-2} at three sites) present on the basal leaves two months after the last application. Levels on the upper leaves could often not be differentiated from the untreated controls.

- At those sites where long term effects were seen from the inoculum suppression treatments, it was sometimes difficult to separate the effects of reduced inoculum on epidemic development from the possible effects of fungicide persistence after application. However, at some sites it was clear that the effects were attributable to inoculum reduction.

- Future work to investigate the role of inoculum in determining disease risk should use less persistent materials, make the last application earlier in the season and use stringent assays (chemical or biological) to ensure that residues have declined prior to the experimental period.

- Inoculum suppression treatments at powdery mildew sites used a morpholine material, known to have a short half life. These treatments provided suppression of disease on the lower leaves only, and had little effect on the development of disease on the upper canopy. However, the results need to be interpreted with caution, due to the risk of inter-plot spread of inoculum re-establishing disease in the low inoculum treated plots.

Disease and yield loss

- The damage potential of mildew appears to be substantially lower than *S. tritici*. Practical experience suggests that growers are over estimating the damage caused by mildew, partly because it is so readily visible in the crop.

- Analysis of data from the *S. tritici* sites, where disease and yield responses to its control were substantial, showed no relationship between the yield potential and the size of the response to treatment. This contradicts the common assumption that high yield potential crops will be more responsive to treatment, and has implications for the application of GPS based yield mapping systems to disease control.

- Variation in the slope of disease-yield regressions between sites and seasons may be explained either by variation between disease assessors, or by differences in the physiological state of the crops, that affected their sensitivity to loss of green leaf area to disease.

- The difficulty of obtaining consistency between different assessors (particularly in the proportion of necrosis that is ascribed to disease, rather than natural senescence) is a key source of inter-site variation (Parker *et al.*, 1992). This probably explains a proportion of the disease-yield loss variation.

- Recent work with yellow rust (*Puccinia striiformis*) (Bryson, *et al.*, 1995), has shown that variation in yield response to disease control can be controlled as strongly by site and seasonal differences in the disease-yield loss relationship, as by site and seasonal differences in disease severity. The mechanistic reasons behind variation in disease-yield loss relationships based on percentage disease measurements, have been reviewed by Gaunt (1995) and shown to apply generally to pathosystems. It may be as important for decision support systems to take account of the causes of this variation, as it is for them to predict disease.

- Current decision models only take account of variation in the diseases-yield loss relationship brought about by crop development (usually by defining the range of growth stages over which treatment can be triggered). This may be restricting their ability to deliver consistent economic benefits.

Implementation

- As over 90% of UK winter wheat crops receive fungicides at reduced doses, it seems logical that a DSS should guide inputs to make the dose used appropriate to the disease risk.

- Direct comparisons between results from systems experiments and commercial practice need to be made with caution, due to, the different operating environment and the ability of a small number of experimental sites to represent the variation in disease risk experienced across the country. Nevertheless, it seems reasonable to conclude that, given appropriate decision support, substantially better disease control could be obtained from the level of inputs currently being used, or equivalent control could be obtained from substantially lower inputs.

- Decision models are subject to conflicting requirements of simplicity of operation and the need to be both robust in operation and accurate in defining inputs close to the economic optimum. The large number of cereal producers in the UK suggests that any system which required a substantial element of face to face user training, would be unlikely to achieve substantial uptake. Failure to operate the system accurately, could raise issues of crop loss liability. Furthermore, disease control decisions form only part of the crop management complex. Disease control decision models might therefore be more effectively implemented as a component of a modular system covering a range of cropping decision.

- With these limitations in mind, it seems unlikely that any of the disease specific models tested here could be implemented effectively as 'stand alone' systems, in their current form.

- Work is underway, based on the systems evaluated here, to develop delivery mechanisms for wheat disease control decision support, in a form that recognises the costs of time spent monitoring crops, and the logistical limitations within which fungicides decisions have to be made. With the aim of transferring current technology to the industry and speeding the exploitation of future improvements in understanding of epidemiology and the role of the crops physiological state in determining response to disease control.

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Appendix 1

DECISION MODEL CRITERIA SUMMARY

Septoria tritici

Managed Disease Control

Spray applications were timed according to leaf emergence and the occurrence of 'Rain Events'. The latter defined as 5 mm or more of rain in any one day or 10 mm or more of rain during a consecutive three day period. Sprays were applied within 10 days of a 'Rain Event' occurring, at any time after the emergence of eventual leaf 3 (for varieties with a *Septoria tritici* resistance rating <4) or leaf 2 (for varieties with a resistance rating 4 or above). Leaves 3 and 2 are generally fully emerged at GS 32 and GS 33 respectively. A three week period was allowed between any fungicide application, and no sprays were applied later than 14 days after anthesis. In the absence of rain events, a prophylactic spray was applied at GS 39.

Bayer CDS

Fungicide applications were made when the following threshold levels were reached:

Threshold for 1st application	*Septoria* lesions on more than 50% of the leaves in the indication leaf layer. ie based on incidence of infection.

Indication leaf layer for 1st application

Growth stage	Leaf position	Decision
37-39	F-4(L5)	Application
43-47	F-3(L4)	if threshold
51-69	F-2(L3)	reached

Threshold for 2nd application	*Septoria* lesions present on more than 50% of the leaves in the leaf position F-2 (leaf 3) during the decision period. At least three weeks should elapse between treatments.

Decision period for 2nd application

Growth stage at first application	Decision period	Decision
37	51-69	Application if
39	59-69	threshold reached
43	65-69	on leaf F-2
47-69		No application

LARS splashmeter based system

Applications were determined according to Aplashmeter readings, following the flow diagram shown on the following page.

