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A VARIETY APPROACH TO IMPROVING GRAIN YIELD AND QUALITY IN SPRING BARLEY

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by

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Abstract

Our results show where opportunities may exist to benefit from variation between spring barley varieties in their yield and grain nitrogen percentage. This should provide opportunities to increase yields and malting premiums, as well as adjusting N fertiliser according to variety. Yield, grain nitrogen precentage nitrogen and nitrogen offtake were measured in eleven varieties at ten sites across Scotland, from harvest 1997. A linear regression was done for variety yield against the mean yield of all varieties (or site yield). The latter, was an indicator of site potential. Regessions were also done for grain nitrogen and nitrogen offtake. The extent to which each variety responded to changes in site potential was determined by its sensitivity score i.e. the slope of the linear regression.

Varieties were grouped according to their yield (and grain nitrogen) at sites of high and low yield (and grain nitrogen) potential: Catagory I indicated those varieties most suited to the site conditions, Catagory III were those varieties that performed least well and Catagory II were intermediate and represented average performance. Delibes and Livet yielded relatively well compared to other varieties at the higher yielding sites, whereas Optic yielded relativley well at the lower yielding sites. Chariot and Derkado had relatively high nitrogen offtakes compared to their yields: this suggests that they are more efficient scavengers for soil and/or fertiliser N than other varieties.

Information from this study could be used in Decision Support Systems and as an addition to Cereals Recommended Lists. We suggest that the variety approach can still be adopted even when choice is restricted in that variety ranking and profiles can be adjusted according to site fertility or potential for grain nitrogen. Choosing a variety that suits site potential, avoiding efficient nitrogen scavengers on sites likely to produce high grain nitrogen and using the relative scavenging ability of varieties to adjust nitrogen rates are three ways in which a varietal approach may be used to improve spring barley management. Our results suggest that there are significant differences between varieties in nitrogen offake and utilisation: the physiological basis for nitrogen scavenging ability and variety differences in N use and partitioning would be worthwhile research areas.

Introduction

A previous analysis of data from SAC spring barley trials showed that relative yield and nitrogen (N) offtake of different varieties was influenced by site yield potential (Cranstoun and Hoad, 1997). As well as consequences for economic return on yield, if varieties vary in their ability to take up nitrogen, this has a bearing on variety choice at sites that are marginal for malting and distilling, and for adjusting the optimum amount of fertiliser nitrogen. For a top graded malting variety a characteristically low grain N percentage (%) is likely to attract a better premium than a high grain nitrogen variety. The former is more likely to meet the maltsters' specification on those sites producing grain nitrogen concentrations close to the threshold of acceptance.

Grain N % is determined by the amount of nitrogen taken up by the crop and its subsequent dilution as yield is created. Nitrogen offtake, defined as the amount of N in the grain at harvest, can be related to the ability of a variety to take up soil and fertiliser nitrogen. It is apparent that varieties are inherently high, low or intermediate in terms of their yield, grain nitrogen and N offtake. This is consistent with the view that varieties differ in the way they scavenge for N and in the ways they utilise N.

Our previous study indicated a comparative yield advantage of Delibes, and a comparative disadvantage of Derkado, at both high and low yielding sites. By contrast, Chariot and Cooper yielded relatively better in low yielding situations whereas Juno and Brewster yielded relatively better on high potential sites. The nitrogen data base used in this work was small and some of the varieties are redundant. The aim of this study was examine more relevant varieties and test the idea that grain yield and quality can be improved by a better understanding of how varieties respond to changes in a site's potential for yield (or fertility) grain N % and N offtake.

Our objectives were:

1) to examine how site conditions influence yield, grain quality and nitrogen offtake.

2) to identifying differences in N use e.g. scavenging ability between varieties.

3) to evaluate of the likely economic benefits of a adopting a variety approach for improving yield and/or grain quality.

4) to indicate of how a knowledge of 1), 2) and 3) could be added to the variety data base.

Materials and Methods

Varieties and sites

Grain yield, grain N % and N offtake were measured in 11 malting spring barley varieties at 10 trial sites across Scotland, from the 1997 harvest. General descriptions of varieties are given in Table 1 (SAC, 1997). The sites were representative of the geographical distribution of spring barley; details are provided in Table 2.

