POSTER SESSION 8A

PEST AND DISEASE MANAGEMENT IN ARABLE CROPS

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The effects of fungicides on *Fusarium graminearum* growth and its consequences to green leaf retention, yield and seedling emergence

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ABSTRACT

The effectiveness of the fungicides flutriafol + carbendazim, fenpropimorph and diclobutrazol in combination with prochloraz was tested in field experiment against *Fusarium graminearum* (*Gibberella* zeae) responsible for fusarium head blight (FHB) on two durum wheat cultivars. The fungicides were applied at full recommended and half-rate. Infected crop residues produced a severe natural epidemic. Fungicide applications were effective against *F. graminearum* at the full rate but less-so at the half rate. Green leaf area (GLA) was increased and maintained for longer with all fungicide mixtures. GLA was negatively correlated with disease severity and positively correlated with yield. High GLA and GLA duration increased grain weight and grain yield. FHB infection of seed collected at GS 85 was lower than those collected at harvest. Germination of GS 85 collected seeds was higher than those collected at harvest. Significant differences were found in seedling emergence of kernels produced from healthy and FHB infected spikes. Seedlings from FHB damaged kernels were characterized by reduced coleoptile elongation and by seedling death. This study indicated that fungicide treatments, although increasing yield and reducing inoculum of diseases, may not be sufficient to reduce FHB contamination in the grain of wheat.

INTRODUCTION

Fusarium graminearum [teleomorphe *Gibberella zeae*] is a serious wheat disease problem on durum wheat and is the dominant pathogen responsible for fusarium head blight (FHB, scab) in Greece. Rainfall, temperature and cultivar are important factors affecting the severity of FHB infection as well as deoxynivalenol (DON) production. In recent years FHB caused yield and quality losses due to the production of smaller and fewer kernels, contaminated with mycotoxins, in many parts of world (McMullen *et al.*, 1997, Warldon *et al.*, 1999). In Greece the incidence and severity of FHB has increased in recent years because of widespread cultivation of durum wheat in areas with more fertile and wet soils, favourable for the development of this pathogen. Development of resistant cultivars has been difficult because of the complex inheritance of resistance. It is based in several factors and the resistance of *F. graminearum* available to hexaploid wheat sources has not successfully been transferred to durum – a tetraploid wheat. Cultivars commonly grown in Greece showed consistent differences in susceptibility to FHB infection with durum cultivars being more susceptible than bread wheat. The occurrence of FHB during recent years also may be attributed to low tillage farming practices, which allow the continuing presence of *F. graminearum* inoculum in the crop residues. Moreover, because *F. graminearum* also is associated with corn stalk and ear rot of maize, the fungus persists and multiplies on infected crop residues, of small grain cereals and maize. Seed born contamination is considered to be the primary source of inoculum. Infected seed also may have low germination ability. Fungicide spray treatments are used to protect the photosynthetically active green area on upper leaves from damage, and thus to improved grain filling and increased grain yield (Bryson *et al*., 1997). It has reported that new fungicides such as strobilurin cause direct physiological changes in treated plants such as an increase in leaf greenness and delayed senescence (Bayles & Hilton, 2000). These changes could be contributory factors to the yield increases. The objective of this study was to evaluate fungicide effects on *F. graminearum* infection, the green leaf area duration, the germination ability of seed and grain yield.

MATERIALS AND METHODS

An experiment was established at a field near the Cereal Institute of Thessaloniki. Seed was drilled on 5th November 1996 into plots 2x20 m at a rate of 300 seeds/m^2 in a split-plot design with four replicate plots per treatments. Main plots were two durum wheat cultivars: Mexicali 81 (early and semi dwarf, 85-95 cm) and Athos (later and taller, 115-125 cm), both durum wheats widely grown in Greece. All other husbandry applications were applied to good farm practice guidelines. Growth stages were assessed according to Tottman (1987). The fungicide treatments were: flutriafol + carbendazim, fenpropimorph + prochloraz and diclobutrazol + prochloraz at full and half label recommended rates (Table 1). A propane pressurized knapsack sprayer was used to apply the fungicides in a volume of 200-300 l/ha at GS 55. The field was naturally severely infected with *F. graminearum* as maize, a host of the pathogen, was grown the preceding summer and residues were left in the field.

Each plot was sampled at GS 75, GS 85 and at harvest time by taking a random sample of 30 plants at ground level from a diagonal traverse across the plot. Greening effects were assessed at GS 75 as the incidence (%) of green leaves and at GS 85 as the incidence (%) of green flag leaves without disease symptoms.

Disease development was assessed by visual inspection at GS 85 and after harvest of the percentage of spikes showing infection as well as the percentage of infected seeds. Experimental plots were harvested using a plot combine to obtain final grain yield. Grain samples were analyzed in the laboratory for thousand grain weight. Germination tests were performed on all treatments for seeds collected from GS 85 to harvest. One hundred seeds were placed in a 9 cm diameter Petri plates on moist filter paper and were incubated in the dark at 18-20°C for two weeks. Four replicates per treatment were used. Analyses of variance were done in all data sets. Linear regression was done to relate effects of fungicides on disease, green leaf area duration, germination ability and grain yield.

RESULTS

Spike and kernel infection

All fungicides tested were able to reduce the level of spike and kernel infection by *G. zeae* at the recommended rate (Table 1). The control achieved by the recommended rate was higher than that of the half rate of the three fungicide mixtures, in both cultivars. Incidence of spike infection of cultivar Mexicali 81 was significantly higher than that of cultivar Athos but not at the full rate of the first two fungicides. It was not, however, possible to obtain complete control of the pathogen. The percent of *G. zeae* infected kernels at harvest was lower in all fungicide treated samples than in the untreated control, except with diclobutrazol + prochloraz at half rate on cv. Athos. The percentage of kernel infection, after visual assessment at GS 85, was lower in all treatments than after harvest.

Table 1. Spikes and kernels infected by *G. zeae* on durum wheat sprayed with fungicides

Fungicide	Rate (l/ha)	Infected spikes (%)		Infected kernels (%)			
				GS 85		harvest time	
		Mexicali 81	Athos	Mexicali 81	Athos	Mexicali 81	Athos
flutriafol+carbendazim	1.25	31.3	25.0	2.6	7.6	16.6	11.7
	0.63	87.3	48.8	12.6	11.6	23.9	34.7
fenpropimorph+prochloraz	2.00	28.8	30.5	3.0	5.0	15.0	10.2
	1.00	68.0	51.3	7.6	13.0	23.0	31.0
diclobutrazol+prochloraz	1.00	66.0	47.8	2	6.4	18.6	14.2
	0.50	84.0	61.0	5.0	10.0	24.5	39.6
Control		85.0	67.8	6.4	17.0	33.7	37.2
LSD(*P*=0.05)		7.9		5.0		4.0	

Green leaf duration

The leaf area remaining green (% green leaves) at GS 75 was increased by fungicide applications at the recommended rates but not at the half rate except with flutriafol + carbendazim on cv. Athos (Table 2). A proportion of this increase may be attributed to the reduction in FHB i.e. disease control. Generally, cv. Athos had a higher percent of green leaf area than cv. Mexicali 81. In untreated and half rate fungicide application plots, green leaf area started to decrease, and was lost, earlier than in the fungicide full rate treatments. At GS 85 most leaves of wheat plants were dry in untreated controls as well as with the half rate fungicide applications, whilst with full rate fungicides the percent of green flag leaves ranged from 32 to 53%. The percent of green leaves was higher with flutriafol + carbendazim than with the other two fungicides.

Table 2. Percent of green leaves at GS 75 and green flag leaves at GS 85 and grain yield (kg/ha) after fungicides application

Fungicide	Rate (l/ha)	Green leaf % at GS 75		Green flag leaf % at GS 85		Grain yield (kg/ha)	
		Mexicali 81	Athos	Mexicali 81	Athos	Mexicali 81	Athos
flutriafol+carbendazim	1.25	42	65	38	53	4428	4095
	0.63	16	30	20	27	3073	2260
fenpropimorph+prochloraz	2.00	35	48	33	41	4770	4333
	1.00	13	22	16	20	3130	2670
diclobutrazol+prochloraz	1.00	34	39	32	36	3993	3558
	0.50	13	24	13	23	2828	2298
Control		11	21	15	19	2269	1902
LSD(*P*=0.05)		5.7		4.1		312	

Germination

The germination of kernels taken at GS 85 and at harvest was very high with the recommended rate of the fungicides and lower with the half rate and lower still with the untreated control (Table 3). The same was true for the kernels collected after harvest but germination was generally lower than that of the kernels collected at GS 85 (Table 3).

Table 3. Germination (%) of seeds of two cultivars (Mexicali 81 and Athos) collected at GS 85 and at harvest, grown under four different fungicide regimes

Fungicide	Rate (l/ha)	GS 83-85, % germination		Harvested seed, % germination	
		Mexicali 81	Athos	Mexicali 81	Athos
flutriafol+carbendazim	1.25	97	91	88	86
	0.63	85	81	69	71
fenpropimorph+prochloraz	2.00	96	91	87	92
	1.00	89	81	75	70
diclobutrazol+prochloraz	1.00	98	92	89	91
	0.50	86	83	64	73
Control (none)		73	65	53	50
LSD(P=0.05)		6.2		5.0	

Germination of seeds from spikes without infection was much higher than from infected spikes (Table 4). These results suggest that *G. zeae* inhibited the germination of infected seeds.

Table 4. Germination (%) and infection (%) with FHB of kernels from healthy and infected spikes

Fungicide	Rate (l/ha)	Germination (%) Healthy	Germination (%) Infected	Infection (%) Healthy	Infection (%) Infected
flutriafol+carbendazim	1.25	89	62	1.0	11.0
	0.63	79	51	0.5	16.0
fenpropimorph+prochloraz	2.00	89	70	0.5	13.0
	1.00	79	67	1.5	17.0
diclobutrazol+prochloraz	1.00	90	59	6.0	21.6
	0.50	81	51	3.0	33.6
Control		63	51	11.6	17.6
LSD(P=0.05)		6.8		5.1	

Grain yield

Recommended rates of the three fungicides increased the yield (Table 2). Reduced rates (half of recommended) gave lower yield increases than the full rate but still significantly higher yields than the untreated controls (Table 2). Fenpropimorph + prochloraz produced higher yields (but not all significantly) than the other two fungicides. Infected kernels were often light and shriveled and it was likely that they contained mycotoxins such as deoxynivalenol (DON).

Correlations between incidence of infected spikes and kernels with all other variables studied were significantly negative at $P=0.01$ level (Table 5). Correlations between the percent of green leaves with all the other variables were significantly positive except with infected spikes and kernels, which were negative.

Table 5. Correlation coefficients between all variables (all significant at $P=0.01$ level)

	Infected spikes	Infected seeds	Green leaves	Green flag leaves	Germination (GS 85)	Germination (harvest)	Yield
Infected spikes	1.000						
Infected seeds	0.552	1.000					
Green leaves	-0.852	-0.600	1.000				
Green flag leaves	-0.814	-0.657	0.926	1.000			
Germination (GS 85)	-0.456	-0.650	0.425	0.571	1.000		
Germination (harvest)	-0.674	-0.767	0.694	0.770	0.769	1.000	
Yield	-0.653	-0.868	0.617	0.746	0.764	0.810	1.000

DISCUSSION

Fungicide treatments tested achieved relatively good control of *G. zeae* and yield benefits through enhanced longevity of the upper leaves. It is therefore likely that the primary cause of the increased in green leaf area in the fungicide treated plots was due to the control of disease. Bryson *et al.* (2000) found that kresoxin-methyl delays leaf senescence and increases the duration of green leaf area, but the mechanism is not clearly understood. There will be inevitably a limit on how long green leaf area can contribute to the yield forming process as grain filling is generally curtailed once the grain has reached <40% moisture especially in the dry conditions of Greece and for the late maturing cultivar, Athos.

Infection severity depended largely on cultivar, rate of fungicide mixture applied and the weather. FHB values, green leaf longevity, seed germination and yield response appear to be related. Some variability is explained by the presence of tolerance mechanisms, which are unknown and affect the relationship between FHB severity and yield response. Disease control is only a partial explanation for the yield advantage obtained with fungicides as reported for other diseases and fungicides. The application of fungicides showed a significant effect on the fungus and it is a useful tool for analyzing disease – yield relationship.

A full dose was necessary to achieve any satisfactory disease control. However, with the level of control of the half dose the yield was higher than that of the untreated control, giving satisfactory profit to the farmers. The rapid destruction of green leaf area even with low levels of *G. zeae* limited the yield and the seed germination ability. These results provide evidence that increasing green leaf area and duration through the use of fungicides has a substantial effect on yield of durum wheat and yield components. Similar results were reported by Dimmock & Gooding (2000) and Gooding *et al.* (2000).

Wet and warm weather favored the development of the pathogen and further rain between 20 March and 30 April enabled the pathogen to infect the spikes and continue to infect the seeds until harvest. There may have been multiple inoculation episodes coinciding with wet periods after GS 85 as seed germination ability decreased between GS 85 and harvest.

Taller cultivars showed reduced severity of ear blight compared to shorter cultivars and no other morphological characters (Mesterházy, 1995). Athos cultivar whilst taller than Mexicali 81, tended to have increased severity of ear blight at the lower fungicide rate compared to the shorter Mexicali 81 and lower percent seed germination even though it had a higher percentage of green leaves at the two stages of assessment. This may be explained by its later maturity and therefore it was exposed to infection for longer time, even though this cultivar is less susceptible to stem infection than Mexicali 81 (Korpetis & Skorda, 2000).

The percentage germination of seeds decreased with the seed weight. Poor emergence was most evident from light seeds as was common from infected spikes. Seed infected with FHB was characterized by both reduced and delayed emergence and by seedling death. The inhibition of coleoptile elongation by trichothecene and DON is well described and these compounds show differences in phytotoxity; DON is most toxic to the coleoptile. Reduction of coleoptile elongation of these cultivars was correlated with FHB susceptibility (Eudes *et al.*, 2000). Hence, fungicides seem to decrease FHB and increase yield.

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Chemical control of eyespot and other stem-base pathogens in an early drilled first winter wheat crop

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ABSTRACT

The effect of nine fungicide treatments on the natural development of eyespot, brown foot rot and sharp eyespot was evaluated in an early drilled first winter wheat crop. All fungicide treatments were applied at GS 31 and visual assessments for stem-base diseases were made before fungicide application and at GS 39 and 69. Competitive PCR was used to quantify *Tapesia yallundae, T. acuformis*, *Microdochium nivale* and *Rhizoctonia cerealis*. PCR results indicated that *T. acuformis* was the dominant species present. Treatments containing cyprodinil were most successful in reducing DNA levels of *T. acuformis* and visual symptoms of eyespot. Treatments containing prochloraz were not effective at controlling eyespot. There was a significant positive relationship between the severity of eyespot and DNA levels of *T. acuformis* recovered at GS 69. DNA levels of *M. nivale* and *R. cerealis* were low throughout the season and none of the treatments showed any significant effect against these pathogens. All fungicides increased yield compared to the untreated control with the largest increase achieved following an application consisting of a mixture of cyprodinil, epoxiconazole and picoxystrobin.

INTRODUCTION

Eyespot is considered to be the most damaging stem-base disease of cereals with estimated induced losses in England and Wales for 1998 of £23.6 million (Hardwick *et al*., 2001). The disease is caused by *Tapesia acuformis* and *T. yallundae* (formerly known as R-type and W-type of *Pseudocercosporella herpotrichoides*) and often occurs with brown foot rot and sharp eyespot, caused by *Microdochium nivale* and/or *Fusarium* spp. and *Rhizoctonia cerealis*, respectively.

Early drilling, close cereal rotation and mild, wet winter weather conditions favour severe eyespot epidemics. Both of the *Tapesia* spp. can cause severe disease at the end of the growing season and recent work indicates that symptoms of similar severity caused by the two pathogens, if achieved, would be equally damaging (Bateman & Jenkyn, 2001). An economic threshold of 20% of infected shoots showing penetrating lesions at GS30/31 (Anon, 1986) is often used to aid decisions on cost-effective fungicide use. However, many field trials have failed to provide a significant yield benefit following fungicide application for the control of eyespot (Morgan *et al*., 1998; Nicholson & Turner, 2000). Such observations have been partially explained by the prevalence of *T. acuformis* in the current eyespot population and the lower efficacy of some of the fungicides used against this species (Bateman & Jenkyn, 2000).

The aims of this experiment was to (i) compare the effectiveness of nine fungicide treatments to control eyespot and other stem-base diseases in an early drilled first winter wheat, (ii) monitor the progression of stem-base pathogens using quantitative PCR and (iii) evaluate any effect on crop yield.

MATERIALS AND METHODS

The field site was ploughed and power-harrowed before drilling winter wheat cv. Consort at 140 seeds m^{-2} on a loamy soil after potatoes on 8 September 2000. The experiment had four completely randomised blocks of 10 plots (3 x 12 m) on which 10 fungicide treatments were compared (including an untreated control) (Table 1). Fungicide treatments were applied at GS 31 in a mixture with plant growth regulator (1.25 l ha^{-1} Cycocel (chlormequat) + 0.2 l ha^{-1} Moddus (trinexapac-ethyl)), using a gas-pressurised knapsack sprayer (Safer spa, Italy). All other husbandry operations were as standard farm practice.

Table 1. Fungicide treatments and rates applied at GS 31.

Treatment	Trade Name	Active ingredient (a.i.)	Rate g a.i.ha^{-1}
1	Untreated	-	-
2	Unix	Cyprodinil	750
3	Opus	Epoxiconazole	62.5
4	Sportak	Prochloraz	405
5	Landmark	Kresoxim methyl + epoxiconazole	62.5 + 62.5
6	Foil	Prochloraz + fluquinconazole	156.6 + 48.6
7	Unix + Opus	Cyprodinil + epoxiconazole	750 + 62.5
8	Sportak + Opus	Prochloraz + epoxiconazole	405 + 62.5
9	Unix + Opus	Cyprodinil + epoxiconazole	500 + 62.5
10	Unix + Opus + Acanto	Cyprodinil + epoxiconazole + Picoxystrobin	500 + 62.5 + 150

Plant samples were taken from the plots at GS 31, 39 and 69. Thirty plants were collected at random from each plot on each sampling date. At GS 69, all assessments were carried out on the main shoot only. Visual assessments of the severity of eyespot, brown foot rot and sharp eyespot were made based on the methods of Goulds & Polley (1990).

The stem bases used for disease assessments were prepared immediately afterwards for DNA extraction. The basal region (4 cm length) of each stem was chopped finely, freeze-dried and milled to a powder in a ball mill. DNA was extracted from the milled plant sample as described by Edwards *et al*. (2001). Total DNA was quantified by spectrophotometry.

Oligonucleotide primers specific to *T. acuformis*, *T. yallundae*, *R. cerealis*, *M. nivale* and *Fusarium* (Beck *et al*., 1996; Beck, 1997) were obtained from Syngenta Biotechnology Inc. (J. Beck pers.comm.). Competitor fragments for quantitative PCR for *T. acuformis*, *T. yallundae* and *R. cerealis* were constructed based on the method of Förster (1994). Total DNA stocks of plant samples at 4 or 40 ng μl^{-1} were amplified using a PTC-100 Thermal Cycler and a PCR programme consisting of 35 temperature cycles of 94 °C for 15 s and combined annealing and extension step of 72 °C for 1 min for *T. acuformis* and *T. yallundae*. The first cycle had an extra 1 min 45 s at 94 °C and the final cycle had an extra 5 min at 72 ° C. The same as described above was used for *R. cerealis* but with annealing temperature of 62 °C for 15 s and *M. nivale* with annealing temperature of 60 °C for 15 s. Fungal DNA standards were prepared as described by Edwards *et al.*, (2001). Following gel electrophoresis, gels were viewed under UV light on a Gel Doc 1000 fluorescent gel documentation system (Bio-Rad Laboratories Ltd., Hemel Hempstead, UK), and unsaturated images were analysed using Molecular Analyst software (Bio-Rad). PCR product ratios were determined for each standard and sample by dividing the band intensity of pathogen DNA product by that of internal standard product. Standard curves were generated using the genomic DNA of each pathogen and the unit of DNA quantified was picograms of pathogen DNA present in nanograms of total DNA (plant and fungal).