Combined treatments (Treatments 9 and 10)

In 91/92 these treatments required both sets of system criteria to be satisfied to trigger a fungicide application. In 92/93 and 93/94, criteria were modified as follows

Treatment 9:

Using the decision criteria described under 3. the rainfall data of the last 15 days need to be considered for a possible first and second fungicide treatment.

A fungicide should be applied if an ADAS rain event has been recorded within a 15 day period before the 50% threshold was reached.

e.g. threshold reached at GS 39 but no rainfall during the last 15 days → no application required; then rain fall at GS 47 → spray a.s.a.p.

Treatment 10:

Criteria for the first application as under 4.

- if a first application was necessary at GS 39-43 record the rainfall starting 10 days after the first treatment.
- an infection event is triggered when an ADAS rain event was recorded.
- a second spray at least 3 weeks after the first application.
- if the threshold was not reached until GS 51 check IOI on F-4 assessed at GS 37/39. If IOI was between 40% and 50% check rainfall from GS 39 onwards. If an ADAS rain event was recorded, then spray a.s.a.p., but in any case not before GS 51.

Integrated Disease Risk (IDR) Developmental System

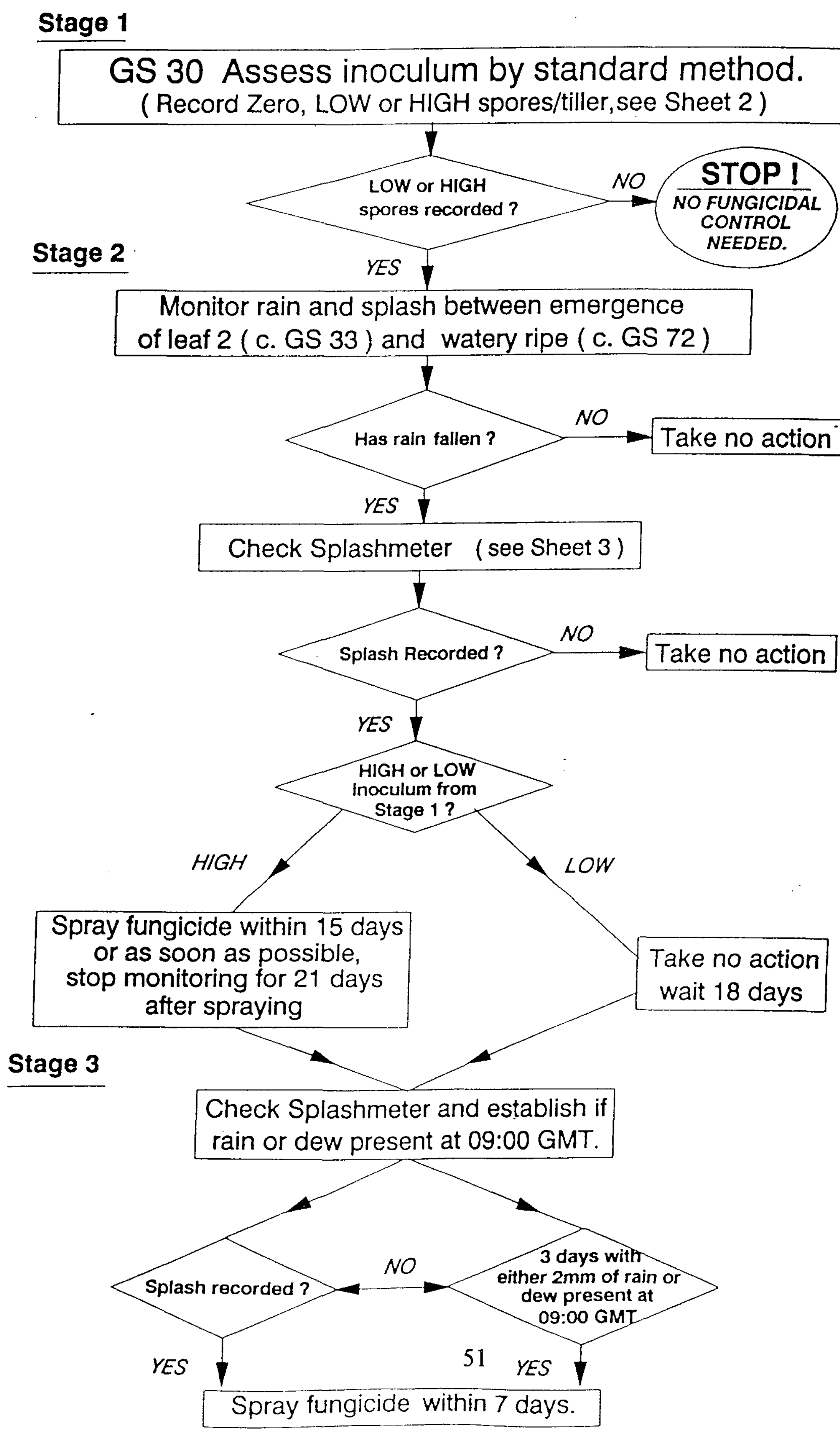
In the absence of data to define the curves of the relationships between inoculum, weather conduciveness, varietal resistance, crop sensitivity; and the risk of disease induced yield loss (or of the relationship between IDR and the appropriate dose), crude curves were defined as shown below.