Table 1. Yield and quality characteristics of malting varieties.

Variety	Description
Chalice	High yielding, recommended for NE region, provisional IOB approval
Chariot	Moderate yields, recommended for general use, graded good for malting and approved by IOB
Delibes	High yielding, recommended for NE and NW regions, graded medium for malting and approved by IOB for special use in grain whiskey production
Derkado	Low yielding, specially recommended for NE region, graded good for malting and approved by IOB
Extract	Moderate yields, a malting variety, considered for 1998 recommended list but not added
Ferment	High yield potential, some malting potential, considered for 1998 recommended list but not added
Landlord	Moderate yields, provisionally recommeneded for NE region, graded good for malting and approved by IOB
Livet	Moderate yield, some malting potential, considered for 1998 recommended list but not added
Optic	Very high yielding, recommended for general use, graded good for malting and approved by IOB
Prisma	Moderate yields, recommended for NE region, graded good for malting and approved by IOB
Tankard	Moderate yields, previously recommended for NE region now becoming outclassed, no longer approved by IOB

Table 2. Details of trial sites

Site	Region	Grid Ref.	Soil texture	Previous crops (1996, 1995, 1994)	N fertiliser (kg/ha)
Kilrie, near Raith, Kirkaldy	SE	NT 257 910	Clay loam	WOR, SB,WW	130
Samuelston, near Pentcaitland, East Lothian	SE	NT 484 698	Clay loam	GPS, WW, WW	120
Spotsmains, near Keslo, the Borders	SE	NT 660 362	Sandy loam	WOR, WB, SB	120
Wolfstar, Ormiston, East Lothian	SE	NT 417 687	*	*	*
Downieken, Newbiggin, near Carnoustie	SE	NO 507 358	*	*	*
Udny, near Aberdeen	NE	NJ 231 907	Silty clay loam	SB, WW, POT	105
Laurencekirk, near Aberdeen	NE	NO 668 696	*	WOR, WOR, WB	118
Inverness	NE	NH 521 883	Sandy loam	WW, GPS, WB	114
Dumfries	SW	NX 990 738	Sandy loam	WW, SB, FMZ	100
Auchincruive, near Ayr	SW	NS 225 380	Sandy loam	WB, G, G	100

WW, winter wheat; WB, winter barley; SB, spring barley; WOR, winter oilseed rape; POT, potatoes; G, grass; FMZ, feed maize; GPS, grain peas

Calculations

Yields were expressed as t/ha at 15% moisture content. Grain N was measured as total N by Kjeldahl digestion and expressed as % of grain dry weight. Nitrogen offtake was defined as the amount of N in the grain at harvest and expressed as kg/ha at 0 % moisture content.

For each variety, variability in yield, grain N and N offtake was expressed as a range between minimum to maxium value, a coefficient of variation (CV; standard deviation as % of the mean) and as a confidence interval (CI) about the mean. Variability within a site was indicated as a CV.

Relationships between yield, grain N and N offtake across varieties were determined by linear regressions using variety means. Standardized residuals (differences between variety means and fitted values divided by the regression standard deviation) were used to identify large deviations from the fitted model. Regressions were also made using all variety *x* site combinations.

The yield response of each variety to changes in site conditions was determined by linear regression of variety yield at all sites against yield of all varieties at the same sites. Thus, each site mean yield was an indicator of site yield potential or fertility. The slopes of linear regressions provided a measure of sensitivity to changing site conditions (see below). The changes in grain N % according to site mean grain N and site mean yield, and N offtake according to site mean N offtake were also established.

Sensitivity score

Sensitivity is term used to describe the way a variety responds to increasing site yield (NIAB, 1997). It was derived from the slope of the linear regression between variety yield and mean site, as described above. A sensitivity greater than 1 indicates that a variety is better able to exploit an increase in site yield potential. A sensitivity of less than 1 indicates that a variety is less responsive to an increase in site yield potential. In addition to yield, sensitivity scores were also calculated for grain N as influenced by site yield and grain N, and for N offtake as influenced by site yield.