Grain yield (at 15% moisture content), thousand grain weight and specific weight were determined at harvest.

RESULTS

Prior to fungicide applications at GS 31, visual assessment of stem-base diseases revealed no significant differences between plots with, on average, 18.9% of plants showing moderate/severe eyespot symptoms. At GS 39, a significant reduction in disease severity (DI) was observed for eyespot and brown foot rot compared to the untreated control where combinations of cyprodinil and epoxiconazole were applied (Table 2).

Table 2. Disease index for eyespot, sharp eyespot and brown foot rot at GS 39 and 69.

	Disease index %					
Treatment	Eyespot		Sharp eyespot		Brown foot rot	
GS	39	69	39	69	39	69
1	21.7	55.0	10.6	7.2	24.2	16.4
2	12.5	35.6	4.4	7.2	9.2	4.2
3	20.8	50.6	4.4	4.4	24.4	15.8
4	21.1	55.3	11.1	11.9	17.2	8.9
5	19.7	54.4	6.9	9.4	17.5	12.5
6	19.4	53.1	12.5	6.7	20.8	10.0
7	8.6	19.2	7.5	7.8	7.5	6.1
8	23.6	50.6	8.1	7.2	15.0	3.9
9	7.2	21.9	5.8	3.3	13.1	5.6
10	5.8	21.4	2.2	3.6	10.8	10.0
l.s.d	12.02	18.4	10.01	8.59	9.62	10.05
P	0.023	0.001	0.533	0.625	0.009	0.136

At GS 69 all treatments containing cyprodinil significantly reduced eyespot disease index compared to the untreated control. In the case of full rate of cyprodinil plus half rate epoxiconazole (Treatment 7), such a reduction was more than 50 % of DI when compared to untreated control. Prochloraz and epoxiconazole applied alone or in mixture failed to reduce eyespot severity at either GS 39 or 69. There were no significant treatment effects for brown foot rot and sharp eyespot at GS 69.

The PCR showed that *T. acuformis* was the dominant pathogen on the plant stem bases. *T. yallundae* was only detected at very low levels at GS 31. No significant effect was observed on DNA levels of *T. yallundae* quantified at GS 39 (mean of 0.52 pg ng^{-1} of total DNA) and GS 69 (mean of 9.07 pg ng^{-1} of total DNA). PCR assays also revealed that *M. nivale* was the main pathogen causing brown foot rot, as DNA levels of *Fusarium* spp. were just detectable. There were no significant effects of treatments on *M. nivale* at any growth stages. Levels of *M. nivale* remained low throughout the growing season and were quantifiable only for GS 39 (mean of 0.27 pg ng^{-1} of total DNA) and GS 61 (mean of 0.59 pg ng^{-1} of total DNA). The same was valid for *R. cerealis* where mean levels were 6.41 and 9.0 pg ng^{-1} of total DNA at GS 39 and 69, respectively. At GS 31 there were no significant differences between treatments for levels of *T. acuformis* DNA. At GS 39 and 69 significant reductions in DNA levels for *T. acuformis* were detected where treatments containing cyprodinil were applied (Table 3).

Table 3. *T. acuformis* DNA (pg ng^{-1} of Total DNA) concentration quantified at GS 31, 39 and 69 and grain yield for each fungicide treatment (back-transformed means are shown in parentheses).

Treatment	Log 10 DNA pg ng^{-1} *T. acuformis*			Yield t ha^{-1}
	31	39	69	
1	-0.93 (0.12)	0.67 (4.72)	1.70 (50.00)	10.05
2	-1.13 (0.07)	0.43 (2.66)	0.63 (4.29)	10.75
3	-1.24 (0.06)	0.46 (2.91)	1.68 (47.42)	11.02
4	-0.94 (0.12)	0.61 (4.03)	1.78 (59.57)	10.49
5	-0.86 (0.14)	0.55 (3.52)	1.62 (41.78)	11.16
6	-0.95 (0.11)	0.60 (4.00)	1.59 (38.90)	10.67
7	-1.33 (0.05)	0.27 (1.85)	0.16 (1.46)	11.38
8	-0.89 (0.13)	0.51 (3.24)	1.65 (44.67)	11.19
9	-0.95 (0.11)	0.47 (2.92)	0.76 (5.79)	11.43
10	-0.98 (0.10)	0.44 (2.75)	0.43 (2.68)	11.76
l.s.d	0.32	0.22	0.49	0.32
P	0.082	0.039	<0.001	<0.001

There were no significant differences between treatments for TGW (mean of 48.73 g) and specific weight (mean of 73.00 kg hl^{-1}) of grain but all treatments provided a significant yield increase compared to untreated control (Table 3). The greatest increase of 1.7 t ha^{-1}, significantly higher than any of the other treatments, was observed for plots treated with a combination of cyprodinil, epoxiconazole and picoxystrobin (Treatment 10).

Regression analysis revealed significant relationships between DNA of *T. acuformis* recovered at GS 69 and eyespot severity at GS 69 and yield (Table 4).

Table 4. Linear regressions of *T. acuformis* DNA at GS 69 on eyespot severity at GS 69 and yield.

Constant	Response variate	R^2	F Probability
Log (*T. acuformis* DNA pg ng^{-1})	*T. acuformis* DI	0.45	< 0.001
Log (*T. acuformis* DNA pg ng^{-1})	Yield t ha^{-1}	0.26	< 0.001

DISCUSSION

The dominant disease on plant stem bases was eyespot with higher disease severity than brown foot rot or sharp eyespot. *T. acuformis* was the main agent causing eyespot on the site and all treatments containing cyprodinil reduced DNA levels of *T. acuformis* resulting in decreased disease severity. This supports earlier records on the effective control of eyespot by cyprodinil (Burnett *et al.*, 2000; Bateman *et al.*, 2000). Treatments including prochloraz or prochloraz alone failed to reduce DNA levels of *T. acuformis* or disease severity in the crop. Inconsistency in control of eyespot by prochloraz has been reported previously and partially explained by its reliance on effective redistribution after chemical application by rainfall (Cooke *et al.*, 1989). Lower sensitivity of *T. acuformis* than of *T. yallundae* to triazoles has also been reported in France (Leroux, 1998) and in this study epoxiconazole alone, and fluquinconazole in mixture with other fungicides, were not effective in reducing visual symptoms of eyespot or DNA of *T. acuformis* at GS 39 or 69.

At GS 39 there was a significant reduction in brown foot rot severity by cyprodinil, however, this was not confirmed by quantitative PCR for *M. nivale* suggesting possible mis-identification with eyespot symptoms. Early symptoms of both eyespot and brown foot rot can be similar and it is evident that PCR assays for each species are more reliable than visual assessment in providing an estimate of pathogen levels especially on young plants.

Generally, fungicides showed no significant effect on disease severity of brown foot rot or sharp eyespot, which remained at low levels throughout the growing season.

The greatest yield increases were observed for treatments that included epoxiconazole, which could be explained by the control of other diseases apart from eyespot. Cyprodinil, epoxiconazole and picoxystrobin provided greater yield gain compared to any other treatment, which again might indicate more effective control of cereal leaf diseases.

The percentage of plants with moderate/severe eyespot symptoms assessed visually at GS 31 was less than 20, which was below the UK threshold level for fungicide treatment (Anon, 1986). Results from this experiment, however, indicated that a significant yield response was achieved by targeting and controlling eyespot disease in a first winter wheat. The positive relationship between visual disease symptoms and DNA levels of *T. acuformis* at GS 69 and negative correlation with crop yield indicates that *T. acuformis* is capable of causing severe eyespot resulting in crop loss in an early drilled first winter wheat. PCR diagnostics are helpful tools in determining the main species causing the disease so that effective fungicide control can be achieved. Cyprodinil was the only effective treatment in reducing *T. acuformis* DNA and eyespot disease severity.

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Control of potato late blight (*Phytophthora infestans*) with a fenamidone-based product in the UK

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ABSTRACT

Fenomen® (common name fenamidone) is a novel fungicide, which acts on the potato late blight pathogen at a number of points in its life cycle. It is effective against all strains of blight and also has activity against tuber blight. Already launched in a number of countries, it is being developed in the UK in coformulation with mancozeb. In field trials in over a number of seasons, it has provided high levels of potato late blight control. Trials have been carried out both in commercial potato crops, where natural infection occurred, and also in experimental conditions where artificial inoculation and mist irrigation was employed to encourage disease development. This paper describes results from laboratory tests demonstrating its anti-sporulant and translaminar activity and demonstrates its field efficacy with reference to UK field trials, when used alone or in practical programmes with other blight control products.

INTRODUCTION

Fenamidone is a novel imidazolinone fungicide with excellent crop safety from Aventis CropScience, which was first introduced at this conference four years ago (Mercer *et al.* 1998). Fenamidone is effective against a wide range of oomycete pathogens including potato late blight *Phytophthora infestans,* vine downy mildew *Plasmopara viticola,* cucumber downy mildew *Pseudoperonospora cubensis;* and is also active against *Alternaria* spp and *Pythium* spp. Already launched in France, Poland and a number of other countries worldwide, fenamidone is being developed for the control of potato late blight in the UK (proposed name Sonata ®), as a WG formulation in mixture with mancozeb. It is a pure optical isomer, which acts by inhibiting mitochondrial respiration (QoI mode of action) and is active at a number of stages in the disease life cycle. Fenamidone is very active against zoospore liberation and direct cyst and sporangial germination, making it highly effective as a blight fungicide (Mercer *et al.* 1998).

Fenamidone has shown equal efficacy on both A1 and A2 mating types and is effective against phenylamide resistant strains of blight (De Wever *et al.* 2000). By combining good protectant activity with translaminar properties and antisporulant efficacy, fenamidone + mancozeb has shown a consistently high level of potato late blight control in trials across Europe. This paper describes results from laboratory tests which show fenamidone's anti-sporulant and translaminar activity; and UK field trials (1999 to 2001) demonstrate the effectiveness of the product used either alone or in programmes with other complimentary blight products. As a fungicide with a QoI mode of action, there is potentially a high risk of resistance developing to fenamidone; a restriction is therefore proposed to limit the number of fenamidone + mancozeb applications that can be made in a season as an anti-resistance management strategy.

MATERIALS AND METHODS

Fenamidone + mancozeb is formulated as a WG containing 100 + 500 g/kg. The recommended dose rate of 1.5 kg/ha delivers 150 g ai/ha of fenamidone and 750 g ai/ha of mancozeb. Commercial formulations of the standard products were used and unless stated they were applied at UK recommended dose rates. In laboratory tests, firstly (Figure 1), potato leaf discs, inoculated on their lower surfaces were treated on their lower surface after 2 days incubation. Two days later the number of sporangia on each disc was counted. Secondly (Figure 2), only the upper surface of the potato leaves were treated, the lower surfaces inoculated 24 hours later and the percentage diseased and sporulated leaf surface was assessed 6 days after treatment.

In the field trials, treatments were applied with pressurised knapsack equipment through flat fan nozzles calibrated to deliver 300 l/ha. A randomised block design was used for all trials, with treatments replicated four times. Foliar blight was assessed on a % scale using the ADAS key. Data were analysed statistically using an analysis of variance and LSD test at the 5% probability level.

RESULTS AND DISCUSSION

Laboratory Tests

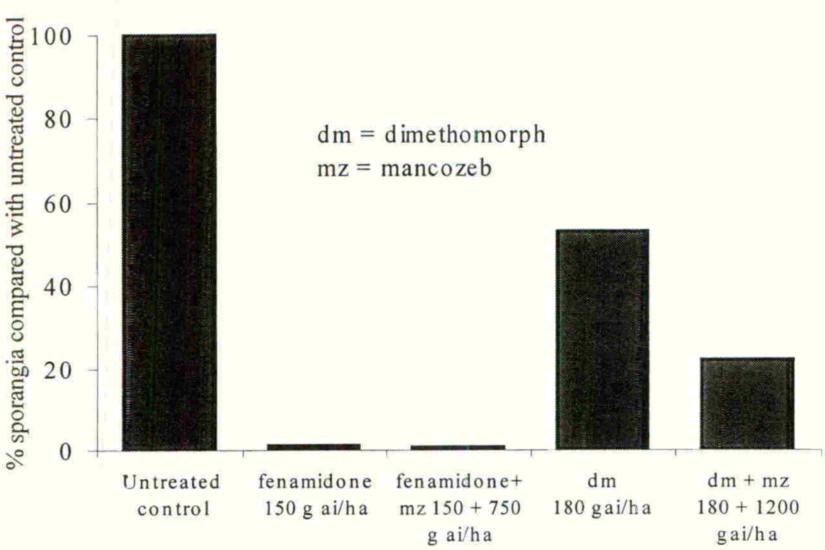

Figure 1. Antisporulant activity of fenamidone alone and fenamidone + mancozeb in comparison with dimethomorph and dimethomorph + mancozeb

In comparison with the untreated control or the commercial standard, virtually no sporulation developed on the discs treated with fenamidone or the fenamidone + mancozeb formulation (Figure 1).

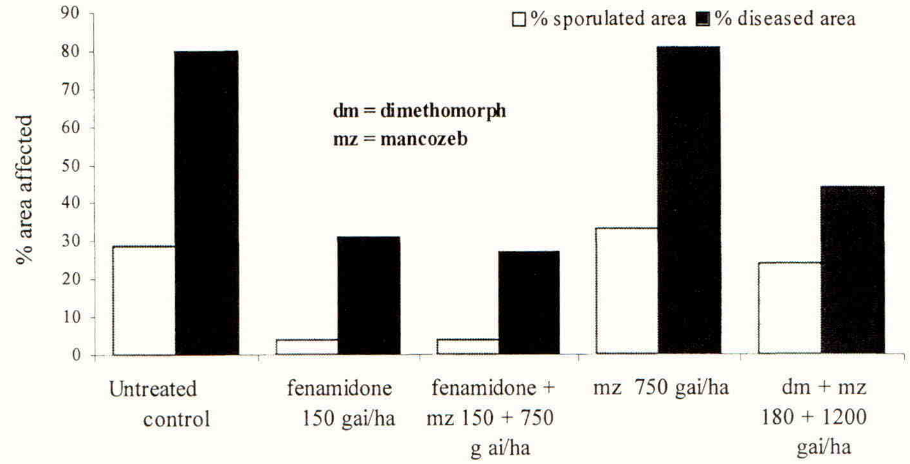

Figure 2. Translaminar activity of fenamidone alone and fenamidone + mancozeb in comparison with mancozeb and dimethomorph + mancozeb

Fenamidone and fenamidone + mancozeb were clearly more effective than mancozeb alone and dimethomorph + mancozeb (Figure 2).

Field Trials

Table 1. Control of late blight with fenamidone + mancozeb compared with fluazinam, Cornwall 1999

Date	Assess-ment	Untreated control	Fenamidone + mancozeb		Fluazinam		LSD
			7 day schedule (9 sprays)	10 day schedule (6 sprays)	7 day schedule (9 sprays)	10 day schedule (6 sprays)	
15/7/99	% blight	0.0	0.0	0.0	0.0	0.0	0.00
23/7/99	% blight	1.9	0.0	0.1	0.5	0.7	0.67
30/7/99	% blight	1.9	0.0	0.1	0.5	0.7	0.67
06/8/99	% blight	30.3	0.2	0.3	0.9	2.3	14.73
12/8/99	% blight	46.3	0.1	0.3	1.1	2.6	20.63
20/8/99	% blight	94.5	0.1	0.3	1.4	2.8	3.34
26/8/99	% blight	100	2.8	3.5	23.8	36.8	13.64
2/9/99	% blight	100	9.5	13.0	56.3	68.8	20.41
5/10/99	Yield t/ha 35-65 mm	0.9	23.5	20.6	21.2	19.3	3.58

Natural infection, cv. Avalanche. Applications commenced 2/7/99.

Table 2. Control of late blight with fenamidone + mancozeb compared with fluazinam, Cornwall 2000

Date	Assess-ment	Untreated control	Fenamidone + mancozeb 7 day schedule (9 sprays)	Fenamidone + mancozeb 10 day schedule (6 sprays)	Fluazinam 7 day schedule (9 sprays)	Fluazinam 10 day schedule (6 sprays)	LSD
18/7/00	% blight	0.8	0.2	0.2	0.3	0.2	0.13
21/7/00	% blight	1.3	0.3	0.3	0.6	0.4	0.31
24/7/00	% blight	4.0	2.4	1.5	2.3	1.5	2.24
31/7/00	% blight	8.8	2.0	1.3	1.8	1.0	1.93
07/8/00	% blight	60.5	4.0	2.4	5.8	4.0	1.8
14/8/00	% blight	71.3	4.1	3.9	21.0	6.5	18.4
21/8/00	% blight	80.5	4.8	6.8	29.5	15.3	4.96
29/8/00	% blight	95.0	16.3	61.3	37.5	80.0	25.18
	Yield t/ha 45-85 mm	17.9	26.9	27.2	26.7	26.0	2.79

Natural infection, cv. Avalanche. Applications commenced 26/6/00.

The first two tables show results from 1999 and 2000 where natural infections of late blight occurred. Results compare the efficacy of fenamidone + mancozeb with the contact blight fungicide fluazinam at 7 and 10 day application intervals. At both spray intervals the fenamidone + mancozeb gave superior control of foliar blight when used all through the season.

Fenamidone inhibits mitochondrial respiration by blocking electron transfer at the level of ubihydroquinone:cytochrome c oxyreductase (complex III) and is therefore similar to that of strobilurins and famoxadone. *P. infestans* in Europe has previously developed resistance to phenylamide fungicides and is considered a high risk pathogen, but there is no evidence to date that it has developed resistance to this mode of action. Following the development of resistance in several plant pathogens to other QoI fungicides Aventis CropScience has taken a pro-active approach in conjunction with the FRAC QoI working group, and proposes that no more than 6 application of fenamidone + mancozeb should be made in a season. Tables 3 and 4 demonstrate how fenamidone + mancozeb can fit into practical spray programmes with other blight fungicides with complementary modes of action.

Programmes shown in Tables 3 and 4 consisted of the following treatments (all applied at 7 day intervals): -

A = 10 x fenamidone + mancozeb

B = fluazinam, cymoxanil + oxadixyl + mancozeb, 3 x cymoxanil + mancozeb, 5 x fluazinam

C = fenamidone + mancozeb, 4 x propamocarb + chlorothalonil, 5 x fenamidone + mancozeb

D = fenamidone + mancozeb, 2 x propamocarb + chlorothalonil, 3 x fenamidone + mancozeb, 2 x fluazinam, 2 x fenamidone + mancozeb.

E = 2 x fenamidone + mancozeb, 5 x propamocarb + chlorothalonil, 3 x fenamidone + mancozeb

All programmes consisted of 10 applications.