Fungicide applications were made at doses determined by the equation:

$IDR = (a + 2b + c) * d$

LONG ASHTON *Septoria* FORECASTING

Sheet 1: SCHEME OF FORECAST-GUIDED CONTROL OF *Septoria*



Long Ashton
April, 1992

Equation variables were preliminarily defined as:

a = Inoculum	1	LARS 'Low' spore count
	2	LARS 'High' spore count
	+ 1	CDS threshold
b = Weather conduciveness	1	3 days with 2 mm rain or dew at 09.00 in past week
	2	5 mm rain on any one day during past week
	3	10 mm rain during a consecutive 3 day period or Splashmeter criteria satisfied
c = Resistance	1	Resistance rating 7
	2	Resistance rating 6
	3	Resistance rating 5
	4	Resistance rating 4
	5	Resistance rating 3
d = Crop sensitivity	1	Leaf 3 fully emerged on primary tillers
	1.5	Leaf 2
	3	Leaf 1
	2	Leaf 1 fully emerged + 2 weeks

At L1 + 2 weeks subtract from calculated required dose the dose remaining from L1 application.

IDR	Dose
0-9	0
10-19	1/4
20-29	1/2
30-39	3/4
40+	Full

Mildew

Managed Disease Control

Managed Disease Control thresholds for 1st and 2nd applications were as follows:

MDC threshold	-	50% of tillers showing active disease pustules on any of the top three fully expanded leaves, from GS 32.
Low threshold	-	50% of tillers showing active disease pustules on any leaf layer with more than 50% green leaf are remaining, from GS 32.
High threshold	-	50% of tillers showing active disease pustules on any of the top two fully expanded leaves, from GS 32.

50 % incidence on a given leaf layer generally equated to a severity of 0.5-1%

Fungicide applications were made after GS 71.

Bayer CDS

Fungicide applications were made when the following threshold levels were reached.

Threshold for 1st application	-	Mildew present on more than 80% of plants, ie based on incidence of 1st infection.
Threshold for 2nd application	-	Mildew level on all green leaves greater than 1% of total leaf area, ie based on severity of infection.

Notes:

a. Mildew was only counted if it formed active pustules on green leaves.
b. Green leaves were fully emerged leaves from all leaf positions with a mean of more than 50% of leaf area green.
c. Plant infections included any mildew present on leaves and leaf sheaths on the main tiller of each plant.
d. Mildew level was the percentage in the total green leaf area covered with mildew pustules, ie the mean infection level of all green leaves.

For treatments 7 and 9 in 92/93 and 93/94:

From GS 32 to GS 43:

1st threshold: based on incidence of infection per plant
(as described for first threshold under 1)

From GS 45/47 onwards:

1st threshold: an incidence of infection of more than 70 to 80 %
- on any of the 4 upper leaf layer (up to GS 59)
- on any of the 3 upper leaves from GS 61 to 69

- if a first application was necessary from GS 32 onwards automatically the threshold described under b; has to be used for possible second fungicide treatment

Integrated Disease Risk (IDR) Development System

In the absence of data to define the curves of the relationships between inoculum, weather conduciveness, varietal resistance, crop sensitivity; and the risk of disease induced yield loss (or of the relationship between IDR and the appropriate dose), crude curves were defined as shown below.

Fungicide applications were made at doses determined by the equation:

IDR - (2a + b + 0.5c) *d

Equation elements were preliminarily defined as:

a = Inoculum	1	Low threshold
	2	MDC threshold
	3	High threshold
b = Weather conduciveness	1	Low risk weather
	2	Average risk weather
	3	High risk weather
c = Resistance	0	Resistance rating 9
	1	Resistance rating 8
	2	Resistance rating 7
	3	Resistance rating 6
	4	Resistance rating 5
	5	Resistance rating 4
	6	Resistance rating 3
d = Crop sensitivity	2	GS 31
	2	Leaf 3 fully emerged on primary tillers
	2.5	Leaf 2
	3	Leaf 1
	2	Leaf 1 fully emerged + 2 weeks

In the absence of reliable data, weather conduciveness was always taken as average risk.

IDR	Dose
0-9	0
10-19	1/4
20-29	1/2
30-39	3/4
40+	Full

Appendix 2

DECISION MODELS FOR THE INTEGRATED USE OF FUNGICIDES ON WHEAT
'LINK' Programme: Technologies for Sustainable Farming Systems
Estimated duration: Three harvest years.
Starting time: February 1992.

PROTOCOL (updated 08-04-92)

Sites

In the first year, trials will be established on single cultivars. In years two and three, trials will be carried out as a factorial design incorporating two levels of host partial resistance (i.e. two cultivars).

A total of six field trials (three trials each for mildew and *Septoria tritici)* will be established, on five sites, for harvest year 1992.

Individual trials will be designed to target either mildew or *Septoria tritici* by choice of cultivar and location. The trials will not specifically target yellow or brown rust, but data on these will be gathered if they occur.

Design and Treatments

Randomised block, factorial design (cultivars and spray criteria), with three replicates (or four in year 1). Plots to be a minimum of 3 m wide in order to minimise inter-plot interference. The two cultivars have been selected to exhibit differing levels of host partial resistance to the target disease. All trials should be on sites following at least a one year non-cereal 'break'.

Each cultivar and inoculum level treatment will receive fungicide application/s, according to individual need.

All spray applications to be made in circa. 250 litres/ha water using 110 degree flat fan nozzles with a 'medium' spray quality (as per BCPC definitions of spray quality).