Economic analysis

Crop output (£/ha) was based on yield and N % from the linear regressions, as described above, using fitted values at x = 5.5 t/ha to represent a low yielding site and at x = 7.5 t/ha to represent a highg yielding site. A low grain N site was defined as x = 1.5 N % and a high grain N site was x = 1.7 N %. Grain was given a feed value of £70/t. A grain quality premium was calculated as £25 above feed value at 1.6%N, with increments of £0.50 for each 0.01% below 1.6%, and dedections of £0.50 for each 0.01% above 1.6%. The threshold for a premium was 1.79% (i.e. a premium of £15.50). Grain above 1.79% received no premium.

Results

The mean yield for all varietites was 6.8 t/ha (Table 1). The lowest yielding varieties were Derkado (6.4 t/ha) and Chariot (6.6 t/ha) and the highest yielding were Delibes (7.1 t/ha) and Chalice (7.0 t/ha). The least variable yields were in Optic, Derkado and Chariot; their CV's were less than 11% and their CI's were less than 0.5 t/ha. The yield range across sites was least in Derkado at 1.6 t/ha. The most variable yields were for Extract, Livet, Delibes and Ferment with CI's above 0.6 t/ha. Extract had theh highest CV at 13.9% and the yield range for Delibes and Livet was more than 2.7 t/ha.

Mean grain N % for all varieties was 1.69% (Table 2). Extract and Livet had the lowest grain N % (less than 1.65%) whilst, Chariot (1.79%) and Derkado (1.75%) had the highest N %. Delibes and Optic were the least variable in grain N %; their CV's were less than 10% and both had CI's of 0.11 N%. Optic had the smallest range of grain N across sites at 0.43 %. Livet, Extract and Derkado had the most variable grain N; with CV's above 13% and ranges of more than 0.7 N%. CI's were highest in Livet (0.19 N%) and Derkado (0.18 N%).

Mean N offtake for all varieties was 98 kg N/ha (Table 3). On average, 1 kg of N offtake was equivalent to 69 kg yield (at 15% mc). Extract, Derkado, Ferment and Prisma had the lowest N offtakes (93-95 kg/ha). Delibes and Chalice had the highest offtakes (104 and 102 kg N/ha, respectivley). Optic and Chariot were the least variable in N offtake with ranges of less than 36 kg N/ha and CI's below 10 kg N/ha . Nitrogen offtake was most variable in Extract; its range was 63 kg N/ha and CI was 14.4 kg N/ha.

There were weak linear relationships between variety yield and N offtake (Fig. 1A) and variety mean grain N and N offtake (Fig. 1B). Yield across varieties increased by 35 kg per kg N offtake and grain N across varieties increased by 0.09% per 10 kg N offtake. Chariot and Derkado had low yields, but high grain N in relation to their N offtakes (Fig. 1A and B) thus, their standardized residuals for yield and grain N were large compared to other varieties (Table 4).

Table 1. Yields of spring barley varieties at different sites

	Chalice	Chariot	Delibes	Derkado	Extract	Ferment	Landlord	Livet	Optic	Prisma	Tankard	Mean	CV
Kilrie	7.2	6.6	7.3	6.4	7.1	7.0	6.8	6.9	7.1	7.1	6.9	6.9	3.8
Samuelston	7.8	7.8	8.3	7.1	7.9	7.7	7.7	8.3	7.9	7.9	8.5	7.9	4.8
Spotsmains	7.0	6.3	7.0	6.6	7.1	6.4	6.5	6.6	6.9	6.3	6.8	6.7	4.5
Wolfstar	7.6	7.0	7.3	6.7	7.0	7.1	7.1	7.0	7.1	6.9	7.1	7.1	3.2
Downieken	7.9	7.1	7.8	7.0	7.3	8.0	7.4	7.8	7.1	6.8	7.5	7.4	5.5
Udny	6.2	5.5	5.6	5.7	5.8	5.5	5.2	5.5	5.8	5.7	5.9	5.7	4.4
Laurencekirk	7.5	6.6	7.6	7.0	8.1	7.0	7.3	7.4	7.2	7.1	7.9	7.3	5.8
Inverness	5.5	5.9	na	5.8	5.7	5.6	5.9	na	7.2	6.0	6.3	6.0	8.7
Dumfries	6.9	6.1	6.2	5.5	6.1	6.0	6.1	6.2	6.7	6.0	6.1	6.2	6.0
Auchincruive	6.5	6.9	6.9	na	5.5	7.3	7.0	6.4	6.1	na	6.8	6.6	8.2
Mean	7.0	6.6	7.1	6.4	6.8	6.7	6.7	6.9	6.9	6.7	7.0	6.8	
Range	2.4	2.3	2.7	1.6	2.6	2.5	2.5	2.8	2.1	2.2	2.6		
CV	10.8	10.3	11.7	9.5	13.9	12.6	11.5	12.2	8.8	10.5	11.6		
Conf. Interval	0.53	0.48	0.63	0.46	0.66	0.61	0.54	0.64	0.43	0.52	0.57		