Table 3. Control of late blight with fenamidone + mancozeb in programmes with other blight products, Cambridge 2001

Date	Assess-ment	Untreated control	Programme					LSD
			A	B	C	D	E	
16/7/01	% blight	0.1	0.0	0.0	0.0	0.0	0.0	0.00
27/7/01	% blight	0.2	0.1	0.1	0.1	0.1	0.1	0.01
30/7/01	% blight	6.4	0.1	0.1	0.1	0.1	0.1	6.04
07/8/01	% blight	37.5	0.1	0.1	0.1	0.1	0.1	12.16
14/8/01	% blight	79.5	0.1	0.1	0.1	0.2	0.1	3.47
17/8/01	% blight	95.8	0.6	1.3	0.6	1.0	0.8	0.93
20/8/01	% blight	98.3	0.9	2.0	1.2	2.2	2.0	1.72
23/8/01	% blight	99.5	1.9	6.3	1.9	4.6	4.1	4.17
28/8/01	% blight	100.0	1.5	6.5	2.0	4.3	4.3	3.9
31/8/01	% blight	100.0	1.5	9.5	2.9	10.8	7.5	7.71
03/9/01	% blight	100.0	5.3	15.8	4.8	10.3	9.8	9.58
	Yield t/ha 45-70 mm	17.7	36.4	40.5	42.1	42.1	44.4	6.87

cv. Russet Burbank. Untreated discard areas around trial plots inoculated with mixed phenylamide resistant and sensitive isolates 9/7/01. The trial was misted during the late evening and early morning to maintain leaf wetness and encourage blight development. Applications commenced 26/6/01.

Table 4. Control of late blight with fenamidone + mancozeb programmes, Herefordshire 2001.

Programme	Area under the disease progress curve (AUDPC) (% days)	Total Ware Yield (> 35 mm) t/ha	% by number of tubers affected by tuber blight Median value
Untreated Control	2476	32.4	6.97
A	17	57.4	0.32
B	17	58.0	0.52
C	12	58.8	0.47
D	21	58.4	0.83
E	26	58.9	1.59
SED	63.0	1.89	
LSD	128.7	3.86	
Freidman's test – Grand median			1.560
(p value)			0.024
(p value adjusted for ties)			0.011

cv. King Edward, ADAS Rosemaund. Applications commenced 2/7/01.
Unsprayed guard areas inoculated and blight development stimulated by irrigation/misting.

CONCLUSIONS

Under high disease pressure as the trials show here, fenamidone + mancozeb gave excellent control of potato late blight.

With the spread of A2 mating types to Europe, late blight populations have become more variable. Strains appear to be more aggressive, infect more rapidly, able to infect at lower temperatures, and complete their life cycles in shorter time (Flier, 2002). In recent years UK growers have tended to shorten their spray intervals as Bradshaw *et al.* (2000) reported. The interval between late blight sprays fell from an average of 9.3 days between 1993 and 1996 (mean of 8 treatments) to 8.1 days between 1997 and 1999 (mean of 10 treatments). Anecdotal evidence suggests that this trend is continuing.

The strong combination of protectant, translaminar and anti-sporulant activity in fenamidone + mancozeb will give good protection from late blight when applied at 1.5 kg/ha every 7 days, but offers flexibility should the interval become stretched. The results in Tables 3 and 4 above show fenamidone + mancozeb should be positioned in small blocks of treatments, ideally after rapid haulm development and following the use of systemic materials e.g. propamocarb. To help avoid resistance issues, Aventis CropScience will follow the FRAC QoI strategy and ensure that the product is used rationally and spray recommendations are robust. The sensitivity of *P. infestans* populations will also be monitored.

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Inoculum sources of the toxigenic ear-blight pathogen, *Fusarium culmorum*, in wheat

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ABSTRACT

Severe ear blight developed in plots of winter wheat that were inoculated by spraying with conidial suspensions of *Fusarium culmorum* during anthesis and, usually, mist-irrigated for 2 days to encourage infection. In the absence of artificial inoculation of the ears, *F. culmorum* caused ear blight only after weather conditions (a warm dry period in early summer) had allowed brown foot rot to develop, which occurred only where soil-surface inoculum (on infested plant material) was available. Seed infection caused no disease. Ear blight therefore depended on adequate viable inoculum on infested plant debris within the crop, conditions favouring brown foot rot development and, subsequently, moist conditions during anthesis. Options for minimising inoculum availability are briefly discussed.

INTRODUCTION

An ideal approach to controlling plant disease is to identify the inoculum source and then eliminate or inactivate it. *Fusarium graminearum* is the prevalent causal fungus of ear blight (head blight or scab) in many cereal-growing areas of the world. It infects the ears of wheat during anthesis (flowering), usually by means of ascospores. These are produced by sexual reproduction in perithecia on debris from previous, infected crops. The prevalent ear-blight pathogen in the UK is *F. culmorum*, which is not known to produce sexual spores. It produces asexual spores (conidia), which are also likely to be dispersed in rain splashes but, being larger than ascospores, may be transported for shorter distances. The conidia of *F. culmorum* infect ears of wheat during a short period of susceptibility during anthesis, the success of the infection depending on a period of moisture availability after infection (Lacey *et al.*, 1999). The routes by which conidia, of either *F. culmorum* or *F. graminearum*, reach the ears are not clearly understood. Field experiments were designed to investigate whether, and in what conditions, infested plant material at the soil surface provided inoculum for ear blight.

MATERIALS AND METHODS

Crops of winter wheat cv. Charger were grown after winter oats in each of four years. Plots of 6x3 m, separated by a minimum of 2.5 m of crop, were marked out within each crop. Treatments, in four replicated, randomised blocks in each experiment, were: non-inoculated; inoculum of *F. culmorum* applied to the ground in spring; inoculum applied to the ears during anthesis; inoculum applied to the ground and to ears (2001 only). Additional treatments were made in some years, including naturally infected seed, which caused no disease, and

inoculation with other *Fusarium* spp. (these results are not described here, but account for differences in degrees of freedom in the statistically analysed data: see Results).
Inoculum was a mixture of six or more isolates of *F. culmorum* from locally grown wheat crops. Inoculum applied to the ground was oat grains, previously soaked in water and killed by autoclaving, and colonised by the fungus. After being allowed to dry, it was broadcast at 1.1-1.6 kg per plot on 31 March 1998 (growth stage, GS, 30), 18 March 1999 (GS 30), 7 April 2000 (GS 30) and 1 May 2001 (GS 31). Inoculum for application to the ears was prepared as suspensions of conidia produced in agar culture and adjusted to 1-2x10^4 ml^{-1}. It was applied at 1 litre per plot using a hand-held sprayer during anthesis (31 May-14 June, depending on the year). Inoculation was followed by mist-irrigation for 2 days in 1998-2000, with duplicate non-irrigated control plots. In 2001, when irrigation was not used, inoculum was applied in the late afternoon before rainfall.

The stems on plants taken from six 15-cm lengths of row from each plot in late June or early September (GS 69-77) were examined for brown foot rot. The incidence of symptoms on internodes and nodes (Goulds & Polley, 1990) was recorded. The symptoms on internodes were assessed as slight or, when lesions extended to more than 25% of the circumference, as moderate or severe. Ear blight was assessed in late June or early July (GS 73-75) as the percentage area of each plot with symptoms. The percentage of the harvested grain affected by common fungi, including *F. culmorum*, was determined on a sample of 60 grains per plot by incubating them on potato dextrose agar (one-fifth-concentration supplemented with four-fifths concentration plain agar). Grain yields and thousand-grain weights were also measured.

RESULTS

Internodal brown foot rot was slight on almost all affected stems in 1998-2000. Application of inoculum to the ground increased significantly the incidence of all symptoms only in 1998 (Table 1). In 2001, an average of 44% of stems had internodal symptoms; the incidence was greater on stems from plots with inoculum applied to the ground than in other plots, but not significantly so (P = 0.06; details not shown). The incidence of moderate or severe lesions was greater where inoculum had been applied to the ground (Table 1). The effects of treatments on nodal symptoms were similar to those on all severity categories of internodal symptoms (results not shown).

Ear blight was most extensive in all experiments where inoculum had been applied to the ears (Table 2). It was more extensive in 2001 where inoculum had been applied to the ground than where no inoculum had been applied. Inoculum to the ground did not add to the symptoms developing from inoculum applied to the ears.

Fusarium culmorum was recovered more frequently in grains from ear-inoculated plots than from other plots (Table 3). Applying inoculum to the ground resulted in a greater frequency of *F. culmorum* in the grain than where no inoculum was applied only in 1998 and 2001. *Microdochium nivale*, which can also contribute to stem-base browning and to ear blight, was isolated from an average of 39% of grains in 1998, with no effect of inoculation treatments. It occurred on an average of 4% of grains in 1999 and was significanlty less frequent after ear inoculation with *F. culmorum* than after other treatments (results not shown). It occurred on 3% of grains in 2000, with no treatment effects, and was not found in 2001.

Table 1. Effects of artificially applied inoculum of *Fusarium culmorum* on the incidence of brown foot rot during grain filling

	Logit % stems with internodal brown foot rot (back-transformed means)			
Inoculum	1998[a]	1999[a]	2000[a]	2001[b]
None	-0.49 (26.8)	-0.03 (48.2)	0.02 (50.7)	-1.55 (3.8)
To ground	0.08 (53.4)	0.06 (52.6)	0.27 (62.6)	-1.18 (8.1)
To ears	-0.50 (26.5)	0.21 (59.9)	0.30 (64.2)	-1.74 (2.5)
To ground and ears	-	-	-	-1.24 (7.3)
SED [d.f.]	0.168 [10]	0.287 [24]	0.221 [24]	0.123 [9]
P	0.009	0.58	0.36	0.004

[a]1998-2000: means of mist-irrigated and non-irrigated plots are used.
[b]2001: no mist-irrigation; 2001 percentages are for moderate and severe lesions only - these were scarce in other years.

Table 2. Effects of artificially applied inoculum of *Fusarium culmorum* on the incidence of ear blight

	Logit % plot area with ear blight (back-transformed mean)			
Inoculum	1998	1999	2000	2001
None	-2.27 (0.5)	-3.00 (0)	-1.78 (2.3)	-1.61 (3.4)
To ground	-2.08 (1.0)	-2.51 (0.2)	-1.42 (5.1)	-0.72 (18.6)
To ears	0.41 (69.0)	-0.36 (32.1)	-0.38 (31.3)	0.38 (67.6)
To ground and ears	-	-	-	0.228 (60.7)
SED [d.f.]	0.108 [10]	0.238 [24]	0.154 [24]	0.242 [9]
P	<0.001	<0.001	<0.001	<0.001

Table 3. Effects of artificially applied inoculum of *Fusarium culmorum* on its incidence on harvested grain

	Logit % grains affected (back-transformed mean)			
Inoculum	1998	1999	2000	2001
None	-1.74 (2.5)	-2.21 (0.7)	-2.21 (0.7)	-1.67 (2.9)
To ground	-0.90 (13.7)	-1.84 (1.9)	-2.19 (0.7)	-0.71 (19.0)
To ears	0.97 (87.0)	-0.19 (40.3)	-0.04 (31.4)	0.14 (56.6)
To ground and ears	-	-	-	0.16 (57.5)
SED [d.f.]	0.244 [10]	0.192 [24]	0.200 [24]	0.252 [9]
P	<0.001	<0.001	<0.001	<0.001

Grain yields were decreased by ear inoculation in 1998-2000 (Table 4). The yields were generally small in 2001 and there were no significant effects of treatments. Effects on thousand-grain weights were similar.

Table 4. Effects of artificially applied inoculum of *Fusarium culmorum* on grain yield (t ha^{-1})

Inoculum	1998	1999	2000	2001
None	6.98	8.91	7.04	5.20
To ground	6.53	8.45	6.96	4.85
To ears	3.64	7.16	6.15	4.80
To ground and ears	-	-	-	4.86
SED [d.f.]	0.231 [10]	0.484[24]	0.208 [24]	0.562 [9]
P	<0.001	0.008	<0.001	0.88

DISCUSSION

Ear blight developed only where inoculum was applied directly to the flowering ears or where extensive brown foot rot had developed (2001 only) as a result of inoculum (artificially applied) on the ground. Brown foot rot occurred as a consequence of applying inoculum to the ground only in 1998 and 2001 and was extensive (moderate or severe symptoms) only in 2001. In those years, a warm, dry period occurred in May or June. Such conditions, which did not occur to any extent in other years, are necessary for the development of fusarium foot rot caused by *F. culmorum*. The conditions causing additional, slight brown foot rot symptoms as a result of inoculum on the ground in 1998 were insufficient to contribute to ear blight, although more *F. culmorum* had infected the grain. *Microdochium nivale* may also have contributed to brown foot rot symptoms, particularly in 1998, when it was subsequently frequent on ears, but isolations from grain suggest that it is unlikely to have contributed to ear blight in any year. There was evidently no, or very little, extraneous inoculum of *F. culmorum* available for ear blight other than that applied artificially.

These results suggest, therefore, that inoculum for ear blight comes directly from the ground in the immediate vicinity of the flowering wheat plants and depends on recent conditions favouring growth of *F. culmorum* at ground level, so that stem-base disease occurs, during the preceding weeks. Removal of straw from the soil surface, for example by burial during ploughing, may remove much of the inoculum source.

ACKNOWLEDGEMENTS

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Development of leaf blotch (*Rhynchosporium secalis*) epidemics on barley

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ABSTRACT

The temporal and spatial development of leaf blotch (*Rhynchosporium secalis*) epidemics was studied in spring and winter barley field experiments at Rothamsted. Weather conditions were recorded and related to the development of epidemics. The disease was present early in crop growth in both winter and spring barley experiments. The pathogen rapidly progressed up the plant, infecting new leaves as they emerged. Disease severity was lower in spring barley than in winter barley at the end of the season but rates of progress were similar when plotted against physiological time (degree-days above 0°C). Early-sown winter barley produced more leaves during winter than late-sown winter barley and disease severity was greater at the end of the season. Disease risk assessment based on an understanding of the pathogen epidemiology will help to minimise inappropriate use of fungicides and benefit the environment.

INTRODUCTION

The symptoms of barley "leaf blotch" are irregular lozenge-shaped pale brown lesions with darker brown edges (Ozoe, 1956). Lesions merge when the disease is severe and whole leaves become brown, dry and shrivelled. Severe epidemics develop when there is rapid infection of newly unfolded leaves during stem extension, resulting in yield losses of up to 30-40% but more usually 1-10% in the UK (Jenkyns & Jemmett, 1967). Sources of conidia initiating leaf blotch epidemics are thought to be infected crop debris on the soil surface or infected seed (Polley, 1971; Stedman, 1982). *Rhynchosporium secalis* can survive over winter on the debris and sporulate for up to 340 days. PCR analysis can detect the disease in young barley up to 14 days (incubation period) before lesions start to appear on leaves. Successive cycles of disease spread conidia from older leaves to healthy young leaves during the growing season. Spread of the disease is associated with rainfall rather than wind as the conidia are embedded in mucilage (Skoropad, 1959; Stedman, 1980). Rain drops falling on infected plants can splash numerous conidia to carry the infection to other leaves and plants (Stedman, 1980). Regular periods of rainfall sustain the disease by splash dispersal (Fitt *et al.*, 1986) and by providing long periods of leaf wetness favouring infection and sporulation (Rowe, 1979). Colder winters also favour the disease, possibly because the primary source of inoculum is depleted more slowly than in mild winters (Skoropad, 1966). Both winter and spring barley are susceptible to leaf blotch, but winter barley is generally affected more severely (Lester, 1966), particularly when sown early (Stedman, 1982).

MATERIALS AND METHODS

Crops of winter barley (cv. Maris Otter) and spring barley (cv. Apex) were grown at Rothamsted over three successive seasons, 1985-88, at sites where barley had not been grown for several years (Davis, 1990). In the 1985-1986 experiment winter barley cv. Maris Otter was sown on October 21st 1985 and in 1986 spring barley cv. Apex was sown on May 6th. In the 1986-87 experiment early winter barley was sown on September 25th and late on November 10th. Inoculum was introduced into all plots except the control by scattering chopped straw from crops previously infected with *R. secalis*; no fungicides were applied. Two plots were used for each inoculated treatment and one for control. Fifty randomly selected plants in each plot were marked with numbered stakes after second leaf expansion and individual leaves were colour tagged. At least 25 marked plants remained in each plot at the end of the season. Leaf blotch severity was recorded as percentage of leaf area covered by lesions on each leaf. Epidemic progress was measured at the leaf level and recorded weekly throughout the life of the crop, while meteorological data were recorded at a station about 100 m from the experimental sites.

RESULTS

Winter and spring barley 1985-1986

The life span of individual leaves and the intervals between the appearance of one leaf and the next differed considerably within and between plants in winter barley, but were more rapid and less variable in spring barley. The percentage area of disease on individual green leaves at each sampling date on winter barley is shown in Figure 1. After rain, *R. secalis* spread onto the first two expanding leaves in late November and further lesions were recorded at low incidences throughout the winter (Figure 2). During April/May (*c.* day 130) growth was rapid and temperatures were relatively high. There was a period of rain in early April, with a sharp increase in leaf blotch by day 163. A period of hot dry weather in June was associated with a check in epidemic progress.

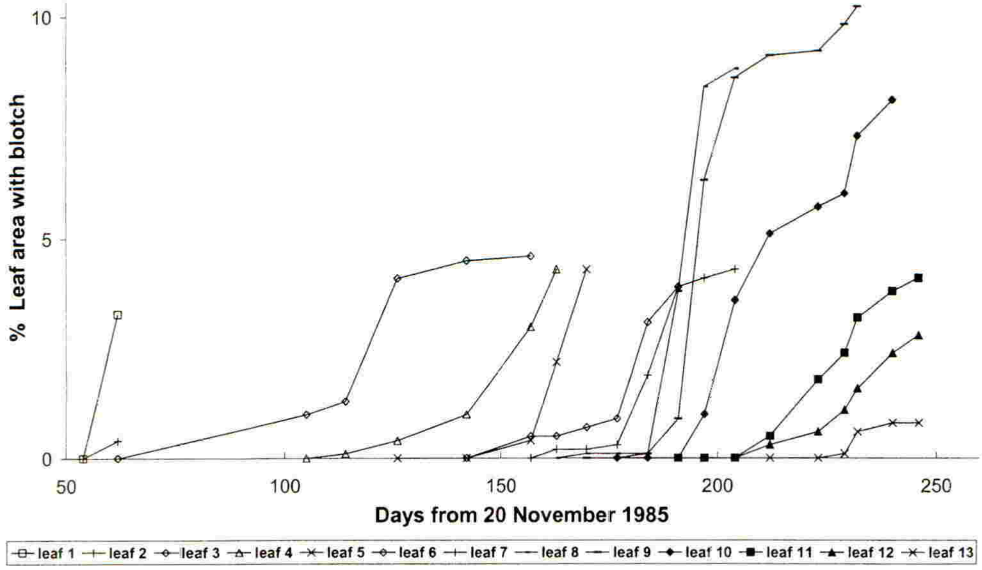
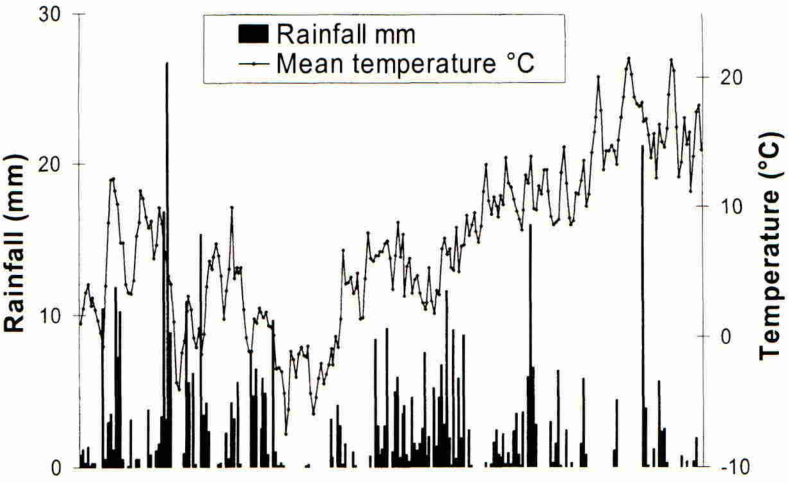


Figure 1. Mean percentage area affected by leaf blotch on leaves of winter barley, cv. Maris Otter, in an inoculated plot in the 1985-86 growing season (mean of 25 plants).