Experiment 1. Target disease - *Septoria tritici*

Treatments

Cultivar Riband Trt.	Beaver $ Trt.	Spray Criteria/fungicide treatment
1.	12.	Untreated
2.	13.	Untreated + Low inoculum
3.	14.	ADAS MDC#
4.	15.	Bayer CDS#
5.	16.	Bayer CDS + Low inoculum
6.	17.	LARS Splashmeter based system
7.	18.	Single spray daylength/GS related*
8.	19.	Three spray programme 32 + 39 + 59
9.	20.	CDS threshold + MDC splash criteria
10.	21.	CDS threshold + LARS splash criteria
11.	22.	IDR developmental system

* - single spray applied on 20 May or GS 39, whichever is the later.

\# - *Septoria tritici* elements only.

Low inoculum = inoculum level artificially reduced by four applications of chlorothalonil from the beginning of February to the end of March.

IDR system = Integrated Disease Risk.

Fungicide = tebuconazole as UK 200 at 1 l/ha.

Experiment 2. Target disease - mildew.

Treatments

Cultivar		
Apollo Trt.	Hereward $ Trt.	Spray criteria/fungicide treatment
1.	15.	Untreated
2.	16.	Untreated without UK152 overspray
3.	17.	Untreated + low inoculum
4.	18.	ADAS MDC #
5.	19.	ADAS MDC # + low inoculum
6.	20.	Bayer CDS #
7.	21.	Bayer CDS # + low inoculum
8.	22.	Bayer CDS **
9.	23.	Bayer CDS ** + low inoculum
10.	24.	Single spray daylength / GS related *
11.	25.	Three spray programme 32/33 + 39 + 59
12.	26.	MDC Low threshold @
13.	27.	MDC High threshold @
14.	28.	IDR developmental system

- mildew elements only.

* - single spray applied on 20 May or GS 39 whichever is the later.

Low inoculum - inoculum level artificially reduced by a single application of fenpropidin at the end of March.

@ - threshold based spray criteria to be derived from further analysis of data from Policy Division and HGCA funded 'wave' type trials (PA51).

** - triazole + morpholine in place of morpholine alone.

IDR system = Integrated Disease Risk

Fungicide = 1.0 l/ha Patrol
** = 0.75 l/ha UK200 + 0.5 l/ha Patrol

All plots, except treatments 2 and 16, to be oversprayed with UK 152 2 l/ha at GS 37 and GS 59, to suppress *Septoria tritici*.

Treatment decision

In order to ensure that decisions are consistently applied across sites, each site manager will contact a pre-determined ADAS and Bayer co-ordinator each week during the growing season (by Fax). A spreadsheet of the latest untreated disease levels and met. data will enable the co-ordinators to determine the timing of spray application for their own system. For second applications, infection levels in the different treated plots will also have to be communicated.

Decisions for the LARS 'Splashmeter system can be made each week by site managers after reference to the guidelines provided. Long Ashton should be consulted if any doubt exists.

Assessments

The following assessments apply to both Experiment 1. (*Septoria*) and Experiment 2. (mildew).

i) Foliar diseases and green leaf area to be assessed weekly from GS 31 to GS 75, in untreated plots and all plots that have received a treatment (or are due to receive a treatment before the next assessment). All leaves with greater than 50% green leaf area to be assessed on each of ten randomly selected tillers per plot. *Septoria tritici* pycnidia numbers should also be counted for Experiment 1 at each assessment. All plots to be assessed at GS 75, regardless of whether they have received a treatment or not. Refer to Disease Assessment Guidelines from ADAS Cereal Disease Compendium.

ii) A random selection of tillers (10 per trial) should be tagged or dissected at each assessment date to establish eventual leaf number. Records, as entered in the computer for analysis, will allow analysis of mean % leaf area affects and % leaves affected (and *Septoria tritici* pycnidia numbers for Experiment 1), for each leaf layer.

iii) Ear diseases to be assessed at GS 85 on 10 randomly selected ears per plot, if more than 5% ear area affected by disease in untreated plots. All lots to be harvested and yield expressed t 85% dry matter. Specific weight and thousand grain weight to be recorded.

iv) Stem base diseases to be assessed on 25 tillers from across the trial area at GS 31 and on 25 tillers from each of the untreated plots at GS 75. (Refer to Disease Assessment Guidelines). Assessment of stem base diseases on every plot may be required at GS 75 if eyespot is of sufficient severity to affect yield.

v) Soil sample to be taken from the trial area and analysed for texture, P, K, Mg index, pH and percent organic matter.

vi) Weather records (max./min. temperature, humidity, rainfall) to be taken from standard Stevenson screens. Data loggers to be sited within the crop canopy to measure temperature, humidity/leaf wetness and rainfall. Rainfall to be recorded at sufficiently short time intervals to enable intensity to be determined.

vii) The following site details will be recorded: location and grid reference, soil type and analysis, previous cropping (3 years), straw disposal method, pre and post-sowing cultivations, date of sowing, seed rate, herbicides, insecticides and growth regulators applied.

viii) Date <u>and time</u> of spray application to be recorded.

ix) When completing data files, <u>all</u> columns must be filled. Where plots have not been assessed (because the treatments have not yet been applied) or leaves have not been assessed (because they have senesced or have yet to emerge), then missing values (*) should be entered (except for green leaf area which becomes, and continues to be, zero when a leaf has senesced). Where a leaf has been assessed but a particular disease was absent then zero (0) should be entered.

DECISION MODELS FOR THE INTEGRATED USE OF FUNGICIDES ON WHEAT

'LINK' Programme: Technologies for Sustainable Farming Systems

PROTOCOL FOR HARVEST YEAR TWO (updated 18-02-93)

Sites

In the first year, trials were established on single cultivars. In years two and three, trials will be carried out as a split plot design incorporating two levels of host partial resistance (i.e. two cultivars).