Table 2. Grain nitrogen % of spring barley grown at different sites

	Chalice	Chariot	Delibes	Derkado	Extract	Ferment	Landlord	Livet	Optic	Prisma	Tankard	Mean	CV
Kilrie	1.63	1.64	1.66	1.58	1.43	1.39	1.64	1.57	1.55	1.60	1.47	1.56	5.9
Samuelston	1.77	1.72	1.70	1.78	1.65	1.67	1.71	1.61	1.68	1.67	1.61	1.69	3.3
Spotsmains	1.94	1.93	1.86	2.01	1.83	1.83	1.89	1.95	1.89	1.79	1.83	1.89	3.5
Wolfstar	1.55	1.73	1.66	1.66	1.55	1.56	1.53	1.56	1.56	1.51	1.58	1.59	4.2
Downieken	1.55	1.89	1.71	1.42	1.23	1.77	1.81	1.14	1.80	1.53	1.68	1.59	15.4
Udny	1.99	2.08	1.79	1.90	1.78	1.66	1.92	1.57	1.72	1.76	1.94	1.83	8.3
Laurencekirk	2.05	2.04	1.97	2.15	1.97	1.96	2.05	2.02	1.89	2.00	1.97	2.01	3.4
Inverness	1.61	1.61	na	1.70	1.49	1.45	1.57	na	1.46	1.51	1.40	1.53	6.2
Dumfries	1.48	1.57	1.46	1.55	1.60	1.58	1.53	1.60	1.51	1.79	1.41	1.55	6.4
Auchincruive	1.55	1.68	1.71	na	1.57	1.79	1.56	1.66	1.62	na	1.65	1.64	4.8
Mean	1.71	1.79	1.72	1.75	1.61	1.67	1.72	1.63	1.67	1.68	1.65	1.69	
Range	0.57	0.51	0.51	0.73	0.74	0.57	0.52	0.88	0.43	0.49	0.57		
CV	12.3	10.2	8.3	13.4	13.2	10.6	10.8	15.5	9.3	9.8	12.4		
Conf. Interval	0.15	0.13	0.11	0.18	0.15	0.13	0.13	0.19	0.11	0.12	0.14		

Table 3. Nitrogen offtake of spring barley varieties at different sites

	Chalice	Chariot	Delibes	Derkado	Extract	Ferment	Landlord	Livet	Optic	Prisma	Tankard	**Mean**	**CV**
Kilrie	99	92	103	86	86	83	95	92	93	97	87	92	6.7
Samuelston	118	114	120	107	111	109	111	113	113	112	116	113	3.3
Spotsmains	116	103	110	112	110	100	104	109	110	95	106	107	5.7
Udny	105	97	85	92	87	77	85	74	84	85	96	88	10.3
Laurencekirk	131	115	128	127	135	116	127	127	116	121	132	125	5.6
Inverness	76	80	na	83	72	69	79	na	90	77	75	78	7.9
Wolfstar	100	103	103	94	93	94	92	93	94	88	95	95	4.8
Downieken	104	114	114	84	76	120	114	76	109	88	106	101	16.3
Dumfries	86	81	77	72	83	81	79	84	86	92	73	81	7.3
Auchincruive	86	98	100	na	73	110	93	90	84	na	96	92	11.7
Mean	102	100	104	95	93	96	98	95	98	95	98	98	
Range	55	35	51	55	63	51	48	53	32	44	59		
CV	16	13	15	18	22	19	16	19	13	14	18		
Conf. Interval	12	9	12	13	14	13	11	13	9	10	13		