(a)



(b)

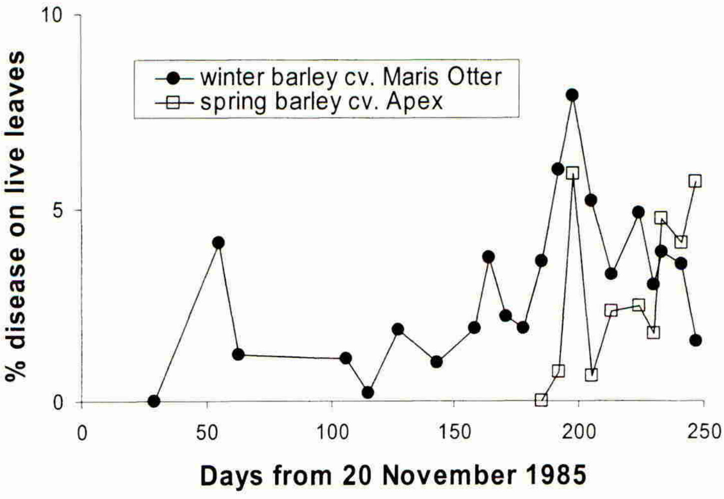


Figure 2. Epidemics of leaf blotch on winter and spring barley (inoculated with infected crop debris) during 1985-1986. (a) Rainfall and mean temperature during 1985-86 growing season (b) Mean percentage area affected by leaf blotch on all living leaves

Spring barley emerged about May 5th 1986 (*c.* day 180 on winter barley scale) and rapid growth occurred, with mean temperatures above 10°C and a period of rain. Extensive leaf blotch developed after about 14 days on the first leaf but the next few leaves seemed to 'grow away' from the infection in spite of suitable temperatures and rainfall. After heavy rainfall at the end of May there was an increase in disease by June 11 (day 220) followed by drier hotter weather with little infection of flag leaves by the final assessment on July 7 (day 246). At the end of the season, there was less disease on spring barley than on winter barley and the rates of progress of the epidemics appeared to be different. However, when disease severity was plotted against physiological time (degree-days above 0°C), the rates of progress appeared similar.

Early-sown and late-sown winter barley 1986-87

The early-sown barley emerged on October 10th 1986, about 14 days after sowing and by the end of a mild wet October (Figure 3a) there were three leaves on main shoots with some tillering. Disease was apparent on the inoculated plots by early November, but not on the uninoculated control. In mid-November, when the late-sown barley was emerging, there was a marked decrease in temperature and plant growth rates on all plots declined. There were more leaves on the early-sown barley than on the late-sown barley and consequently more disease on the inoculated early-sown plots (Figure 3b).

(a)

(b)

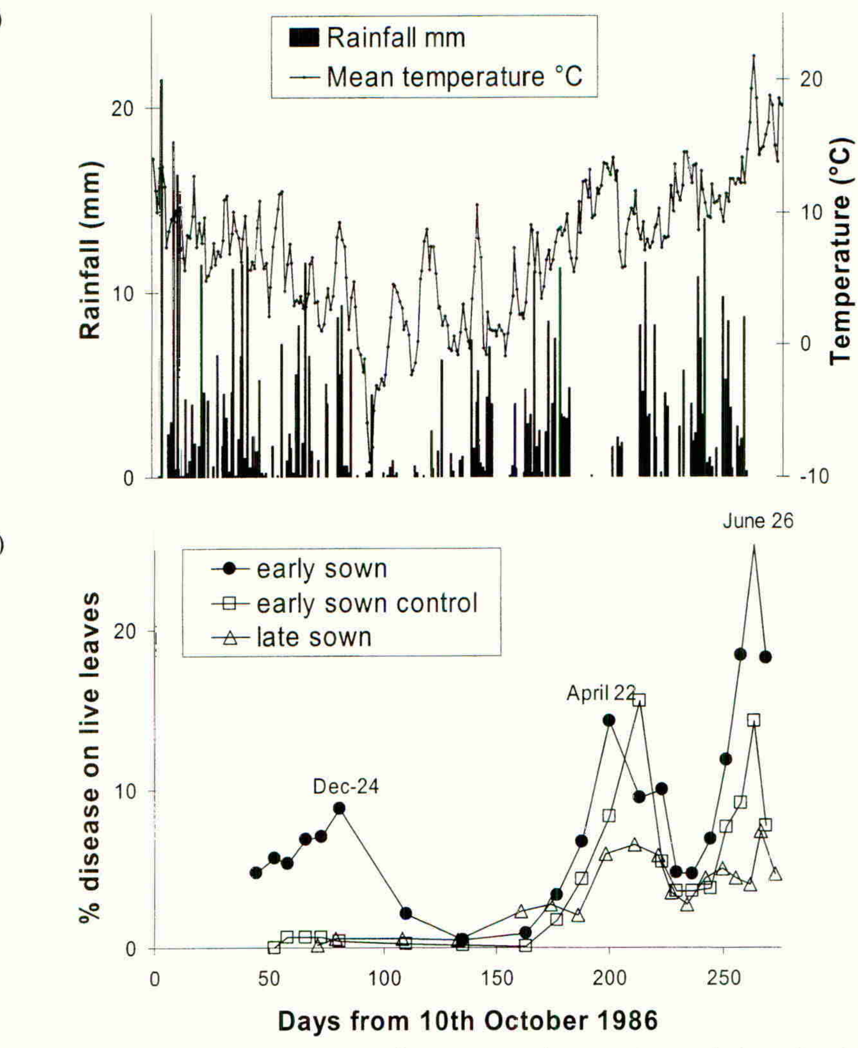


Figure 3. Epidemics of leaf blotch on uninoculated early-sown (control), inoculated early-sown and late-sown winter barley during 1986-1987. (a) Rainfall and mean temperature (b) Mean percentage area affected by leaf blotch on all living leaves

Disease severity increased until December on the inoculated early-sown plots (Figure 3a and 3b) but the uninoculated control and late-sown plots showed little disease. Conditions in March were mild and new lesions appeared on all plots, with proportionately more on the early-sown plots. The weather then became dryer with a sharp increase in temperature to a max of 28°C in April. There were few new lesions and rapid production of new leaves so that plants 'grew away' from the disease.

Plants grew rapidly after the increase in temperature in March and by June the number of leaves produced on main shoots were similar in all plots, though the height of the flag leaf was 85 cm in early-sown barley compared to 75 cm in late-sown barley. The flag was leaf 14 on the inoculated early-sown and late-sown barley but on the uninoculated plot the flag was leaf 15.

DISCUSSION

The strong correlation between disease progress and degree-days in 1985-86 and 1986-1987 suggests that epidemic progress was a function of accumulated temperature. However some of the fluctuations in amounts of disease were probably related to specific weather events such as periods of rain or temperatures above 20°C. In particular, in the autumn of 1986 there were high incidences of disease in early-sown winter barley that developed when there were frequent periods of rain and mean temperatures between 5° and 15°C. In the winter months, temperatures below 5°C apparently limited the amount of disease that developed on all the winter barley crops. Even when there were periods of rain in 1986 and 1987 there was little additional disease recorded while mean temperatures were ≤ 0°C.

In spring, once mean temperatures were above *c.* 5°C, the largest increases in amounts of disease could generally be related to periods of several days with rain *c.* 15-20 days earlier. In dry weather, infected leaves senesced more rapidly and the largest decreases in amounts of disease on the remaining live leaves generally occurred *c.* 15-20 days after a dry period. Dry periods were often accompanied by daytime temperatures above 25°C, unfavourably high for *R. secalis*, which may also have played a role in impeding the progress of epidemics.

Temperature differences initially affected the amounts of disease at the rosette pre-extension stage on plants sown at different dates. Early-sown winter barley emerged in late autumn when conditions were favourable for disease and when the production of new leaves was relatively rapid. Thus there was an opportunity for a reservoir of disease to be established at the base of the main shoot and tillers. Poor growth and a reduction of tillering in barley crops affected with *R. secalis* is observed commonly (Jenkyn *et al.*, 1989; Ozoe, 1956). When conditions are favourable for *R. secalis*, particularly at the rosette stage, a reduction in barley growth rate could also contribute to the reservoir of disease. Late-sown winter barley emerged when temperatures were low and consequentially less favourable for disease, and when the production of new leaves was slower. There was therefore a smaller reservoir of disease at the base of the late-sown plants. Spring barley emerged when the conditions were again favourable for the disease but the rosette stage was short by comparison with that of winter barley and fewer leaves were involved. For both late-sown winter barley and spring barley there was less inoculum at the base of the plants to initiate further infections during the period of stem extension.

Canopy density in barley crops is also an important factor when considering conditions for disease development and a lower canopy density can provide less favourable conditions (Mayfield & Clare, 1984). Differences in canopy density may also have affected the rates at which leaf blotch spread up the plants in these experiments. In the coldest period in the 1986-87 winter, there was a loss of winter barley plants with fewer plants lost in the well-established early-sown winter barley than the late-sown barley. The difference in canopy density (not measured here) may partly explain why the amount of disease was greater on early rather than late-sown barley in the 1986-87 season, particularly on later leaves.

ACKNOWLEDGEMENTS

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Why do cereal diseases occur where they do?

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ABSTRACT

Since the early 1970s the Central Science Laboratory and ADAS have carried out an annual survey of diseases found on the leaves and stem bases of winter wheat crops across England and Wales. Concentrating on data from the last 10 years, a set of disease severity maps were generated using a geostatistical interpolation technique. These were analysed with similar maps of fungicide use to assess the possible influence crop protection chemicals may have on the spatial distribution of disease severity. Three major diseases of wheat showed markedly different distributions than the chemicals intended to control them. Although such analyses may be simplistic the potential for regionally applicable disease forecasts with a national coverage is suggested.

INTRODUCTION

Starting in 1970 and continuing annually to the present day (with the exception of 1982 and 1983) the Central Science Laboratory and ADAS have conducted a survey of diseases found in winter wheat crops across England and Wales. The data represent the only long term dataset of disease severity/incidence and offer a unique opportunity to assess the influence of changing husbandry practices, the introduction of new cultivars and crop protection chemicals.

The results of analyses on long term disease trends have been published periodically (Polley & Thomas, 1991; Hardwick *et al*., 2001). In addition the data from 10 years of the surveys have been used to develop a complex model of the regional distribution of leaf blotch (*Mycosphaerella graminicola*) based on cultivar resistance, fungicide use and derived weather factors (Gladders *et al*., 2001).

The location of the field from which each sample was collected was recorded giving rise to a spatial dataset of disease severity and the associated husbandry factors, pesticide inputs and cultivar resistance rating. The aim of this paper was to establish how far fungicide inputs influenced the spatial distribution of severity for three major wheat diseases and whether other factors would need to be considered if national forecasts were to be developed.

MATERIALS AND METHODS

A target of 450 samples each year, from farms selected at random in proportion to the area of wheat grown in a county, were collected from fields over the years 1992 – 2001 when the crop reached the early to medium milk development stage (GS 73 – 75). The percent area affected by the major foliar pathogens on the top two leaves was assessed on a sample of 25 plants from 50 collected at random from each field. Assessments of stem base and ear diseases were also made and added to data on location and husbandry details supplied by the farmer via a questionnaire. Over the 10 years that samples were collected a total of 4359 wheat crops were assessed, the disease severity data from these were averaged and sample locations thinned so that all were separated by at least 7.5 km leaving 984 locations for interpolation (Figure 1).

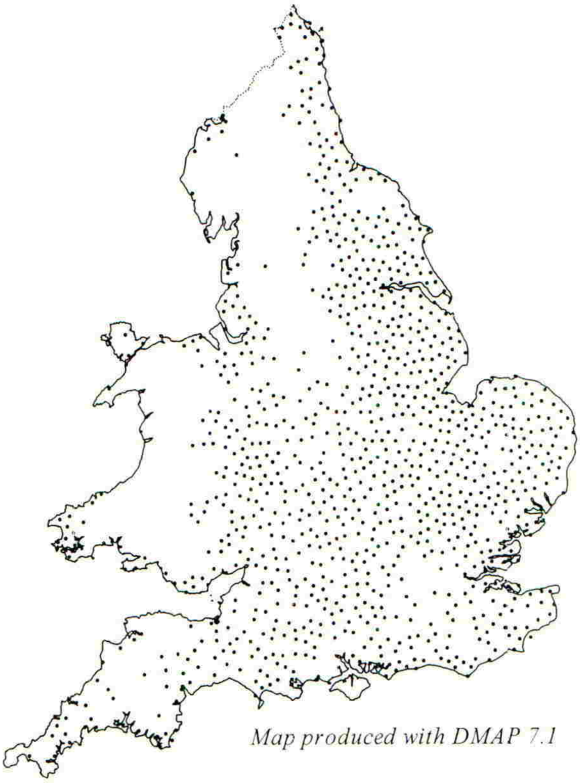

Figure 1. Locations of wheat survey locations after thinning of the 10 year data set.

A distribution map of the winter wheat crop at a resolution of 4 km^2 in 1995 was obtained from the Edinburgh Data Library (http://datalib.ed.ac.uk/index.html) which comprised 26528 grid squares across England and Wales where winter wheat was present. To produce a continuous surface of a spatially distributed variable for wheat growing areas, the 26528 grid locations must be interpolated from the 984 sample locations. There are many methods of spatial interpolation and with the comparatively large dataset available the geostatistical technique of Kriging was chosen (Webster, 1996). The procedure was carried out using the GSTAT software (Department of Physical Geography, Utrecht University, Netherlands, http://www.geog.uu.nl/gstat/) contained within the Idrisi Geographical Information System (Clark Labs, Worcester, MA, USA, http://www.clarklabs.org).

Surfaces of three major diseases of wheat were generated, leaf blotch (*Mycosphaerella graminicola*), powdery mildew (*Blumeria graminis*) and eyespot (*Tapesia* spp.). Three more surfaces were generated representing the number of fungicide applications used to combat each of the diseases using the data supplied by farmers when their crops were sampled. Only fungicides with active ingredients likely to have been targeted at the specific diseases and made at growth stages when treatment was most effective were included. Specifically for *M. graminicola*, only fungicides from the triazoles or strobilurin groups were considered. For *B. graminis*, only morpholine, piperidine, quinoxyfen, spiroxamide or difenzoquot containing products were included. For *Tapesia* spp., only products containing carbendazim, prochloraz, flusilazole or cyprodinil and applied between end of tillering (GS 29) and fifth node detectable (GS 35) development stages were included. The methodology therefore created three pairs of maps, one of the pair being an image of disease severity and the other an image of fungicide use aimed at the control of that disease. Linear regression analysis was carried out on the respective image pairs to assess the influence on the observed disease severity attributable to fungicide use.

RESULTS

Rather than carry out the regression calculations on all 26528 data points in each image pair, 500 random locations were sampled. Tests showed that this sub-sample represented the major features of each dataset and reduced autocorrelation.

Leaf blotch (*M. graminicola*)

The regression for leaf blotch showed a trend of decreasing disease severity as fungicide use increased (Figure 2), although there was some evidence of a second population exhibiting greater disease in the presence of more fungicide.

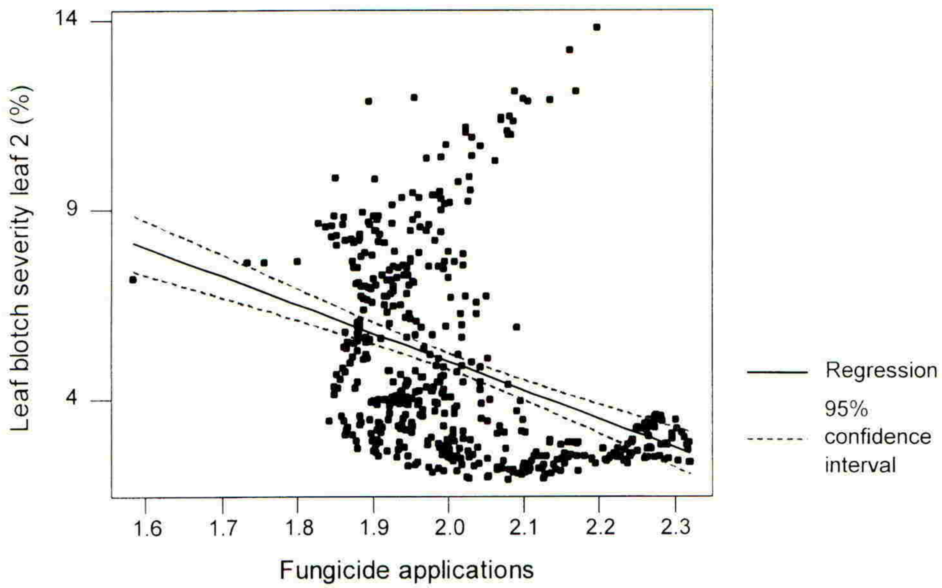

Figure 2. Linear regression of 500 random points from interpolated leaf blotch severity on leaf 2 and fungicide application maps. Line equation is severity = 19.92 - 7.5 x fungicide, R-Sq = 13.2%

Powdery mildew (*B. graminis*)

The regression for powdery mildew resulted in a more conventional type of graph (Figure 3), although in this case the incidence of disease increased as the number of fungicide applications rose.

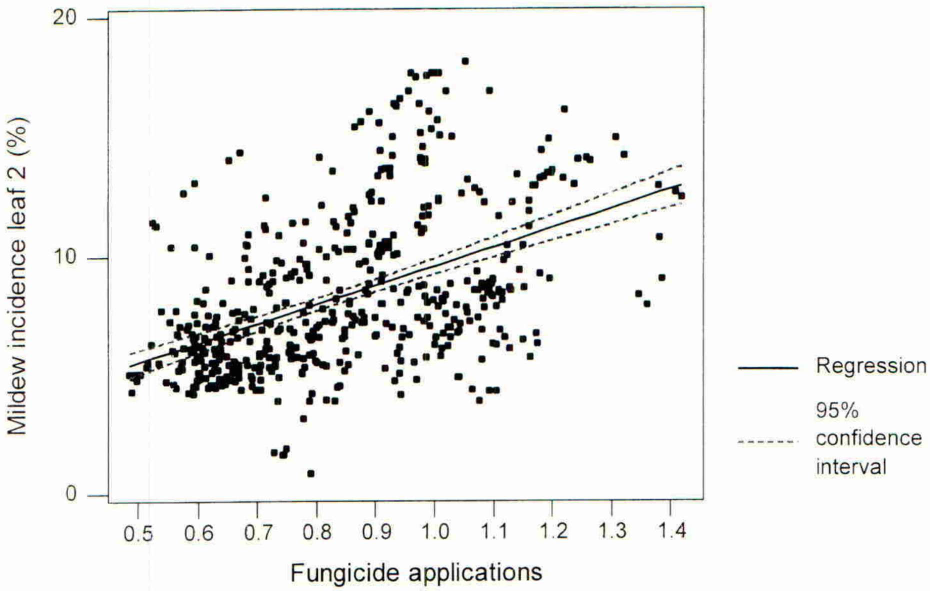

Figure 3. Linear regression of 500 random points from interpolated powdery mildew incidence on leaf 2 and fungicide application maps. Line equation is incidence = 1.48 + 8.1 x fungicide, R-Sq = 23.0%

Eyespot (*Tapesia* spp.)

The regression for eyespot showed that there was very little relationship between fungicide use and eventual disease severity (Figure 4). The majority of the data were clustered into a narrow range of fungicide application values.