A total of six field trials (three trials each for mildew and Septoria tritici) were established, on five sites, for harvest year 1992; and eight trials (four sites each for mildew and Septoria tritici) on six sites for each of harvest years 1993 and 1994.

Individual trials will be designed to target either mildew or Septoria tritici by choice of cultivar and location. The trials will not specifically target yellow or brown rust, but data on these will be gathered if they occur.

Design and Treatments

Randomised block, in year 1. Split plot (as per D. Royle design) in years 2 and 3, with three replicates (or four in year 1). Plots to be a minimum of 3m wide in order to minimise inter-plot interference. The two cultivars have been selected to exhibit differing levels of host partial resistance to the target disease. All trials should be on sites following at least a one year non-cereal 'break'.

Each cultivar and inoculum level treatment will receive fungicide application/s, according to individual need.

All spray applications to be made in circa. 250 litres / ha water using 110 degree flat fan nozzles with a 'medium' spray quality (as per BCPC definitions of spray quality).

Experiment 1. Target disease - Septoria tritici

Treatments

Cultivar		
Riband	Beaver £	
Trt.	Trt.	Spray Criteria / fungicide treatment
1.	12.	Untreated
2.	13.	Untreated + Low inoculum
3.	14.	ADAS MDC
4.	15.	Bayer CDS
5.	16.	Bayer CDS + Low inoculum
6.	17.	LARS Splashmeter based system
7.	18.	Single spray daylength / GS related *
8.	19.	Three spray programme 32 + 39 + 59
9.	20.	CDS threshold + Retrospective MDC splash criteria @
10.	21.	CDS threshold + MDC splash criteria for 2nd spray @
11.	22.	IDR developmental system

* - single spray applied on 20 May or GS 39, whichever is the later.

£ - Harvest years 2 and 3 only.

 - Septoria tritici elements only.

@ - Treatment criteria redefined for years 2 and 3.

Low inoculum = inoculum level artificially reduced by four applications of chlorothalonil from the beginning of February to the end of March.

IDR system = Integrated Disease Risk.

Fungicide = tebuconazole as UK200 at 1.0 l /ha.

Experiment 2. Target disease - mildew.

Treatments

Cultivar Apollo Trt.	Hereward £ Trt.	Spray criteria / fungicide treatment
1.	15.	Untreated
2.	16	Untreated without UK152 overspray
3.	17.	Untreated + low inoculum
4.	18.	ADAS MDC
5.	19.	ADAS MDC + low inoculum
6.	20.	Bayer CDS
7.	21.	Bayer CDS + IOI based second spray
8.	22.	Bayer CDS **
9.	23.	Bayer CDS + IOI based second spray **
10.	24.	Single spray daylength / GS related *
11.	25.	Three spray programme 32/33 + 39 + 59
12.	26.	MDC Low threshold @
13.	27.	MDC High threshold @
14.	28.	IDR developmental system

- mildew elements only.

* - single spray applied on 20 May or GS 39 whichever is the later.

£ - Harvest years 2 and 3 only.

Low inoculum = inoculum level artificially reduced by a single application of fenpropidin at the end of March.

@ - threshold based spray criteria to be derived from further analysis of data from Policy Division and H-GCA funded 'wave' type trials (PA51).

** - triazole + morpholine in place of morpholine alone.

IDR system = Integrated Disease Risk
IOI = Incidence of infection

Fungicide = 1.0 l / ha Patrol.
Fungicide for treatments marked ** = 0.75 l/ha UK200 + 0.5 l/ha Patrol.

All plots, except treatments 2 and 16, to be oversprayed with UK152 2 l / ha at GS 37 and GS 59, to suppress Septoria tritici.

Treatment decisions

In order to ensure that decisions are consistently applied across sites, each site manager will contact a pre-determined ADAS and Bayer co-ordinator each week during the growing season (by Fax). A spreadsheet of the latest untreated disease levels and met. data will enable the co-ordinators to determine the timing of spray application for their own system. For second applications, infection levels in the different treated plots will also have to be communicated.

Decisions for the LARS 'Splashmeter' system can be made each week by site managers after reference to the guidelines provided. Long Ashton should be consulted if any doubt exists.

Assessments

The following assessments apply to both Experiment 1. (Septoria) and Experiment 2. (mildew), except where noted.

i) Foliar diseases and green leaf area.

All foliar diseases and green leaf area (GLA) to be assessed weekly in all replicates from GS 31 to GS 85.

Early in the season some of the plots will have received the same treatment or will have received no treatment. There is no need to assess all plots. To ensure some uniformity across sites, where several treatments are identical, assess only the treatment within that group with the lowest treatment number. As soon as 50% of treatments with either cultivar have received different sprays, or GS 39 has been reached (whichever occurs first), all plots of both cultivars should be assessed at each assessment date.

All leaf layers with greater than 50% GLA to be assessed on each of ten randomly selected tillers per plot. All leaves should be assessed for a particular leaf layer if the mean GLA for that leaf layer, across all treatments, is greater then 50%. Only assessing individual leaves or treatments with more than 50% GLA would distort the data. In Experiment 1, all leaves from the leaf layer below the layer defined above should be assessed for incidence and (for treatments 1 & 2) sampled for pycnidia counting.

Leaf area affected by *Septoria tritici* should only include lesions or necrotic areas where the presence of pycnidia are observed (by hand lens if necessary).