Table 4. Variety standardized residuals for relationships between (A) yield and N offtake (Fig. 1A), (B) Grain N and N offtake (Fig. 1B) and (C) Yield and grain N (dashed line, Fig. 2A).

	Chalice	Chariot	Delibes	Derkado	Extract	Ferment	Landlord	Livet	Optic	Prisma	Tankard
A. Yield v offtake	0.36	-1.62	0.44	-1.69	0.76	0.10	-0.58	1.04	0.59	-0.28	0.88
B. Grain N v offtake	-0.35	1.70	-0.51	1.65	-0.83	-0.22	0.58	-0.86	-0.55	0.29	-0.90
C. Yield v grain N	1.22	-0.37	1.80	-1.48	-0.81	-0.42	-0.26	0.06	0.40	-0.73	0.59

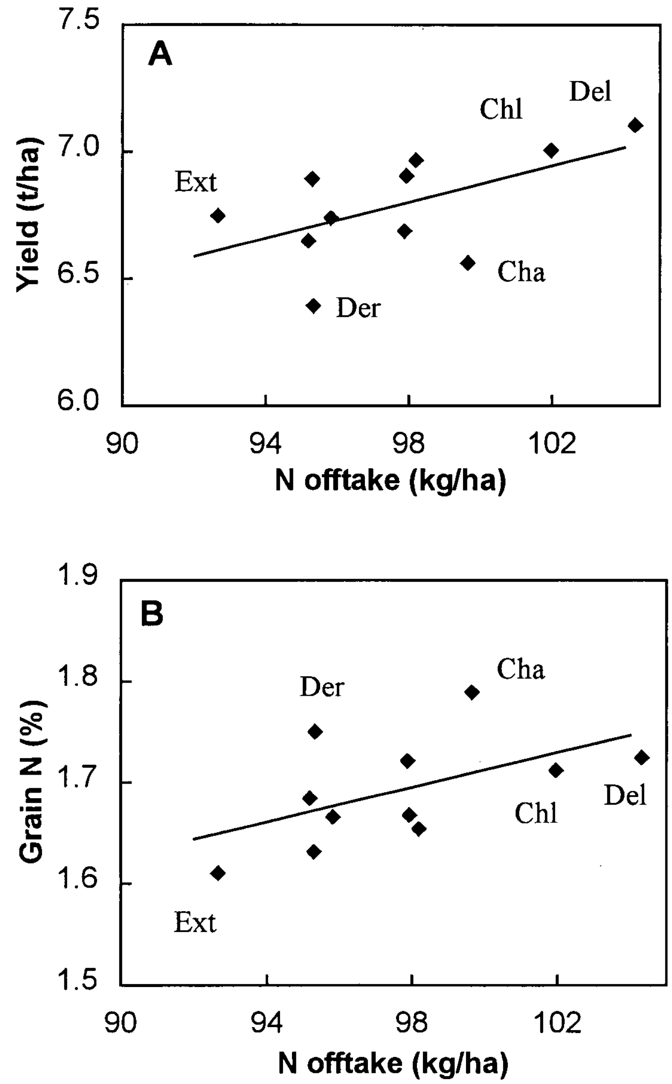

Figure 1. (A) Relationship between variety yield and N offtake; y = 3.33 + 0.035x, r^2 = 31.9%, P = 0.07, n=11. (B) Relationship between variety grain N and N offtake; y = 0.86 + 0.0085, r^2 = 28.9%, P = 0.09, n=11. Key to selected varieties: Cha, Chariot; Chl, Chalice; Del, Delibes; Der, Derkado; Ext, Extract.