DISCUSSION

Despite the relatively low R-Sq values, all three regression analyses were statistically significant at $P<0.001$, although the sub-sample size of 500 meant that many data points were lying close to the line of best fit. The data illustrated that the number of fungicide applications did not have a large influence on final disease severity. Furthermore they suggested that increasing applications of fungicide were not always associated with a decline in diseases they might be expected to control. The key question is whether the small changes in numbers of fungicide applications seen in the interpolated maps could result in the often quite large changes in severity (Paveley *et al.*, 1997). There are complicating factors regarding which sources of advice farmers may have while making spray decisions, what their intended market may be and hence what they are prepared to spend on disease control or the possibility that multiple applications may be a response to already severely infected crops.

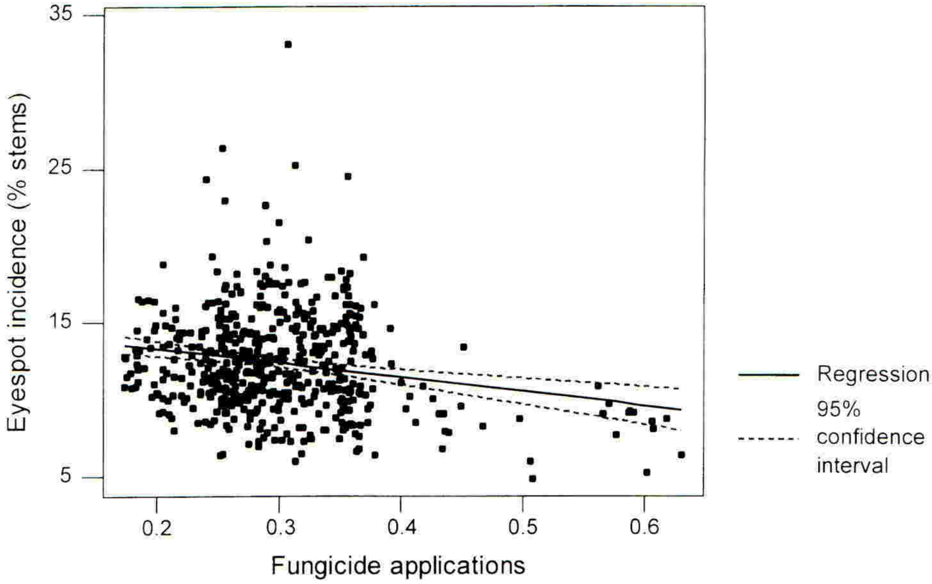

Figure 4. Linear regression of 500 random points from interpolated eyespot incidence as severe and moderate symptoms and fungicide application maps. Line equation is incidence = 15.11 - 9.2 x fungicide, R-Sq = 4.0%

The interpolated values from which the sub-samples were drawn were derived from a statistical model describing their distribution and magnitude in space. The variance of the interpolated values was not constant across the map but tended to be greatest close to the edges of a study area and where known sample points were sparse. The influence that this variability might have on the outcome of the regression analyses was not investigated but in light of the high degree of variability already present it would be unlikely to be significant on its own.

If fungicides are not the major determinant of eventual disease severity, then what other factors could be included in future analyses? Cultivar resistance is a possibility but this may not have any consistent regional distribution and resistance ratings are prone to change over time. Altitude and field aspect can be determined but the locations where such factors vary most dramatically and therefore exert greatest influence are often not those where cereal growing is the major farming activity.

Weather factors are clearly obvious candidates for inclusion in a more complex model but it has been difficult to collect measurements that are directly applicable to pathogens, usually some form of derived forecasting scheme has been developed, e.g. Thomas *et al*. (1989) for leaf blotch, Rowe & Powelson (1973) for eyespot and Rossi *et al*. (2000) for powdery mildew. These in turn would introduce further assumptions and uncertainties into a model but would not preclude an attempt being made if the required weather data could be interpolated in a similar manner to the disease distribution. Much depends on where meteorological variables are recorded and how well they relate to cropping areas.

The long term knowledge regarding disease status in wheat crops shortly before harvest, which the annual surveys provide, would serve as an excellent validation tool for complex models relating fungicide use and weather variables to eventual disease severity. This paper has shown that fungicide use alone is inadequate to describe the observed distribution of disease severity but offers a methodology for producing better predictive maps via interpolation and regression of other influential factors. Maps of an expected disease severity distribution would be a powerful aid to farmers and advisors when compared to point forecasts as the regional situation and even national situation may influence disease control decisions Nelson *et al.*, 1999).

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Disease and canopy control in oilseed rape using triazole fungicides

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ABSTRACT

Light leaf spot (*Pyrenopeziza brassicae*) and Phoma (*Leptosphaeria maculans*) are major diseases of oilseed rape and each can cause yield losses greater than 1 t ha^{-1}. Control of these diseases can be achieved using the triazole fungicides flusilazole and tebuconazole. Tebuconazole also has plant growth regulating activity, reducing crop height and lodging if applied at stem elongation. The plant growth regulating (PGR) effect can also increase yield. Spraying of larger crops may result in a better canopy structure and increased yield, whereas spraying smaller crops may result in an over-regulated canopy and loss of yield and pod quality. The aim of this investigation is to look at the fungicidal and plant growth regulating activity in relation to timing of application and crop status, whilst maintaining optimum disease control and yield. Different sowing dates and seed rates will result in different canopy sizes and structures and therefore the different responses to chemicals applied can be monitored. This poster will describe the results of first year trials.

INTRODUCTION

Oilseed rape (*Brassica napus*) is an important combinable crop in the UK: between 300-500,000 ha are grown each year, with an estimated value of £360M. Diseases of oilseed rape can account for substantial losses in yield. In the UK, two of the major diseases are *Leptosphaeria maculans*, the causal agent of phoma leaf spot and stem canker and *Pyrenopiziza brassicae*, the causal agent of light leaf spot. These organisms can reduce yields by 50% and 40% respectively.

In autumn ascospores of *L. maculans* infect leaves and cause phoma leaf spots, the pathogen then spreads systemically down the stem and causes stem cankers. Substantial yield loss can result from stem canker, so early control of phoma leaf spot is important. Light leaf spot can be controlled in autumn, but spring applications appear to give benefits (Lunn *et al.*, 2002b).

Zhou *et al.* (1999) showed that early stem canker lesions in May and June had a greater affect on yield losses, even if initially small as the severity increased with time. Triazole fungicides can provide effective control of these diseases but the timing and rate are crucial to their success.

Inconsistency in oilseed rape yield has always been a problem, the crop can be very sensitive to environmental conditions and yields can vary between 2-5 t ha^{-1} (Anon. 2002). Early establishment can help reduce over winter losses, disease and pigeon grazing. The resultant canopy architecture however, may be too dense and prone to lodging. An efficient canopy is also important to yield and the canopy needs to be open enough for the pods, stems and leaves to utilize the sunlight effectively. Similar or better yields have been obtained from less dense canopies than are usual in commercial practice (McWilliam, 1995). Optimum canopy sizes can be produced by reduced seed rates, later sowing dates (Lunn *et al.*, 2002a) or an established canopy structure can be manipulated by spraying with a plant growth regulating chemical (Lunn *et al.*, 2002b). The triazole fungicide tebuconazole is highly active and systemic. This chemical inhibits the biosynthesis of sterols essential for normal fungal cell growth and also has plant growth regulating activity due to the inhibition of GA synthesis. It has shown stem extension and leaf expansion inhibition, which was then followed by compensatory growth (Child *et al.*, 1993). On the other hand, flusilazole also has fungicide activity but has no PGR effect and these two chemicals may be suitable for different crop types. There are also many pressures to reduce costs and producers would like to apply only one fungicide or PGR treatment and therefore there is a compromise decision between phoma control, light leaf spot control and the PGR effect.

MATERIALS AND METHODS

A field trial of the oilseed rape variety Apex was sown in the autumn of 2001 at Sutton Bonington, Leicestershire. The treatment design was a split block design with four replicate blocks. The sowing dates of 29.08.01 and 17.09.01 were the main plot treatment with a factorial combination of seed rate x fungicide as sub-plots, each plot measuring approximately 2 x 24 m. Seed rates used were 120 and 60 seeds m^{-2}.

The seed used was Apex dressed with Chinook, Rovral and Thiram, thousand seed weight 5.5 g. The fungicides used were tebuconazole and a mixture of flusilazole + carbendazim.

The fungicide regimes applied were as follows:

1- Untreated,
2- Flusilazole + carbendazim (0.8 l/ha) sprayed 12.03.02
3- Tebuconazole (1 l/ha) sprayed 12.03.02
4- Flusilazole + carbendazim (0.8 l/ha) sprayed 12.03.02 followed by tebuconazole (1 l/ha) sprayed on 11.04.02

Disease analysis

Samples were taken at regular intervals through out the season. Ten plants from each plot were collected at random from a 0.25 m^2 quadrat area. Each plant was assessed for presence of light leaf spot, phoma and other diseases and the percentage infected green area recorded. Later samples scored stems for number of lesions of phoma and light leaf spot. Pods and leaves were incubated for 5 days at 4°C for light leaf spot disease assessment (Fitt *et al.*, 1998).

Growth analysis

All above ground dry matter in a randomly placed quadrat (0.25 m^2) was collected from each plot in November, February, March, late April and June. Plant numbers and fresh weight were recorded and plants were divided into stem and leaf. Flower, bud and pod were separated dependent on the growth stage and fresh weight and dry weights recorded. Stem, leaf and pod green area were also measured and the green area index (area of green material per square metre of ground) determined with a Licor planimeter. For cylindrical structures (stems and pods) a factor of $\pi/2$ was used to calculate surface from longitudinal-sectional area (Bilsborrow, 1985).

RESULTS AND DISCUSSION

Disease assessment

Disease assessment in early May showed that the three fungicides treatments produced good levels of disease control with total percentage disease severity in treated plots at < 1%. A good level of disease control was achieved in May due to the fungicide treatments, with a total severity< 1%, compared to 15-20% in untreated plots. By May all three fungicide treatments reduced light leaf spot in comparison to the severity observed in the untreated plots. Treatments three and four produced less than 1% severity of infection by light leaf spot (Figure 1).

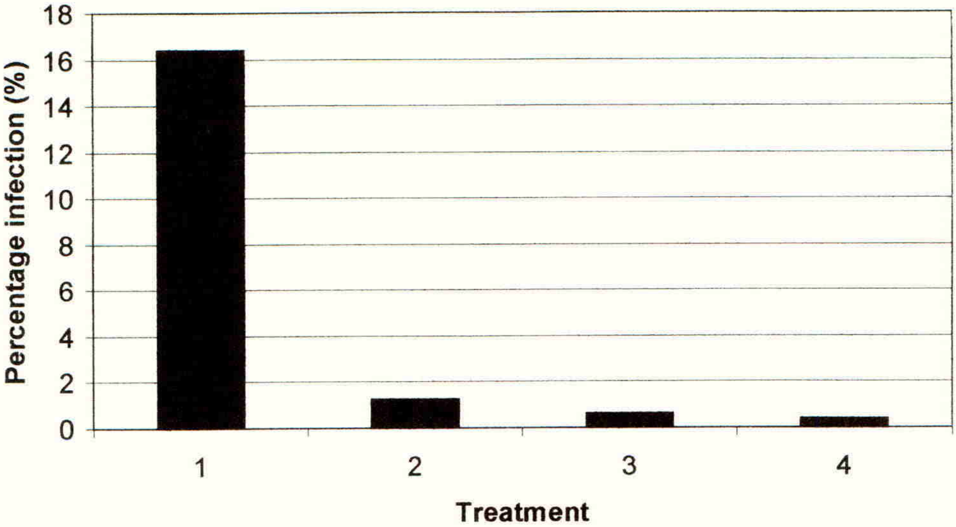

Figure 1. Percentage leaf area infection of light leaf spot on winter oilseed rape cv. Apex in untreated plots (1) and after three different fungicide regimes (2, 3 & 4; see methods for details).

Phoma leaf severity was 1% and below initially but a high incidence of stem cankers was observed in June. Stem canker did not appear to have been sufficiently controlled on those plants sown early, probably due to the absence of an autumn fungicide spray. The late sown plants had fewer lesions, with treatments 2 and 4 having the smallest number of lesions (Figure 2). The untreated plots and treatment three showed the highest number of stem lesions. Yield results should show the early-sown crops have suffered the greatest yield losses from phoma.

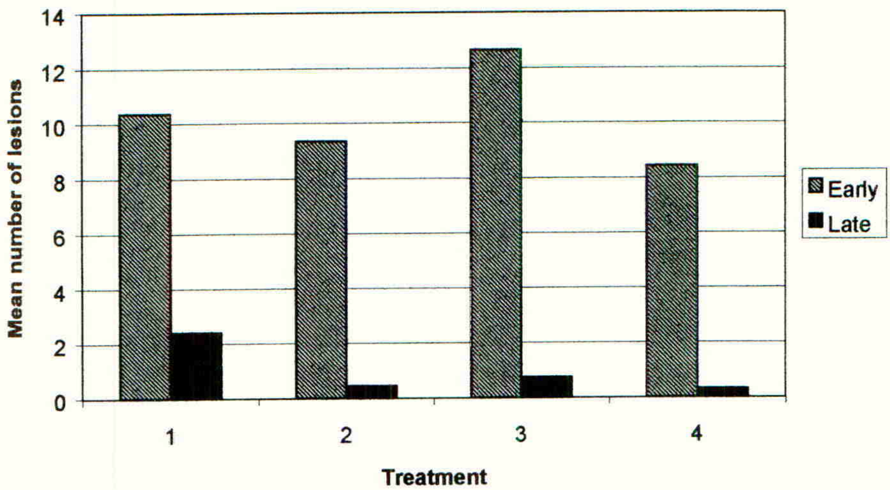

Figure 2. Mean number of phoma cankers per plant in June in plots sown early (29/8/01) and late (17/9/01) and under four different fungicide regimes

Growth analysis

All the fresh weight and dry weight results were statistically analysed using analysis of variance (Genstat 5) and throughout the season, sowing date had a significant effect on the results. Seed rate was not shown to be significant except on the number of plants per plot. Plots sprayed with tebuconazole in treatments three and four showed reduced plant heights. In March, two weeks after the first fungicide spray, the earlier sown oilseed rape had larger green area index than the later sown, as expected, and there were no significant differences between treatments (Figure 3). Six weeks after the first spray and two weeks after the second spray in April the differences in green area index were more pronounced. Late sown plants had a similar or higher green area index due to compensatory growth and treatment four had the lowest green area index for both late and early sowing dates.

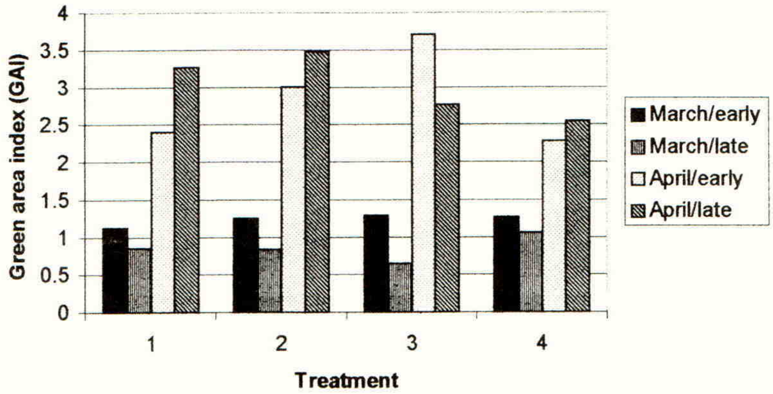

Figure 3. Effect of sowing dates (early or late) and four different fungicide regimes on green area index (GAI) of plants in March and April

There was a significant difference between early and late sowing date yields (Figure 4), treatment four had the highest yield in both early and late sown plots. There was a significant difference between the yields of treatment one (no Fungicide) and treatment four.

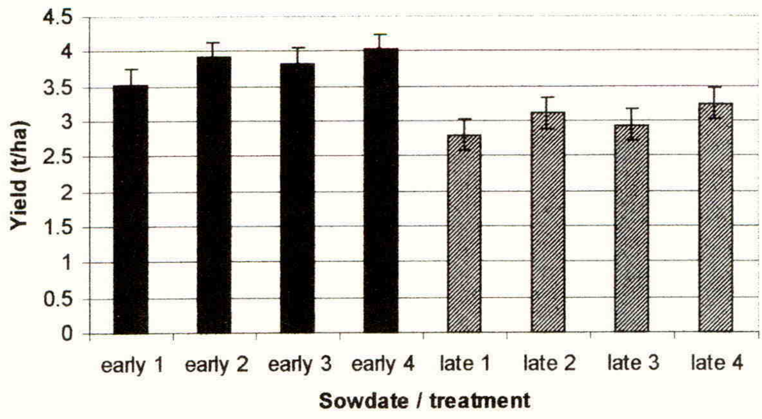

Figure 4. Yield results for 2002 showing differences between sowing dates (early or late) and the four different fungicide regimes.

CONCLUSIONS

The four fungicide regimes reduced disease levels in most cases but further trials need to be undertaken to include an autumn spray for more effective stem canker control. Tebuconazole reduced plant height and green area index this showed the effect of treatments on canopy structure. The different fungicide regimes had an effect on yield. Further trials will be conducted next year at different locations where disease levels are variable and with varieties of different resistance. Also a greater range of sowing dates will be investigated.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the financial support from Dupont chemicals and HGCA.

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HEC 5725- chemodynamic behaviour of a new leaf systemic strobilurin fungicide

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ABSTRACT

HEC 5725 is a novel leaf systemic fungicide of the chemical class of strobilurines. It shows a broad spectrum of disease control with high efficacy against diseases when used as a foliar fungicide, e.g. against stem base disease complex, Septoria, Mildew, Fusarium, Net blotch and Rhynchosporium. Studies to investigate the uptake and distribution within the plant have shown that HEC 5725 is a leaf systemic compound. Most of the compound is absorped by the wax-layer of the leaf and therefore remains available as a depot of fungicidally active substance. The localisation of the fungicide on and within the leaf is shown after spray application. HEC 5725 shows very good rain-stability. Artificial rain applied three hours after spray application leads to hardly any decline in efficacy against various plant pathogens. After seed treatment HEC 5725 shows a weak systemicity in acropetal direction. The biological mode of action is the inhibitory effect on fungal spore germination and on other early stages in the development of the pathogens e.g. germtube growth and penetration into the leaf as well as mycelial growth.

INTRODUCTION

HEC 5725 (proposed common name: Fluoxastrobin) belongs to the chemical class of the Methoxyimino-dihydro-dioxazines. This fungicide is a strobilurin analogue and binds to the Q_o–ubiqinone binding-site of the cytochrome bc_1 subunit of complex III (Becker *et al.* 1981). HEC 5725 is cross-resistant to other QoI fungicides. HEC 5725 controls economically important pathogens from all fungal classes by inhibition of the mitochondrial respiration. Affected diseases include: Septoria leaf and glume spot, brown and stripe rust, tan spot, scald, netblotch (Dutzmann *et al.* 2002). In addition to controlling diseases, the fungicide causes a higher physiological activity in plants compared to plants treated with a non-strobilurin fungicide e.g. increased chlorophyll content and higher photosynthesis index.
This poster describes the chemodynamical behaviour as regards rain-fastness and biological efficacy, uptake and translocation after seed treatment or spray application. The *in-vitro* spectrum of activity against different fungi is also demonstrated.