Septoria tritici pycnidia numbers will be counted by Bayer on treatments 1 and 2 of Experiment 1. All leaves that have been assessed should be dried and sent to Ulli Schoefl at Elm Farm Development Station (EFDS). Leaves shoud be grouped for each leaf position for each plot assessed. Leaves can be dried by placing on paper towels and leaving in a warm room for 24 hours. They can be stored in brown paper envelopes, labelled with plot ref., date and leaf layer number. Sending these to EFDS at regular intervals would ease the workload. EFDS will return the count data to the site of origin as soon as practicable, for the data to be entered into the computer data files.

The first threshold in the CDS decision system for Experiment 2, is based on incidence of mildew on plants not tillers. Also, infection of the leaf sheaths could be important. Until all of the four CDS treatments have received a spray, record overall incidence of mildew on whole plants - in treatments 1 and 3 only - and add these data to the weekly summary. If every tiller is infected the plant assessment will not be needed.

ii) Leaf number determination

A random selection of tillers (10 per trial) should be tagged or dissected at each assessment date to establish eventual leaf number. Records, as entered in the computer for analysis, will allow analysis of mean % leaf area affected and % leaves affected (and Septoria tritici pycnidia numbers for Experiment 1), for each leaf layer.

iii) Ear disease assessment

Ear diseases to be assessed at GS 85 on 10 randomly selected ears per plot, if more than 5% ear area affected by disease in untreated plots. All plots to be harvested and yield expressed at 85% dry matter. Specific weight and thousand grain weight to be recorded.

iv) Stem base disease assessment

Stem base diseases to be assessed on 25 tillers from across the trial area at GS 31 and on 25 tillers from each of the untreated plots at GS 75. (Refer to Disease Assessment Guidelines). Assessment of stem base diseases on every plot may be required at GS 75 if eyespot is of sufficient severity to affect yield - ie. >20% of tillers affected.

v) Ecotype analysis

Leaf samples to be taken from Experiment 1 sites, at GS 30/31 and GS 75, for determination of Septoria tritici ecotypes. Refer to D. Royle protocol dated 27 January 1993.

vi) Inoculum measurement

Inoculum to be assessed, in Experiment 1, by the leaf washing technique (refer to 'Forecasting Septoria in winter wheat - The Long Ashton Approach' for protocol), for treatments 2 and 5 (all reps) at the time of first application of chlorothalonil. This should then be repeated following the final chlorothalonil application at late GS 30/early GS 31 and again at GS 32, on these same treatments plus treatment 6 (LARS 'Splashmeter').

vii) Chlorothalonil analysis

Whole tiller samples to be taken from treatments 1 and 2 of Experiment 1, for chlorothalonil analysis. Sample numbers / dates and storage protocol to be defined by D. Royle.

viii) Crop measurements

Fertile tiller count, in treatment 1 only,converted to fertile tillers m^{-2}. Rapid measurement of average main tiller height to ligule of flag leaf ca. GS 75.

ix) Soil analysis

Soil sample to be taken from the trial area and analysed for texture, P, K, Mg index, pH and percent organic matter.

x) Met. data collection

Weather records (max. / min. temperature, humidity, rainfall) to be taken from standard Stevenson screens. Data loggers to be sited within the crop canopy to measure temperature, humidity / leaf wetness and rainfall. Weather data to be recorded from crop emergence to senescence (loss of all green leaf). Rainfall to be recorded at a sufficiently short time intervals to enable intensity to be determined.

xi) Site details

The following site details will be recorded: location and grid reference, soil type and analysis, previous cropping (3 years), straw disposal method, pre and post-sowing cultivations, date of sowing and harvest, seed rate, fertilizer, herbicides, insecticides and growth regulators applied.

xii) Spray application recording

Date and time of spray application to be recorded

xiii) Date entry

When completing data files, all columns must be filled. Where plots have not been assessed (because the treatments have not yet been applied) or leaves have not been assessed (because they have senesced or have yet to emerge), then missing values (*) should be entered (except for green leaf area which becomes, and continues to be, zero when a leaf has senesced). Where a leaf has been assessed but a particular disease was absent then zero (0) should be entered.

DECISION MODELS FOR THE INTEGRATED USE OF FUNGICIDES ON WHEAT

'LINK' Programme: Technologies for Sustainable Farming Systems

PROTOCOL FOR HARVEST YEAR THREE (updated 03-04-94)

Sites

In the first year, trials were established on single cultivars. In years two and three, trials will be carried out as a split plot design incorporating two levels of host partial resistance (i.e. two cultivars).

A total of six field trials (three trials each for mildew and Septoria tritici) were established, on five sites, for harvest year 1992; and eight trials (four sites each for mildew and Septoria tritici) on six sites for each of harvest years 1993 and 1994.

Individual trials will be designed to target either mildew or Septoria tritici by choice of cultivar and location. The trials will not specifically target yellow or brown rust, but data on these will be gathered if they occur.

Design and Treatments

Randomised block, in year 1. Split plot (as per D. Royle design) in years 2 and 3, with three replicates (or four in year 1). Plots to be a minimum of 3m wide in order to minimise inter-plot interference. The two cultivars have been selected to exhibit differing levels of host partial resistance to the target disease. All trials should be on sites following at least a one year non-cereal 'break'.

Each cultivar and inoculum level treatment will receive fungicide application/s, according to individual need.

All spray applications to be made in circa. 250 litres / ha water using 110 degree flat fan nozzles with a 'medium' spray quality (as per BCPC definitions of spray quality).