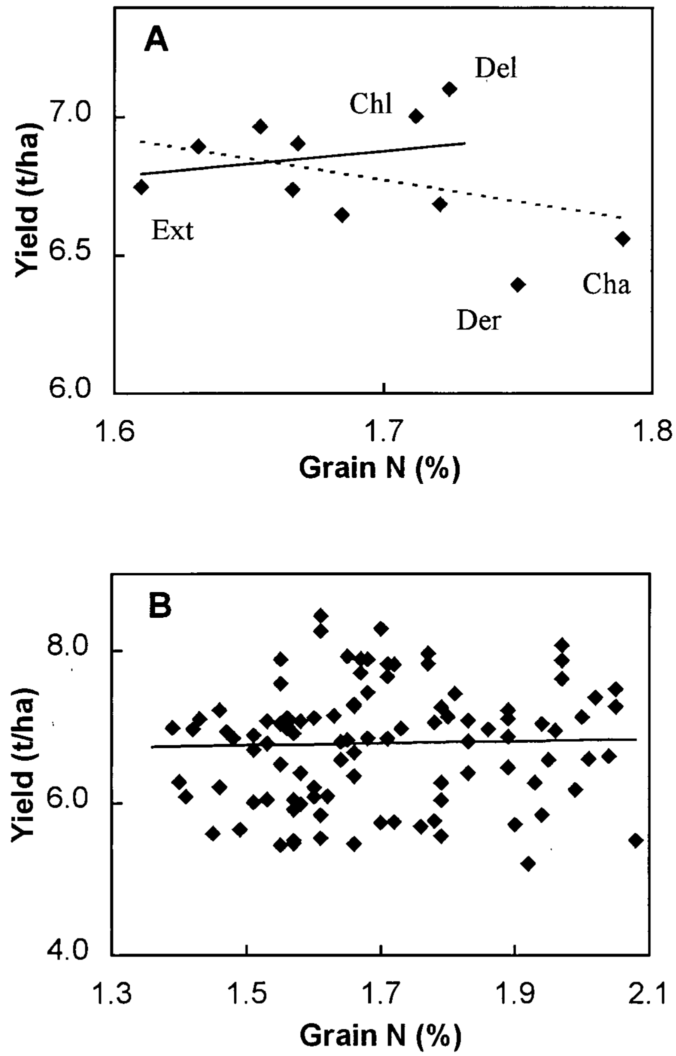

Figure 2. Relationhips between yield and grain N for (A) variety means and (B) all variety *x* site combinations. In (A) dashed line, y = 9.39 - 1.54x, r^2 = 15.1%, P = 0.24, n = 11 and solid line, y = 5.30 + 0.93x, r^2 = 6.0%, P = 0.54, n = 9. In (B) y = 6.57 + 0.13x, r^2 = 0%, P = 0.73, n = 106. Key to selected varieties: Cha, Chariot; Chl, Chalice; Del, Delibes; Der, Derkado; Ext, Extract.

There was no clear relationship between variety yield and grain N% (Fig. 2A). However, a linear regression across all varieties (Fig. 2A, dashed line) indicates large positive residuals for the high yielding Chalice and Delibes and a large negative residual for the high grain N Derkado. The exclusion of Chariot and Derkado from the regression analysis (Fig. 2A, solid line) highlights the low yield and high grain N charactersitic of these varieties. There was no relationship between yield and grain N across all variety *x* site combinations (Fig. 2B).

Annexe 1 indicates weak linear relationships between yield or grain N and N offtake across variety *x* site combinations (Fig. 3A and B).

Table 5 demonstrates how variety yield changes according to site yield potential (site fertility). At low yield potential (<6.0 t/ha) the yield difference between varieties was 0.8-1.1 t/ha; Extract and Livet were 0.3-0.4 t/ha below site yield whereas, Optic was 0.6-0.8 t/ha above site yield. At high yield potential (>7 t/ha) the yield difference between varieties was 1.0-1.2 t/ha; Dekardo was 0.6-0.7 t/ha below site yield whereas, Delibes was 0.4-0.5 t/ha above site yield. Chalice consistently yielded 0.2-0.3 t/ha above site potential. Livet, Delibes and Extract were the most sensitive to an increase in site fertility with a gain of about 1.2 t/ha for each t/ha increment in site yield. By contrast, Optic and Derkado where least sensitive site yield potential with a gain of less than 0.8 t/ha per t/ha increment in site yield.