MATERIALS AND METHODS

Spectrum of activity *in-vitro* and in field conditions

Microtitre plates with 96 wells were prepared in the following way: each well of a row was first filled with 140 µl of a medium containing 8 different concentrations of HEC 5725. 60 µl of a spore or mycelium (*Rhizoctonia* spp.) suspension were then added to each well. Spore concentration depended on the fungus tested. The resulting test concentration of the fungicide was within a range of 0-30 µg a.i./ml. A duplicate was prepared from each isolate so that it was possible to test 6 isolates/plate. The plates were then incubated on a shaker at 20°C and 90% relative humidity for 6 days. Growth was determined photometrically at 405 nm (microtitre plate reader SLT, Spectra Image). EC_{50} values were calculated according to the extinction values. Fungicide activity against obligate pathogens such as rusts was tested in field conditions.

Rain-fastness experiments

Wheat and barley was grown for 7 days at 18°C and rel. humidity of 80%. Plants were homogenously treated in a spray cabin with 250 and 500 ppm HEC 5725 before simulated rainfall. All plants were exposed to 20 mm rain 15 min, 1 h, 3 h, 6 h and 24 h after spray application. Two plants from each sample were taken for quantitative analysis. The remaining deposit of HEC 5725 on the plants was analysed by HPLC analysis. Plants from each sample were inoculated with the following pathogens: *Drechslera teres, Septoria nodorum, Blumeria graminis* f.sp. *tritici, B. graminis* f.sp. *hordei*. Efficacy was calculated as % control (% infection relative to that of the untreated control, also called Abbott) i.e.

$$\frac{\text{\% infection of control} - \text{\% infection of treatment}}{\text{\% infection of control}} \times 100 = \text{\% control}$$

Seed treatment with radioactive labelled ^{14}C- HEC 5725

Wheat cultivar Kanzler was seed-treated with ^{14}C-HEC 5725 and cultivated for 8, 11 and 15 days at 18°C and 70 % rel. humidity in a hydroponic test-system. Plants were harvested, dried and exposed to an Image Analyser (Fuji X BAS 2000) for 24 h. Printouts were revised with TINA and Powerpoint. Quantitative analysis was carried out by cutting the plants into kernel, root and coleoptile and leaf. The amount of radioactivity taken up into the different samples was determined by combustion in an oxidiser.

SEM-micrographs of spray deposits on barley and wheat leaves

The upper leaf side of barley was sprayed with an optimised EC 100 formulation of HEC 5725. The nozzle type was an XR 110015 VS, water volume was 200-400 l/ha and concentration 0.5 g/l a.i. Deposits were studied after evaporation of water in the laboratory at 2 hours.

RESULTS AND DISCUSSION

Spectrum of activity *in-vitro* and in field conditions

HEC 5725 exhibited a high level of efficacy against a broad spectrum of phytopathogenic fungi of the classes Ascomycetes, Basidiomycetes and Oomycetes. In table 1 the EC_{50} values are listed. Even at concentrations beyond 0.1 ppm, inhibition of mycelial growth was observed. HEC 5725 showed *in vitro* especially high activity against *Monographella nivale* and *Drechslera teres*. Excellent inhibition was also demonstrated against *Alternaria mali*, *Ustilago avenae* and *Helminthosporium solani.* In field tests HEC 5725 provided complete control of Septoria leafspot diseases (*Mycosphaerella graminicola*) and Septoria glume blotch (*Phaeosphaeria nodorum*) in winter wheat. Furthermore rust diseases (*Puccinia recondita, P. striiformis)* were particularly well controlled.

Table1. *In-vitro* spectrum of activity of HEC 5725 against different fungi

Species	EC_{50} (mg a.i./litre) mycelial growth
Alternaria mali	<0.1
Botrytis cinerea	18.06
Fusarium moniliforme	0.31
Giberella zeae	3.19
Helminthosporium solani	< 0.03
M. nivale var. majus	0.002
M. nivale var. nivale	0.002
Mycosphaerella graminicola	0.096
Plasmopara viticola	0.09
Pythium aphanidermatum	< 0.03
Pyrenophora teres	0.0075
Rhizoctonia cerealis	0.035
Rhizoctonia solani AG 3	0.048
Ustilago avenae	0.16

Rain-fastness

Rain may decisively influence the product's efficacy in the field by removing the deposit from the plant or leaf surface. More than 20% of the applied a.i. could be detected by HPLC either on the leaf surface or in the leaf after 3 h of drying of the deposit. This is in contrast to the behaviour of the a.i. due to penetration and translocation after seed treatment. These differences may also be due to different application and formulations used. Not only the chemodynamical behaviour was determined, but also the biological performance of HEC 5725 was tested. The absolute activity in inhibiting the tested pathogens was about the same after 3-6 h drying of the spray deposit whether rain was applied or not. The efficacy of the compound against all the pathogens tested, following simulated rain, indicatedvery good rain-fastness. As an example, the efficacy against *Drechslera teres* (250 ppm spray application) is shown in Fig. 1.

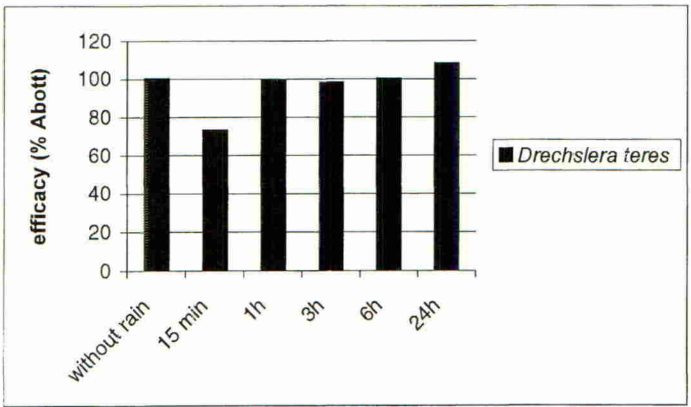

Fig. 1: efficacy against *Drechslera teres* after spray application and simulated rainfall

Seed treatment

More than 84% of applied label stayed within the kernel 8 days after sowing. In the coleoptile and in the roots about 16% of the applied radioactivity was detected, whereas in the first emerging leaf no measurable radioactivity was found. After 11 days about 3% and after 15 days about 4% of the total applied radioactivity per kernel was in the first leaf. In the second leaf nearly 1% of the total radioactivity was observed after 15 days and in the third emerging leaf the translocated amount of HEC 5725 was beyond quantitative measurement. HEC 5725 showed low systemicity in seed treated wheat plants but showed good protection against seed and soil-borne diseases from its locosystemic activity in the seed kernel.

Table 2: Distribution of ^{14}C HEC 5725 in wheat plants after seed treatment

Period after planting	% of applied activity in kernels	% of applied activity in root and coleoptile	% of applied activity first leaf	% of applied activity second leaf	% of applied activity third leaf
8d	84%	16%	0	-	-
11d	73%	23%	3	0	-
15d	70%	>25%	4	<1	0

SEM-micrographs of spray deposits on barley and wheat leaves

Spray retention on barley leaves of HEC 5725 with the EC 100 formulation was at least 75% of the amount sprayed on the exposed leaf area. This applies to the recommended rates and to water volumes of 200-400 l/ha. No significant differences were observed with flat fan or air injection nozzles. Spray deposits were investigated with the EC 100 formulation at 0.5 g/l HEC 5725. A strikingly even distribution of an amorphous deposit was observed 2 hours after application on barley leaves (Fig. 3 & 4). There was no accumulation of solid at the edge of the droplet area. It appears that there is good absorption into the accessible fraction of surface waxes and between the crystalline wax fraction. Wax crystals were actually still visible and were slightly protruding from the drop deposit. Diffusion into the cuticle was substantial as suggested by a continously decreasing deposit 2 hr after application. With wheat, surface waxes appeared occasionally redeposited/melted resulting in a smooth amorphous structure of blended deposit and waxes. First experiments on the rainfastness of this deposit showed no change when 20 mm rain was applied about 5 hrs after application.

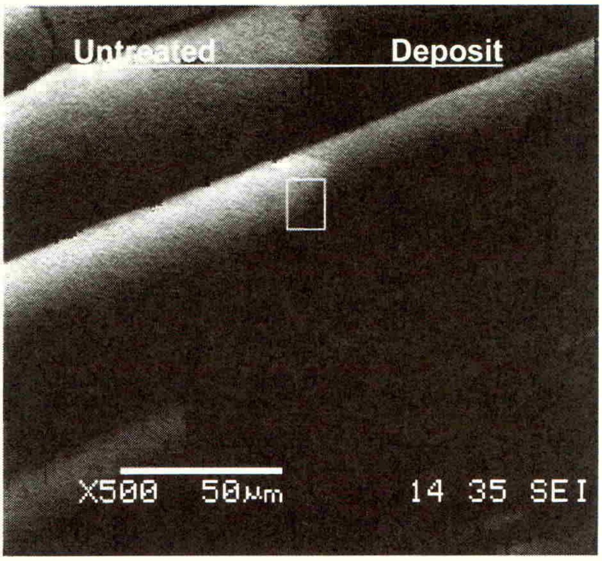

Fig.3: HEC 5725 deposit on a barley leaf after spray application

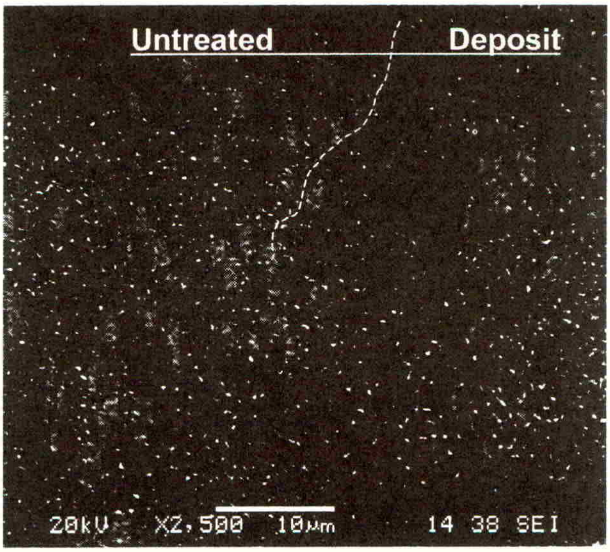

Fig.4 : higher magnification of the transition between spray deposit and untreated area

CONCLUSION

HEC 5725 exhibits a broad spectrum of activity against pathogens of nearly all fungal classes.

Early stages in the disease cycle of the fungus are primarily inhibited such as spore germination and the formation of early infection stages.

Fluoxastrobin is absorbed into the waxy layer of the leaves and shows very good preventive and curative efficacy (Dutzmann *et al.* 2002).

A rapid uptake and even acropetal distribution of the substance into the leaf was demonstrated after spray application of HEC 5725 (EC100).

The rain-stability of the compound is excellent.

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Effects of light leaf spot (*Pyrenopeziza brassicae*) infection on winter survival and yield of oilseed rape (*Brassica napus*)

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ABSTRACT

The *direct* effects of light leaf spot on winter oilseed rape ground cover in winter and the relationship between decreased ground cover and yield loss was investigated in a field experiment at SAC Aberdeen (Scotland). In the experiment with cultivars Bristol (susceptible) and Capitol (resistant), light leaf spot was the main disease on leaves in winter. Measurements of ground cover were made in early spring and differences between treatments were assessed by analysis of variance. Linear regression was used to relate light leaf spot severity to ground cover in early spring and yield at the end of the season. Differences in ground cover between plots, which were untreated or treated with different fungicide regimes, were much greater for the susceptible cultivar than for the resistant one. Decreases in ground cover associated with light leaf spot were related to substantial yield losses. These results will be discussed in relation to strategies for management of light leaf spot to optimise yield of winter oilseed rape.

INTRODUCTION

Light leaf spot (LLS, causal agent: *Pyrenopeziza brassicae*) is a polycyclic disease of winter oilseed rape. Epidemics are initiated by wind-dispersed ascospores in autumn and maintained by secondary spread of rain-splashed conidia (Rawlinson *et al.*, 1978; Gilles *et al.*, 2000a). Leaf wetness is required for infection by ascospores or conidia, and the length of the latent period (from infection to production of conidia) is temperature-dependent (Gilles *et al.*, 2000b; Gilles *et al.*, 2001; Karolewski *et al.*, 2002). During epidemic years, initial infection in late autumn/early winter can lead to high levels of infection at a time when oilseed rape plants are vulnerable. This often leads to winter kill, particularly in the north of England and Scotland. However, it has been shown that light leaf spot incidence over the winter period can be decreased by fungicide applications between November and February (Sansford *et al.*, 1996). This paper reports the results of work on the effects of tebuconazole on light leaf spot severity on oilseed rape leaves in relation to ground cover, winter survival and yield.

MATERIALS AND METHODS

Cultivars Bristol and Capitol, with LLS resistance ratings of 2 (susceptible) and 8 (resistant), respectively (Anon., 1997), were grown at Tillycorthie Farm, SAC Aberdeen in 1998/1999. Plots were drilled on 11 September 1998 at 6 kg/ha, and standard basal treatments of fertiliser, insecticides and herbicides were applied to all plots. The 60 plots were organised in a split-plot design with three replications. Cultivars were allocated to whole plots and 9 different fungicide treatment regimes were allocated to sub-plots. Fungicide treatments were applied according to the schedule shown in Table 1. The fungicide was Folicur (250g/l EW, tebucanoazole) applied at full rate of product (1.0 l/ha) or half rate of product (0.5 l/ha). In addition to fungicidal activity, tebuconazole is known to produce growth regulatory effects when applied in the spring and may also have a frost protection effect when applied in the autumn/winter. Light leaf spot was assessed on 11 December, 1 March and 14 April. Ground cover and % leaves affected by frost scorch were assessed on 14 April and 1 March, respectively. Crops were harvested on 11 August 99 and the yield (at 10% moisture) was determined (Steed *et al.*, 1999).

Table 1. Treatment codes, dates and rates of application of tebuconazole

Code	Treatment	Application date
1	Untreated	-
2	Routine (half rates)	19-Sep-98, 10-Dec-98, 4-Mar-99, 14-Apr-99
3	Nov (full rate)	19-Nov-98
4	Dec (full rate)	10-Dec-98
5	Mar (full rate)	4-Mar-99
6	Nov+Apr (half rate)	19-Nov-98, 14-Apr-99
7	Dec+Apr (half rate)	10-Dec-98, 14-Apr-99
8	Mar+Apr (half rate)	4-Mar-99, 14-Apr-99
9	Apr (full rate)	14-Apr-99

Treatment effects on ground cover for cultivar Bristol were analysed using analysis of variance. Analysis of covariance was used to investigate the relationship between disease and ground cover, defining % leaf area affected with light leaf spot as a linear covariate term. For graphical representation, residuals of an analysis of variance on % leaf area infected were regressed on the residuals of an analysis of variance on ground cover to take into account the design effects.

Analysis of covariance with a linear covariate term was applied to investigate the yield versus ground cover relationship, while taking into account design effects and differences between cultivars and treatments with growth regulating effect (2, 5, 6, 7, 8, 9). For graphical representation, analysis of variance residuals of ground cover were regressed on residuals for yield. All analysis was done using the GenStat statistical package (Payne, 2000).

RESULTS

Immediately after drilling, weather was very wet and emergence slow and poor, especially for Bristol. A wet autumn was followed by a severe winter, with particularly slow plant growth. Light leaf spot was first observed in March at low levels (2% leaf area affected on untreated plots) and increased substantially by April (15% leaf area for Bristol and 12% for Capitol). Other diseases (phoma leaf spot, alternaria, downy mildew) were present at low levels (<1% leaf area affected). Differences in % leaves affected by frost scorch between cultivars (Bristol 43%, Capitol 28%, P = 0.047, 2 df) were significant but those between treatments were not.

Ground cover in April was generally greater for Capitol (90.1%) than for Bristol (51.7%). Treatment effects on ground cover were significant (P < 0.001, 41 df, Figure 1). For cultivar Bristol, a full rate November or December or three half rate treatments (3, 4 and 2, respectively) increased ground cover significantly, compared to no autumn treatment (1, 5, 8, 9) and performed better than single half rate treatments (6, 7).

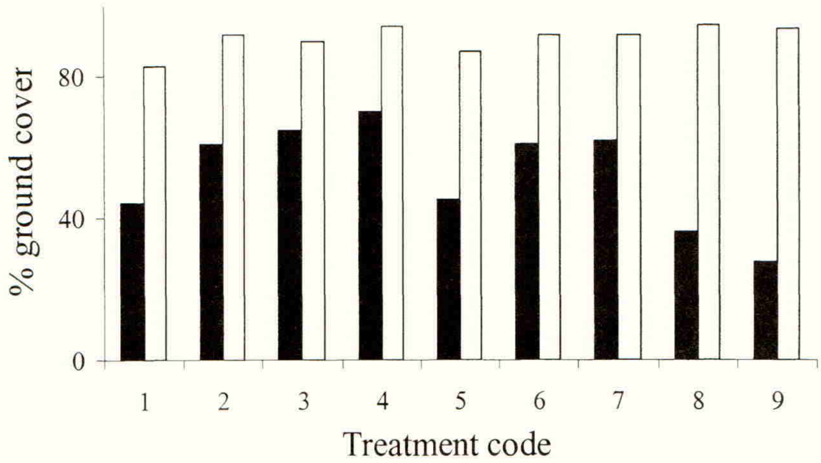

Figure 1. Ground cover in April for different treatments and cultivars (■ Bristol, □ Capitol). Least significant difference (5% level) between treatment means for the same cultivar was 13.7 for untreated (1) against treated (2-9) and 15.8 for comparisons between treatments 2 to 9. Treatment codes explained in Table 1.

For cultivar Bristol, ground cover in April was negatively related to % leaf area affected with light leaf spot in April (P = 0.001, 26 df) and the regression line accounted for 32% of the variation (Figure 2). A 4 percentage point increase in leaf area affected was related to a 5 percentage point decrease in ground cover.

Yields were poor due to severe weather conditions, with a higher average for Capitol (2.8 t/ha) than for Bristol (2.1 t/ha). A linear increase in yield with ground cover in April was observed (P < 0.001, 41 df), with a 0.5 t/ha yield loss for a reduction in ground cover by 20 percentage points.

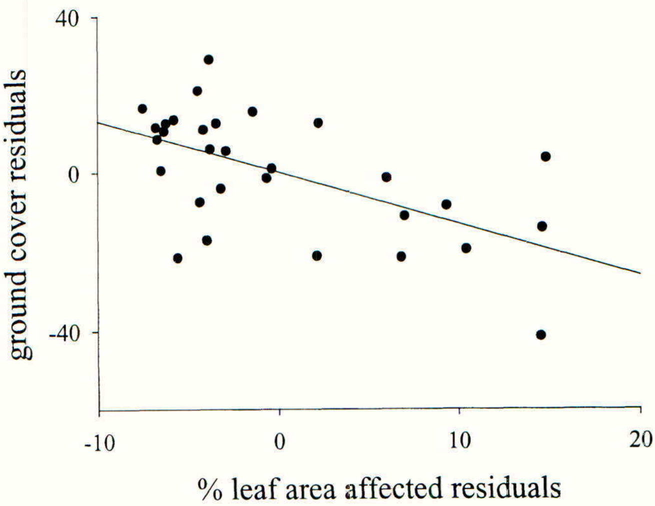

Figure 2. Relationship between ground cover in April (*g*) and % leaf area affected by light leaf spot in April (*l*) for cultivar Bristol after taking design effects into account. The linear regression ($g = -1.3\ l$) accounted for 32 % of variation ($P = 0.001$, 26 df).