Experiment 1. Target disease - Septoria tritici

Treatments

Cultivar Riband Trt.	Cultivar Beaver $ Trt.	Spray Criteria / fungicide treatment
1.	12.	Untreated
2.	13.	Untreated + Low inoculum
3.	14.	ADAS MDC #
4.	15.	Bayer CDS #
5.	16.	Bayer CDS + Low inoculum
6.	17.	LARS Splashmeter based system
7.	18.	Single spray daylength / GS related *
8.	19.	Three spray programme 32 + 39 + 59
9.	20.	CDS threshold + Retrospective MDC splash criteria @
10.	21.	CDS threshold + MDC splash criteria for 2nd spray @
11.	22.	IDR developmental system

* - single spray applied on 20 May or GS 39, whichever is the later.

$ - Harvest years 2 and 3 only.

\# - Septoria tritici elements only.

@ - Treatment criteria redefined for years 2 and 3.

Low inoculum = inoculum level artificially reduced by four applications of chlorothalonil from the beginning of February to the end of March.

IDR system = Integrated Disease Risk.

Fungicide = tebuconazole as UK200 at 1.0 l /ha.

Experiment 2. Target disease - mildew.

Treatments

Cultivar Apollo Trt.	Hereward $ Trt.	Spray criteria / fungicide treatment
1.	15.	Untreated
2.	16	Untreated without UK152 overspray
3.	17.	Untreated + low inoculum
4.	18.	ADAS MDC #
5.	19.	ADAS MDC # + low inoculum
6.	20.	Bayer CDS #
7.	21.	Bayer CDS + IOI based second spray #
8.	22.	Bayer CDS ** #
9.	23.	Bayer CDS + IOI based second spray ** #
10.	24.	Single spray daylength / GS related *
11.	25.	Three spray programme 32/33 + 39 + 59
12.	26.	MDC Low threshold @
13.	27.	MDC High threshold @
14.	28.	IDR developmental system

- mildew elements only.

* - single spray applied on 20 May or GS 39 whichever is the later.

$ - Harvest years 2 and 3 only.

Low inoculum = inoculum level artificially reduced by a single application of fenpropidin at the end of March.

@ - threshold based spray criteria to be derived from further analysis of data from Policy Division and H-GCA funded 'wave' type trials (PA51).

** - triazole + morpholine in place of morpholine alone.

IDR system = Integrated Disease Risk
IOI = Incidence of infection

Fungicide = 1.0 l / ha Patrol.
Fungicide for treatments marked ** = 0.75 l/ha UK200 + 0.5 l/ha Patrol.

All plots, except treatments 2 and 16, to be oversprayed with UK152 2 l / ha at GS 37 and GS 59, to suppress Septoria tritici.

Treatment decisions

In order to ensure that decisions are consistently applied across sites, each site manager will contact a pre-determined ADAS and Bayer (Ulli Schoefl, Munich) co-ordinator each week during the growing season (by Fax). A spreadsheet of the latest untreated disease levels and met. data will enable the co-ordinators to determine the timing of spray application for their own system. For second applications, infection levels in the different treated plots will also have to be communicated.

Decisions for the LARS 'Splashmeter' system can be made each week by site managers after reference to the guidelines provided. Long Ashton should be consulted if any doubt exists.

Calirus oversprays

For Experiments 1 and 2, a Calirus overspray should be applied to any individual variety to control rusts, if:

GS 31 to 59, yellow rust starts to form foci.

or

GS 39 to 59, brown rust affects > 1% of any of leaves 1,2 or 3.

or

GS 59 to 75, brown rust affects > 1% of any of leaves 1 or 2.

No more than two Calirus oversprays should be applied.

Each replicate block of each variety should contain a 'spare' plot. These plots should remain completely untreated. If Calirus oversprays are applied, the 'spare' plots of the variety/s that have received an overspray should be assessed for disease and GLA at each subsequent assessment, and should be harvested for yield determination.

Assessments

The following assessments apply to both Experiment 1. (Septoria) and Experiment 2. (mildew), except where noted.

i) Foliar diseases and green leaf area.

All foliar diseases and green leaf area (GLA) to be assessed weekly in all replicates from GS 31 to GS 85.

Early in the season some of the plots will have received the same treatment or will have received no treatment. There is no need to assess all plots. To ensure some uniformity across sites, where several treatments are identical, assess only the treatment within that group with the lowest treatment number. As soon as 50% of treatments with either cultivar have received different sprays, or GS 39 has been reached (whichever occurs first), all plots of both cultivars should be assessed at each assessment date.

All assessable leaf layers (as defined in the Guidance Notes below) should be assessed on each of ten randomly selected tillers per plot. To avoid distortion of the data ALL ten leaves should be assessed from all assessable leaf layers. In Experiment 1, all leaves from the leaf layer below the layer defined above should be assessed for incidence.

Leaf area affected by Septoria tritici should only include lesions or necrotic areas where the presence of pycnidia are observed (by hand lens if necessary).

Septoria tritici pycnidia numbers will be counted by Ulli Schoefl on treatment 1 of Experiment 1. Ten leaves per leaf layer, per plot, that have been assessed should be dried and sent to Munich. All ten leaves should be sent even if some or all of them are undiseased. The number of leaf layers collected and sent should always be the same as for the 'best' treatment, even if that many leaf layers are not being assessed in treatment 1 (untreated). Leaves should be grouped for each leaf position for each plot assessed. Leaves can be dried by placing on paper towels and leaving in a warm room for 24 hours. They can be stored in brown paper envelopes, labelled with plot ref., date and leaf layer number. Sending these to Munich at regular intervals would ease the workload. Ulli will return the count data to the site of origin as soon as practicable, for the data to be entered into the computer data files.