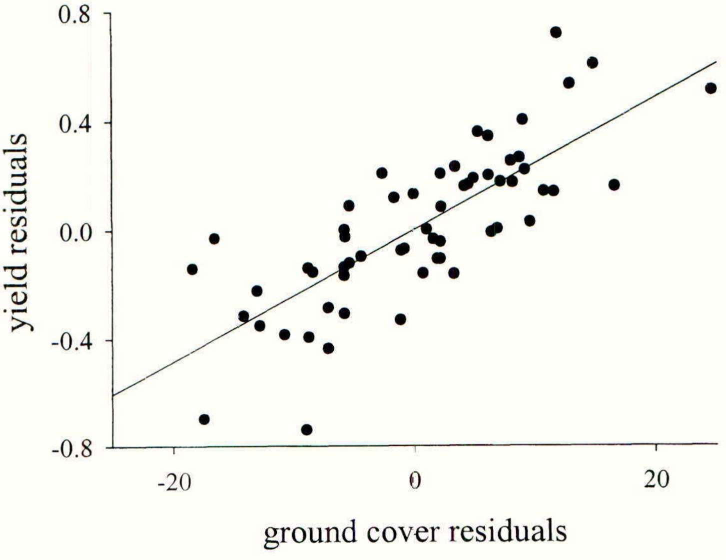

Figure 3. Relationship between yield (*y*) and ground cover (*g*) after taking into account design, cultivar and growth regulating effects. The linear regression ($y = 0.024\ g$) accounted for 62% of variation ($P < 0.001$, 41 df).

DISCUSSION

The work shows that a combination of light leaf spot and a severe winter can cause leaf loss and/or plant death and substantial yield loss in winter oilseed rape crops. Reduced ground cover is related to the amount of disease (light leaf spot) on plants. Fungicide application in autumn can effectively control disease and therefore decrease winter kill, with the best response from a full dose application in November or December.

For a susceptible cultivar, severe frost damage (40% leaves affected) together with treatment related variation in disease levels can produce substantial differences in ground cover (30 to 70%). Reduced green area of the crop available for photosynthesis limits numbers of pods and seeds, as well as assimilate for seed filling (Lunn *et al.*, 2002). Although oilseed rape is able to compensate effectively for widely differing plant densities, substantial yield losses were observed. Fungicide applications in early spring (treatment codes 5, 8, 9) were not able to fully compensate for losses caused by light leaf spot through winter kill. This demonstrates the importance of an autumn spray application when a severe light leaf spot epidemic is forecast (Welham *et al.*, 1999).

Reduction in ground cover through winter kill shows that light leaf spot on leaves can cause immediate damage to oilseed rape crops that results in yield loss, in addition to providing a source of inoculum for transmitting the infection to the canopy of the plant later in the season.

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Pest and disease management constraints under climate change

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ABSTRACT

A series of models was used to assess the effect of climate change on seven different farm types in 13 locations in England and Wales. The models used included simulations of crop yield responses and weekly Available Work Days (AWDs) to determine the pattern and timing of crop production under one climate change scenario. The project used the UKCIP98 Medium High scenario, which projects a warmer climate (1.7-2.0°C) and a higher annual rainfall (101-105%) giving wetter autumns and winters, but drier summers than at present, producing a longer growing season and far less frost days. These changes could mean a change in pest and disease patterns through the year and changes in species' profiles. The ECOMAC II model of available work days indicated that in spring AWDs may remain at current levels or decline, whilst in early autumn soil moisture deficits (SMD) will initially be higher, but fields may become wet at a faster rate than at present. This may limit opportunities to control pests and diseases.

INTRODUCTION

Climate change is now recognised to be a global concern, the impacts of which can no longer be avoided (Met Office/DETR 1999). This project aimed to identify how and over what timescale, adaptations to climate change would be needed at the farm level (Hossell, *et al.*, 2001). This paper reports the findings with regard to climate change and its effects on available work days (AWDs) for farm operations.

Based on the UKCIP98 scenarios, mean annual temperatures in the UK could rise by between 0.7°C and 2.3°C over the next 50 years (Hulme & Jenkins, 1998). Winter and autumn are projected to be wetter than at present, with little change in spring, but a decrease in summer rainfall in England and Wales. For agricultural production, the significant climate changes by the 2050s under the Medium High scenario are:

- An increase in the growing season length by about 40%;
- A reduction in summer precipitation of between 0 and 20%;
- An increase in winter and autumn precipitation of 9-13%;
- An increase in summer potential evapotranspiration of 6-17%;
- A reduction in frost days of around 70%;
- A threefold increase in days with maximum temperatures greater than 25°C;
- Increased incident short-wave radiation in summer of 3-8% and in autumn ≈4%;
- An increase of atmospheric CO_2 of 66% on present day levels.

METHOD

Selection of Farm Types and Locations

The project explored the impact of climate change on a number of key farm types:

- arable combinable cropping
- specialist dairy
- lowland livestock
- mixed
- arable with roots
- lowland dairy
- hill livestock

For each farm type, a location where it was the dominant or the core system (C) was selected along with one where it was marginal (M). For the mixed farm type, only a single location was chosen. For each location, an appropriate soil type was selected. The site selection was based on MAFF census data 1996 and enabled the sensitivity to climate change, of different sizes/mixes of enterprise, to be assessed. This paper considers two farm types, the core combinable arable cropping type (CAC) located in eastern England and the marginal combinable arable cropping type (MAC) located in northern England, both on heavy land sites.

The UKCIP98 baseline data (covering the climatic normal averaging period of 1961-90) and the two Medium High scenarios for the 30 years centred on the 2020s and 2050s were run through a weather generator to produce 100 years of daily weather data at the 13 locations in England and Wales. No detail is provided in the UKCIP98 scenarios of the number of rain days under altered climate. Hence, the same sequence of rainfall events was used as had been established for the baseline climate, i.e. it always rained on the same days in both baseline and future climate. This therefore resulted in an increase in rainfall intensity, where rainfall totals increased in the Medium High scenario. However, this assumption may still underestimate the severity of intense rainfall events. A rain day was defined as being a day in which more than 6 mm of rain fell i.e. sufficient to prevent any fieldwork.

Crop Models

The model chosen to simulate all the arable crops was the ACCESS II model derived from the EU ACCESS model (Loveland *et al.*, 1996). A vernalisation function was included within the crop growth model, based on accumulated vernalisation degree-days (Hough, 1990). Within ACCESS II, the parameters for sowing and harvesting dates for each crop were based on Nix (1999) values and experience of ADAS consultants on the variation in dates for different soil types.

ECOMAC II: A Model of Available Work Days (AWDs)

ECOMAC II is an economic model that considers the operational aspects of fieldwork. For this project, only the first level of the model, which determines the amount of time available for fieldwork based on climate and soil type, was used. An AWD was defined as a day when soil moisture deficit (SMD) rose above a threshold value for a given soil, thus allowing fieldwork without damaging the surface.

The original ECOMAC (Harris, 1996) data were based on Technical Bulletin 35 (MAFF, 1976). This considered Soil Moisture Deficit (SMD) in the top one metre of soil under a grass cover, using meteorological data for the climatic normal period 1941 - 70. For this project, ECOMAC was updated to use climate data for 1961 – 90, with SMD in the top 300mm soil under a continuous spring barley crop as derived from ACCESS II.

RESULTS

Available Workdays and Soil Moisture

Table 1 shows the available work days for the two farms for the baseline, 2020s and 2050s scenarios. There is little effective difference in AWDs between the baseline and future climate during the growing season from weeks 13 to 35. But as the land dries out around week 12 in spring and as the land becomes wetter in autumn (weeks 36 – 52), differences in AWDs become apparent between the baseline and future climate conditions

Table 1. Available Work Days and Soil Moisture Deficits for the Baseline and Medium High Scenario for 2020s and 2050s in core (CAC) and marginal (MAC) arable combinable farm types

	Weeks 1 - 12	Week 12	Weeks 36 – 52	Week 36
	AWDs	**SMD**	**AWDs**	**SMD**
CAC				
Baseline	24.5	15	87.5	58
2020s	18.5	14	85.0	63
2050s	17.5	15	85.0	70
MAC				
Baseline	5.0	10	53.0	36
2020s	5.0	10	50.5	40
2050s	5.5	10	52.0	44

Within an AWD, SMD can also be important, since although a field may be dry enough to support equipment, conditions may be too dry to work effectively. In the baseline climate SMD reaches 15 mm by week 12 at the core arable site and by week 15 at the marginal arable site. After these dates, there is a rapid increase in AWDs due to drying out of the soil (Figures 1 and 2). For weeks 13 to 24 SMDs show little difference between baseline and the 2020s and 2050s, but for weeks 25 to 35, both sites are consistently drier in the 2020s and 2050s. At the core arable site, autumn SMDs are 5 mm higher in the crucial crop establishment period from weeks 36 to 40 in the 2020s, but this rises to at least 12 mm in the 2050s. These differences are mirrored at the marginal arable site, being 4 mm in the 2020s and 8 mm in the 2050s.

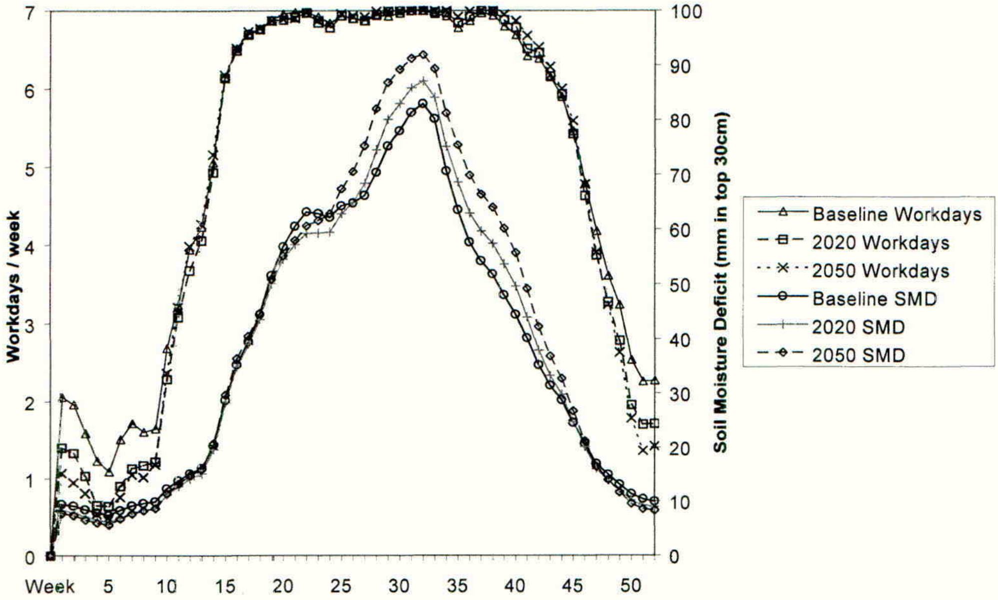

Figure 1: Workdays available and soil moisture deficit (SMD) on Core Arable Combinable crops farm type (Cambridge site) for baseline and future climate conditions

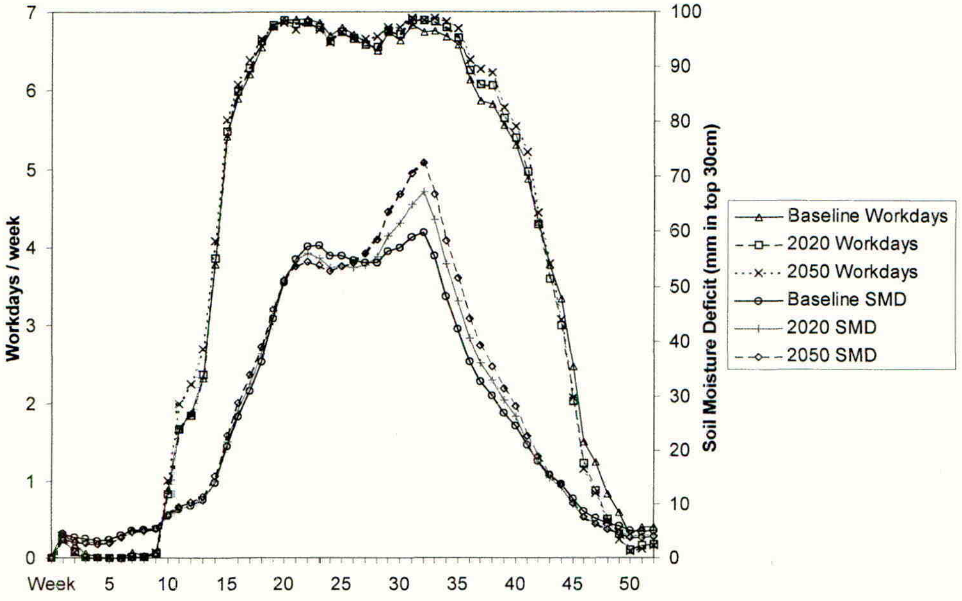

Figure 2: Workdays available and soil moisture deficit (SMD) on Marginal Arable Combinable crops farm type (North East England site) for baseline and future climate conditions

DISCUSSION

It should be noted that the values used are the average AWDs and SMDs for the locations and that any changes in the frequency of extreme events (such as the very wet autumn of 2000, when monthly rainfall totals were up to 200% higher than normal over much of the country (Anon. 2001) have not been considered. In addition to changes in opportunities to control pests and diseases, other significant factors are the reduced frost kill during winter and warmer conditions over a longer growing season possibly leading to faster development of higher pest population levels (Hardwick *et al.*, 1996).

Core Arable Combinable Farm Type

Under current climate, changes in AWDs on a heavy soil occur in weeks 10-12. Prior to that, little fieldwork is currently undertaken and the wetter conditions of the 2020s and 2050s mean there would be fewer opportunities. This means that up to week 10, fieldwork such as spraying will be increasingly risky in the future, with the possibility of loss of timeliness of spring pest and disease control. Examples include wheat bulb fly (*Delia coarctata*) and *Septoria tritici* on cereals, and light leaf spot (*Pyrenopeziza brassicae*) and pollen beetles (*Meligethes* spp.) on oilseed rape. However, climate change may produce a temporal change in the phenology of pests and diseases and it may also adversely affect survival of those that are currently considered to be important. Conversely, species currently considered to be minor may start to become more serious if cropping patterns change due to climate shifts.

During weeks 13 to 24, AWD and SMD results show little change, although there is will be greater rainfall and increased evapotranspiration under the climate change scenarios. During harvest (weeks 25 – 35), the higher SMDs in the 2020s and 2050s suggest conditions will be drier and easier. From week 36, the climate change scenarios suggest drier autumn soils, with the average SMD 5 mm greater throughout September in the 2020s and 10 mm in the 2050s. However, with increased autumn rainfall, the soil will become rapidly wet with, on average, a small loss of AWDs by November. This means that after a dry start, there will be greater pressure to accomplish autumn establishment in terms of maximising potential yield. This may mean less time for trash disposal and greater pest and disease populations entering the winter. With the great reduction in frost days forecast under climate change, this could allow a far greater carry over of pests and diseases to the following spring. Increased pressure on crop establishment could result in poor seedbeds and shallow rooting, producing less vigorous crops and consequences for pest and disease development on less vigorous crops.

Marginal Arable Combinable Farm Type

For this farm type, there is currently little expectation of fieldwork on its heavy soil in the spring and opportunities will decline under climate change. The major changes in the year are in the second half where conditions may be drier. This will mean a minor delay in reaching suitably moist crop establishment conditions in the autumn in the 2050s compared with the baseline, so conditions may be reliably better for this type of farm. The marginal decline in opportunities for late season work will have little effect on how crops are grown, although there will be fewer chances to carry out late drilling and spraying.

CONCLUSION

In considering the effects of climate change on agriculture, it is important not only to examine the impacts on crop pests and disease, but also on the potential for and timing of farming operations that control them. The ECOMAC II results presented above provide one approach to assessing how farming operations may be affected in the future under one climate change scenario. Climate change may benefit some aspects of farming because of increases in the growing season length, but there may be significant consequences for pest and disease development where opportunities to control them decline and the lack of frost days over the winter allow greater survival into spring.

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MASTER: Management Strategies for European Rape pests - a new EU Project

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ABSTRACT

MASTER (MAnagement STrategies for European Rape pests) is the acronym for a new 4-year project entitled 'Integrated pest management strategies incorporating bio-control for European oilseed rape pests' (QOL –2000-01447). This is funded by the EU under its Framework 5 'Quality of Life and Management of Living Resources' programme. It is co-ordinated by IACR-Rothamsted, and has eight partners from six countries. It aims at scientific development of a low pesticide, environmentally-friendly regime for growing winter oilseed rape, with full social and economic evaluation. The project brings together European expertise to construct and evaluate, through trans-European collaborative experiments, economically-viable and environmentally-less harmful IPM Strategies for the crop. These will maximise biological control of pests and minimise pesticide use, through enhancement of naturally-occurring natural enemies of the pests. Technical Guidelines for end-users and a Phenological Model for the natural enemies will be produced for Decision Support. New information on the

information on the pest/natural enemy community in the crop ecosystem and new insight into the socio-economic processes affecting new technology adoption by farmers will be acquired.

THE PROJECT: MASTER

MASTER (MAnagement STrategies for European Rape pests) is the acronym for a new project, entitled 'Integrated pest management strategies incorporating bio-control for European oilseed rape pests' (QLK5-CT-2001-01447) being funded by the EU under its Framework 5 Quality of Life and Management of Living Resources programme. The project is of 4-year duration. It has eight partners from six countries: Estonia, Finland, Germany, Poland, Sweden and UK. The primary objective of the project is to construct, develop, evaluate and promote an Integrated Pest Management (IPM) System for the European winter oilseed rape crop incorporating biological control of pests.

Why IPM ?

Arable farming systems research has focussed on cereals. MASTER is the first Europe-wide co-ordinated R&D project to focus on IPM Strategies for the winter oilseed rape crop, a major break crop within the cereals rotation.

The management of pests on the European oilseed rape crop still relies heavily on chemical pesticides, most often applied routinely and prophylactically, often without regard to pest incidence, and at best, according to threshold values of the pest population (Arthur *et al.*, 1999; Christen *et al.*, 1999). This leads to over-use of chemical pesticides which reduces the economic competitiveness of the crop and threatens biological diversity.

The pesticides also kill the natural agents of biological control, which would otherwise be a natural resource of great potential benefit to the farmer and consumer. Most of the natural enemies of the pests of oilseed rape attack their hosts during the larval stage, on the plants, on the soil surface and in the soil. By killing natural enemies, pesticide applications must be increased further to achieve pest control (Pickett *et al.*, 1995; Murchie *et al.*, 1997).

The Organisation for Economic Co-operation and Development (OECD) recognises the intense use of pesticides on the crop as a key negative indicator of sustainable production. MASTER seeks alternative methods to replace plant protection products withdrawn or to be withdrawn from the market. For example, in the UK, gamma HCH was prohibited as a seed treatment for cabbage stem flea beetle control in oilseed rape in 1999. Recent reports indicate that pollen beetles have developed resistance to pyrethroids in France and in Scandinavia and are no longer being controlled by this group of pesticides. The use of plant protection products in the EU is governed by EU Directive 91/414/EEC and is currently being updated and under review (http://europa.eu.int./comm/food/index_en.html)

MASTER will develop IPM for winter oilseed rape to improve the efficiency, profitability and environmental acceptability of production and, thereby, to contribute towards sustainable production of the crop.

Objectives

MASTER has the following five objectives:

1. To determine the identity, status and potential of bio-control agents for rape pests in Europe, to increase knowledge of their ecology and identify key factors affecting their efficacy.
2. To develop economically viable, environmentally acceptable IPM strategies for European rape that maximise bio-control of key pests and minimise pesticide use.
3. To determine the socio-economic feasibility, importance and economic efficiency of the IPM strategies in Europe, including gains in environmental quality and rural viability, and to assess the socio-economic factors influencing their adoption.
4. To construct a Phenological Model of key pests and their bio-control agents, relating occurrence on the crop to growth stage and climatic/weather conditions, for integration into existing Decision Support systems.
5. To produce Technical Guidelines for end-users on the IPM strategies.

Which pests?

MASTER is targetting the six most important pests of winter oilseed rape in Europe. These are *Psylliodes chrysocephala* (the cabbage stem flea beetle), *Meligethes aeneus* (the pollen beetle), *Ceutorhynchus assimilis* (the cabbage seed weevil), *Ceutorhynchus napi* (the rape stem weevil), *Ceutorhynchus pallidactylus* (the cabbage stem weevil) and *Dasineura brassicae* (the brassica pod midge). These attack the crop successively at various stages of its growth and damage different parts of the plant.

Which natural enemies?

MASTER will seek to control these six pests using the naturally-occurring parasitoids, predators and pathogens that attack them. Current knowledge of these natural enemies was collated by the EU Concerted Action project FAIR-CT96-01314 'Minimizing pesticide use and environmental impact by the development and promotion of bio-control strategies for oilseed rape pests (BORIS) 1997-9' (Alford *et al.*, 2000). A book 'Biocontrol of oilseed rape pests' containing this information is to be published by Blackwells (Oxford, UK) next year.

The pests are host to at least 60 known species of parasitoid. These are of varying importance in different countries but at least 10 are probably sufficiently widespread and abundant to be of potential economic importance. The main epigaeic predators are the carabid beetles, staphylinid beetles and spiders while dolichopodid flies and hybotids are the most abundant predators in the crop canopy. Pathogenic organisms exerting natural control of oilseed rape pests include entomopathogenic fungi, entomopathogenic nematodes, bacteria and protozoa and the most promising of these will be selected for pest control.

Strategic research

MASTER will address gaps in our knowledge of the natural enemies through strategic research into factors affecting their abundance, phenology, distribution and host location. Within-field synchrony and co-incidence of the pests and their natural enemies will be investigated to give a more detailed and informative picture of crop colonisation than hitherto achieved and aid precision treatment timing and targetting for natural enemy conservation. Studies on the effect of physical and chemical cues on habitat and host location by natural enemies, and the effect of plant density and host plant architecture on within-plant distribution of host larvae and their natural enemies are planned. This information will be used in IPM Strategies to manipulate crop canopy structure and insect behaviour to enhance their efficacy. The relative advantages and disadvantages of minimum tillage or direct drilling over ploughing for conservation of key species will be evaluated. The feeding preferences and capacities of key predator species will be determined. Farm-scale enhancement, application and dissemination technologies will be utilised for the first time in oilseed rape to increase the field abundance and efficacy of key pathogen species.

Collaborative IPM strategies experiments

MASTER will conduct collaborative field experiments to compare two pest management systems for winter oilseed rape within a cereal rotation and on a farm-scale, in five European countries (Estonia, Germany, Poland, Sweden, UK): a Standard European Farming System (**STN**) and an Integrated Crop Management System (**ICM**). Crop management and data collection will follow agreed protocols. Evaluation of crop performance will be by means of agreed indicators. Results will be assessed collaboratively and be made widely available to end-users.

The **STN** System will use current conventional practice for the European oilseed rape crop as defined by the EU Concerted Action, COST-project AIR 3 CT 94-2231: Research for the Adaptation of Oilseed Crops Management to the new requirements of the Common Agricultural Policy. This network collated information on oilseed rape husbandry practices used in all 15 EU Member States (Arthur *et al.*, 1999; Christen *et al.*, 1999). Tillage will be by ploughing, followed by harrowing. Nitrogen application (150-230 kg/ha according to soil analysis), will be principally applied in spring with sufficient in the autumn to compensate for winter uptake. Seed will be drilled at a standard seed rate with a 0.12m row width from mid-August to mid-September depending on locality and conditions to give a final plant population of 50-60 plants/m^2. A standard hybrid cultivar will be used in all experiments. Crop protection will follow current commercial practice and will rely heavily on pesticides. These will include application of pre-emergence herbicide to control broad-leaved weeds and if necessary a post-emergence graminicide to control grass weeds and volunteer cereals. Fungicides will be applied in autumn to control light leaf spot (*Perenopeziza brassicae*), in early spring to control light leaf spot and stem canker (*Leptosphaeria maculans*) and during flowering to control stem rot (*Sclerotinia sclerotiorum*).

The **ICM** System will modify conventional practice to enhance bio-control of Rape Pests. The definition of ICM used in this project description is that of the Integrated Crop Production Alliance (IACPA), i.e. *'A whole farm policy aiming to provide the basis for efficient and profitable production which is economically viable and environmentally responsible. It integrates beneficial natural processes into modern farming practices using advanced technology and aims to minimise environmental risks while conserving, enhancing and recreating that which is of environmental importance'*. Husbandry protocols will be defined using existing knowledge of partners, information from published literature, and suggestions from the EU Concerted Action: FAIR-PL96-1314 'Minimising pesticide use and environmental impact by the development and promotion of bio-control strategies for oilseed rape pests, acronym: BORIS' (Alford *et al.*, 2000). This latter programme identified conventional practices (crop rotation, tillage, sow dates and rates, row spacing, cultivar choice, nutrient use, timing of pesticide inputs, choice of insecticide and pest thresholds) with potential for modification for an ICM System to enhance the integration of beneficial natural processes. Farming system and crop performance will be analysed using methods developed in the EU project AIR 3 CT920755 'Research network on integrated and ecological arable farming systems'.

The Phenological Model for natural enemies

MASTER will produce a trans-European Phenological Model for rape pests and their natural enemies. For most partner countries, the phenology for the six target pests is known, but there is little information on phenology of their key natural enemies. MASTER will focus on obtaining new and more comprehensive trans-European information on the phenology of occurrence, flight and activity of both pests and their natural enemies in relation to vulnerable crop growth stages and to climatic/weather conditions. This information will help define spray windows compatible with natural enemy conservation.

Computer-based decision support

MASTER has a sub-contract with Pro_Plant GmbH to incorporate the Phenological Model for natural enemies into their PC-based computerised decision support system (DSS) Pro_Plant. The PRO_PLANT DSS was first developed for managing cereal diseases and later extended to cover growth regulators in cereals, diseases in sugar beet, weeds in maize, potato late blight and pests in oilseed rape (Johnen & Meier, 2000). The PRO_PLANT DSS for Rape Pests already has pest Phenological Models for the six key pests targetted by this project, based on eight years of field observations on the influence of the weather on their population dynamics in different regions of Germany. The program takes into account numbers of adult pests, weather-based forecasts of flight conditions, egg-laying periods and larval development. The models automatically collect regional meteorological data via internet or home-run meteorological stations to predict pest infestation and the need for control. This phenology-based strategy improves the basis for treatment decisions and optimises dates for field inspection and insecticide application. Experience in Germany shows that PRO_PLANT's new strategy has recommended fewer treatments than the standard threshold-based control strategy; only 1-2 applications of insecticide per season instead of the usual 2-3. These pest models will be used as the basis for the integration of the natural enemy models to be developed.

Farmer survey

MASTER will conduct a Europe-wide survey of oilseed rape farmers to find out about their attitudes to different pest management systems, how and why they adopt IPM systems and how they evaluate cost/benefits. Analyses of grower views will aid the drafting of the Technical Guidelines and development and promotion of environmentally-friendly sustainable IPM Systems. Conceptual and simulation models will be constructed to examine how best to optimise the socio-economic efficacy of the envisaged IPM strategies for oilseed rape providing predictive tools to help in evaluation of different options.

Technical guidelines

MASTER will produce Technical Guidelines on the IPM Strategies developed and these will be widely disseminated. They will be presented in the form of practical, on-farm, management measures that will enhance the positive effects of the key bio-control agents and minimise pesticide use while maximising cost effectiveness of crop production. The intention is that they will identify the most rapid and effective way of promoting alternatives to the prophylactic use of pesticides.

Dedicated Workshop

MASTER will disseminate the results of the project through a European workshop. Organisation of the workshop is subcontracted to BCPC (British Crop Protection Council). It will include papers from partners, invited papers, offered papers, a forum for discussion of results with end-users and discussion of future research needs.

Website

Further information about the project can be found on the website www.iacr.bbsrc.ac.uk/pie/master/master.htm

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The effect of clothianidin on aphids and virus yellows in sugar beet

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ABSTRACT

In three field trials conducted in 1998, 2000 and 2001, in which six plants per plot were inoculated with virus-infective *Myzus persicae*, clothianidin, applied to pelleted sugar beet seed at 30, 45, 60 and 90 g a.i./unit gave excellent control of green aphids for up to 10 weeks after sowing, comparable to the standard imidacloprid seed treatment at 90 g a.i./unit. The incidence of beet mild yellowing virus in the first two years and beet yellows virus in the third was also significantly reduced. At rates above 45 g a.i./unit virus yellows incidence was consistently but not significantly less in plots treated with clothianidin than in plots treated with imidacloprid. Sugar yields were significantly higher in all treated plots compared to untreated plots, but there were no significant differences between insecticide treatments. Clothianidin would be a suitable alternative to imidacloprid for aphid and virus yellows control in sugar beet.

INTRODUCTION

Pest control in sugar beet is now dominated by the pelleted seed treatment, imidacloprid (Gaucho, Bayer), which has been applied to over 70% of crops in the UK since 1999. Imidacloprid gives good control of many of the pests attacking sugar beet, especially soil pests such as springtails, symphylids, and pygmy beetles, and foliar pests such as aphids and leaf miners (Schmeer *et al.*, 1990; Wauters & Dewar, 1996; Dewar *et al.*, 1996, 2001).

In this paper we report the results from three field trials conducted in 1998, 2000 and 2001 to assess the efficacy of another neonicotinoid, clothianidin (TI 435, Bayer) compared to the standard imidacloprid, against aphids and two of the yellowing viruses they transmit in inoculated field trials.

MATERIALS AND METHODS

In each of the three years, sugar beet seed cv. Impulse in 1998, Helix in 2000 and 2001 was sown 18.2 cm apart within rows that were 50 cm apart. Plots were 12 rows by 12 m and treatments were replicated four times in randomised blocks. In mid-June each year six plants per plot, located in the centre and 3 m from each end of rows five and eight, were inoculated with aphids carrying either beet mild yellowing virus (BMYV) in 1998 and 2000, or beet yellows virus (BYV) in 2001. This represented approximately 2% primary infection, similar to that which would occur in a moderate risk year. The aphids came from glasshouse cultures maintained on either Shepherd's purse (*Capsella bursa-pastoris*), which is a host for BMYV, or *Tetragonia expansa*, which is a host for BYV.

Treatments

Insecticide treatments were applied as a film-coat to the outer surface of the pellets at rates (expressed as g a.i. per unit of 100,000 seeds) listed in Table 1. An untreated control was compared to treatments containing the insecticides, imidacloprid at 30 (1998 only), 60 or 90 g a.i./unit, clothianidin at 30 (1998 only), 45 (2000 and 2001 only), 60 or 90 g a.i./unit. In 1998 the clothianidin formulation contained 350 g a.i./l, but in 2000 and 2001 the formulation was 600 g a.i./l. Other treatments were included in the trial but are not reported here.

Observations

The number of plants in each plot was counted on two occasions to determine if there was any effect of treatment on rate of emergence and final establishment. Natural colonisation by aphids was assessed on two to four occasions on between four and ten plants per plot depending on plant size, taking care to avoid the marked plants that had been inoculated. Aphids were classed as green or black, winged or wingless. The green aphids were either *M. persicae* or *Macrosiphum euphorbiae*, and the black aphids were mostly *Aphis fabae*. Virus yellows incidence was assessed visually in late August/September in the same area that was used to assess establishment and in which the inoculated plants were located, i.e. the central six rows x 10 m (30 m^2). Sugar beet was harvested by machine, an Edenhall 422 two-row harvester, usually in November, from the four central rows by 9.7 m per plot (19.8 m^2). Root weight, sugar concentration, and levels of impurities were determined in the tarehouse at Broom's Barn. Data were analysed by analysis of variance using GENSTAT V. Aphid data were transformed logarithmically ($\log_{10}(n + 1)$) before analysis.

RESULTS

Effects of treatments on emergence and establishment

There were no significant effects of treatments on rate of emergence or final plant population (Table 1). Nor were there any significant effects on plant vigour.

Efficacy of treatments against aphids

Seed treatments generally have little effect on colonisation of plants by winged aphids. Treatment effects were mainly manifest in the subsequent development of wingless aphid colonies on plants. Therefore only data on wingless aphids is presented, and only when numbers were high enough to show possible significant differences between treatments.

In 1998 numbers of green wingless aphids on 9 June reached nine per plant on untreated plants. All insecticide treatments significantly reduced their number but there were no differences between treatments (Table 2). Three weeks later black aphids predominated, but their numbers were relatively low due to the activities of predators, and there were no differences between treatments. In 2000, all rates of both imidacloprid and clothianidin significantly reduced numbers of green aphids on 13 June, but their efficacy had worn off by 28 June, 11 weeks after sowing, when a large number of black aphids had colonised the plants (Table 2). In 2001, the trial was sown very late due to wet weather throughout April. The number of green aphids was again significantly reduced in all treatments on 25 June, 8 weeks after sowing. However, on 11 July, 10 weeks after sowing, there were significantly more black aphids on all insecticide treatments compared to the untreated plots (Table 2).

Table 1. Effect of insecticide seed treatments on the establishment of sugar beet (% of seeds sown) at Broom's Barn

Treatment	Rate g a.i./unit	Year		
		2 June 1998	24 May 2000	8 June 2001
		63 DAS	44 DAS	38 DAS
Untreated		72.3	64.3	77.0
Imidacloprid	30	76.2	-	-
Imidacloprid	60	73.4	68.9	78.7
Imidacloprid	90	73.1	71.5	78.6
Clothianidin	30	72.8	-	-
Clothianidin	45	-	66.4	76.5
Clothianidin	60	72.5	67.0	76.1
Clothianidin	90	74.8	73.8	75.0
SED (27 df, 21 df)		2.09	3.17	1.85
LSD (5%)		4.30	6.59	3.84

DAS = days after sowing

Control of virus yellows

In all three years the incidence of virus yellows in untreated plots was at least fifteen times greater than the original primary infection. All insecticide treatments significantly reduced infection at the end of August/early September (Table 3), but lowest infections were consistently recorded in plots treated with clothianidin at 45 g a.i./unit or above.

Sugar yield

The consequences of good virus control were manifest in improved sugar yields in all three years. In 1998, all treatments except the lowest rate of imidacloprid (30 g) significantly increased yields by 10-18 % (Table 4). In 2000, only clothianidin at 45 and 90 g a.i./unit increased yields (by circa 12%). In 2001, all insecticide treatments improved yield by a substantial and significant 40-57%, but there was no significant difference between them

Table 2. Effect of insecticide seed treatments on the number of aphids per plant ($\log_{10}(n+1)$) on sugar beet at Broom's Barn

Treatment	Rate g a.i./unit	1998		2000		2001	
		9 June 70 DAS	26 June 87 DAS	13June 64 DAS	28 June 79 DAS	25 June 55 DAS	11 July 71 DAS
		Green wingless	Black wingless	Green wingless	Black wingless	Green wingless	Black wingless
Untreated		1.000 (9.0)	0.160 (0.4)	0.612 (3.1)	1.976 (93.6)	0.893 (6.8)	0.338 (1.2)
Imidacloprid	30	0.094 (0.2)*	0.523 (2.3)	-	-	-	-
Imidacloprid	60	0.094 (0.2)*	0.044 (0.1)	0.075 (0.2)*	1.924 (82.9)	0.075 (0.2)*	0.966 (8.3)+
Imidacloprid	90	0.031 (0.1)*	0.201 (0.6)	0.033 (0.1)*	1.924 (82.9)	0.112 (0.3)*	1.244 (16.6)+
Clothianidin	30	0.217 (0.6)*	0.446 (1.8)	-	-	-	-
Clothianidin	45	-	-	0.220 (0.7)*	1.873 (73.6)	0.075 (0.2)*	1.124 (12.3)+
Clothianidin	60	0.000 (0)*	0.000 (0)	0.061 (0.2)*	1.889 (76.4)	0.048 (0.1)*	1.102 (11.6)+
Clothianidin	90	0.000 (0)*	0.088 (0.2)	0.219 (0.7)*	1.956 (89.4)	0.000 (0)*	0.959 (8.1)+
SED (27 df or 21 df)		0.0736	0.2735	0.1431	0.1443	0.1003	0.2334
LSD (5%)		0.1509	0.5607	0.2976	0.3001	0.2085	0.4854

Figures in parentheses are back-transformed values minus 1. * significantly less or + significantly more than untreated at $P < 0.05$;
DAS = days after sowing

Table 3. Effect of insecticide seed treatments on virus yellows incidence (% plants infected) in sugar beet at Broom's Barn

Treatment	Rate g a.i./unit	Year 1998 (BMYV)	2000 (BMYV)	2001 (BYV)
		1 September	24 August	22 August
Untreated		33.16	36.4	50.9
Imidacloprid	30	19.94*	-	-
Imidacloprid	60	16.22*	23.0*	32.5*
Imidacloprid	90	14.24*	20.6*	30.3*
Clothianidin	30	22.18*	-	-
Clothianidin	45	-	15.8*	20.9*
Clothianidin	60	10.00*	17.2*	19.5*
Clothianidin	90	10.52*	16.0*	17.1*
SED (27 df, 21 df)		3.000	2.59	5.79
LSD (5%)		6.155	5.39	12.04

* significantly less than untreated at $P < 0.05$

Table 4. Effect of insecticide seed treatments on sugar yield (t/ha) of sugar beet at Broom's Barn

Treatment	Rate g a.i./unit	1998 Yield t/ha	1998 % of control	2000 Yield t/ha	2000 % of control	2001 Yield t/ha	2001 % of control
Untreated		9.44	100	9.92	100	6.23	100
Imidacloprid	30	9.78	104	-	-	-	
Imidacloprid	60	10.71*	114*	10.97	111	8.73*	140*
Imidacloprid	90	11.07*	117*	11.01	111	8.89*	143*
Clothianidin	30	10.38*	110*	-	-	-	-
Clothianidin	45	-	-	12.33*	124*	9.38*	151*
Clothianidin	60	11.17*	118*	10.97	111	9.78*	157*
Clothianidin	90	10.78*	114*	12.27*	124*	9.43*	151*
SED (27 df, 21 df)		0.435	4.6	0.532	5.4	0.612	9.8
LSD (5%)		0.892	9.4	1.107	11.2	1.272	20.4

* significantly more than untreated at $P < 0.05$

DISCUSSION

Clothianidin at all rates tested, had no effect on rate of emergence, or plant growth compared to untreated plants. It has been reported that imidacloprid occasionally slows emergence of seedlings especially in cold wet conditions (Dewar *et al.*, 1997), but that effect was not apparent in these trials, probably because the trials were sown into favourable seed beds in warm weather. Control of green aphids by clothianidin was excellent at all rates tested for up to 10 weeks after sowing, comparable to that of the commercial rate of imidacloprid (90 g a.i./unit). However, control of black aphids after that was poor for both clothianidin and imidacloprid, because the insecticides had probably degraded to non-toxic metabolites by then. In 2001, there were more black aphids in the treated plots. This may have been due to the non-uniform distribution of predators, such as ladybirds, in the trial, which were probably attracted to the untreated plots earlier in the season by the presence of higher numbers of green aphids, and laid their eggs there. Then later, when black aphids migrated in, they were eaten quickly by resident predators in those untreated plots, but had free reign to increase in the treated plots, which would have been devoid of predators. Clothianidin gave consistently greater reductions of virus yellows than imidacloprid, but these were never significantly different from one another except at the lowest rate of the latter (30g). Yield responses were consistent with their effect on virus incidence. The proposed commercial rate of clothianidin (60g a.i./unit) performed at least as well and occasionally better than the standard imidacloprid at 90 g a.i./unit.

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