The first threshold in the CDS decision system for Experiment 2, is based on incidence of mildew on plants not tillers. Also, infection of the leaf sheaths could be important. Until all of the four CDS treatments have received a spray, record overall incidence of mildew on whole plants - in treatments 1 and 3 only - and add these data to the weekly summary. If every tiller is infected the plant assessment will not be needed.

ii) Leaf number determination

A random selection of tillers (10 per trial) should be tagged or dissected at each assessment date to establish eventual leaf number. Records, as entered in the computer for analysis, will allow analysis of mean % leaf area affected and % leaves affected (and Septoria tritici pycnidia numbers for Experiment 1), for each leaf layer.

iii) Ear disease assessment

Ear diseases to be assessed at GS 85 on 10 randomly selected ears per plot, if more than 5% ear area affected by disease in untreated plots. All plots to be harvested and yield expressed at 85% dry matter. Specific weight and thousand grain weight to be recorded.

iv) Stem base disease assessment

Stem base diseases to be assessed on 25 tillers from across the trial area at GS 31 and on 25 tillers from each of the untreated plots at GS 75. Assessment of stem base diseases on every plot may be required at GS 75 if eyespot is of sufficient severity to affect yield - ie. >20% of tillers affected.

v) Ecotype analysis

Leaf samples to be taken from Experiment 1 sites, at GS 30/31 and GS 75, for determination of Septoria tritici ecotypes.

On each occasion leaves bearing lesions should be removed from plants in three of the replicate plots of treatment 1 (untreated) only. Adequate random sampling will be achieved if approximately 10 infected leaves are gathered from each of 3 random locations within each of the 3 plots. This will give 10*3*3 = ca. 90 leaves which can be pooled and sent in a polythene bag, in a cardboard box, by first class mail to LARS. If leaves are dry at the time of collection please add a plug of wet cotton wool/filter paper in the bag before despatch.

On receipt the leaves will be washed, incubated in moist chambers for 24h and then a spore suspension made to use for inoculation of potted plants straightaway or after storage in milk at $-20^{o}C$. The standardized procedure for this inoculation has been developed in work with a US University for comparison of septoria populations between sites.

vi) Inoculum measurement

Inoculum to be assessed, in Experiment 1, by the leaf washing technique (refer to 'Forecasting Septoria in winter wheat - The Long Ashton Approach' for protocol), for treatments 2 and 5 (all reps) at the time of first application of chlorothalonil. This should then be repeated following the final chlorothalonil application at late GS 30/early GS 31 and again at GS 32, on these same treatments plus treatment 6 (LARS 'Splashmeter'). LARS will provide sites with instructions for sample packaging and despatch if the counting is to be carried out at LARS to ensure standardization.

vii) Crop measurements

Fertile tiller count, in treatment 1 only, converted to fertile tillers m^{-2}. Rapid measurement of average main tiller height to ligule of flag leaf ca. GS 75.

viii) Soil analysis

Soil sample to be taken from the trial area and analysed for texture, P, K, Mg index, pH and percent organic matter.

ix) Met. data collection

Weather records (max. / min. temperature, humidity, rainfall) to be taken from standard Stevenson screens. Data loggers to be sited within the crop canopy to measure temperature, humidity / leaf wetness and rainfall. Weather data to be recorded from crop emergence to senescence (loss of all green leaf). Rainfall to be recorded at a sufficiently short time intervals to enable intensity to be determined.

x) Site details

The following site details will be recorded: location and grid reference, soil type and analysis, previous cropping (3 years), straw disposal method, pre and post-sowing cultivations, date of sowing and harvest, seed rate, fertilizer, herbicides, insecticides and growth regulators applied.

xi) Spray application recording

Date and time of spray application to be recorded

xii) Date entry

When completing data files, all columns must be filled. Where plots have not been assessed (because the treatments have not yet been applied) or leaves have not been assessed (because they have senesced or have yet to emerge), then missing values (*) should be entered (except for green leaf area which becomes, and continues to be, zero when a leaf has senesced). Where a leaf has been assessed but a particular disease was absent then zero (0) should be entered.

<u>Guidance Notes for Foliar Disease Assessments</u>

Mildew sites

1. Assess a constant number of leaf layers on all plots. Ten leaves per plot (per leaf layer) should always be assessed even if some of them are below 50% green leaf area. At each assessment, the number of leaf layers to be assessed should be decided, as an average across the experiment, as those layers with greater than 50% GLA. It is accepted that occasionally it may be necessary to assess one fewer leaf layers in the untreated plots.

Septoria sites

Problems can occur when severe <u>Septoria tritici</u> (or brown rust !) causes such high levels of damage that it drives a leaf layer in a given treatment below the 50% GLA threshold for assessment. If that leaf layer is not assessed, the assessment data will not truly reflect the level of damage caused by the disease. This seems to be the main reason behind Ulli's request to assess 'dead' leaves.

Hence:

1. Look in the plots with the most green leaf. The difference between these plots and those with least green leaf must be primarily due to disease. The assessment scores need to reflect this. The % area

scored for a given disease should be the area of green leaf loss that can reasonably be attributed to the presence of that diseases.

2. Decide, on average across the experiment, how many leaf layers can be assessed - bearing in mind the comments above. It is possible to assess septoria on leaves with less than 50% GLA, as the pycnidia remain visible and the original outline of the lesion can sometimes be seen.

3. Assess a constant number of leaf layers on all plots. Ten leaves per plot (per leaf layer) should always be assessed even if some of them are below 50% green leaf area. It is accepted that occasionally it may be necessary to assess one fewer leaf layers in the untreated plots.