Table 6 shows how variety grain N% changed with site fertility. Generally, grain N was not strongly influenced by site fertility; with increases or decreases of less than 0.04% per tonne increment in yield. However, grain N in Optic and Ferment increased by approximately 0.08% for each t/ha increment in yield.

Table 7 shows how variety grain N % changed according to a site's potential for grain N. At sites of low grain N (<1.6%), Extract, Livet and Tankard had the lowest N % (<1.45 %), whereas Chariot had the highest N %. At sites of high grain N (>1.8%), Optic, Extract, Livet, Prisma and Ferment had relatively low N %, whereas Derkado, Chalice and Chariot had above average N %. Derkado and Chalice were the most responsive to an increase in site grain N with sensitivity scores of about 1.2. Delibes and Optic were the least sensitive to site grain N with sensitivity scores of <0.85.

Table 5. Yield (t/ha) of spring barley varieties as influenced by site yield potential (t/ha). Data are fitted values from linear regressions of variety yield against the mean yield of all varieties at each site. The sensitivity score is the coefficient of the linear regression.

		Chalice	Chariot	Delibes	Derkado	Extract	Ferment	Landlord	Livet	Optic	Prisma	Tankard
	5.0	5.3	5.0	4.9	5.0	4.7	4.8	4.8	4.6	5.8	5.1	5.0
	5.5	5.8	5.4	5.5	5.4	5.3	5.3	5.3	5.2	6.1	5.5	5.6
Site yield	6.0	6.3	5.9	6.1	5.8	5.9	5.9	5.9	5.8	6.4	6.0	6.1
potential (t/ha) 6.5		6.7	6.3	6.7	6.2	6.4	6.4	6.4	6.5	6.7	6.4	6.7
	7.0	7.2	6.8	7.3	6.6	7.0	7.0	6.9	7.1	7.2	6.8	7.2
	7.5	7.7	7.2	7.9	6.9	7.6	7.5	7.5	7.7	7.7	7.3	7.8
	8.0	8.2	7.7	8.5	7.3	8.2	8.1	8.0	8.3	8.2	7.7	8.3
Sensitivity score (t/t)		0.96	0.90	1.21	0.77	1.16	1.10	1.06	1.23	0.64	0.89	1.11

Table 6. Grain nitrogen (%) of spring barley varieties as influenced by site yield potential (t/ha). Data are fitted values from linear regressions of variety grain N against the mean yield of all varieties at each site.

		Chalice	Chariot	Delibes	Derkado	Extract	Ferment	Landlord	Livet	Optic	Prisma	Tankard
	5.0	1.71	1.77	1.65	1.77	1.67	1.53	1.65	1.69	1.52	1.70	1.61
	5.5	1.71	1.78	1.67	1.76	1.65	1.57	1.67	1.67	1.56	1.69	1.62
	6.0	1.71	1.78	1.69	1.76	1.64	1.61	1.69	1.66	1.60	1.69	1.63
Site potential	6.5	1.71	1.79	1.71	1.75	1.62	1.64	1.71	1.65	1.65	1.69	1.65
(t/ha)	7.0	1.71	1.79	1.73	1.75	1.60	1.68	1.73	1.63	1.69	1.68	1.66
	7.5	1.71	1.80	1.75	1.74	1.58	1.72	1.75	1.61	1.73	1.68	1.67

8.0	1.71	1.80	1.77	1.74	1.57	1.76	1.77	1.60	1.77	1.68	1.68

Table 7. Grain nitrogen (%) of spring barley varieties as influenced by site potential for grain N (%). Data are fitted values from linear regressions of variety grain N against the mean grain N of all varieties at each site. The sensitivity score is the coefficient of the linear regression.

		Chalice	Chariot	Delibes	Derkado	Extract	Ferment	Landlord	Livet	Optic	Prisma	Tankard
	1.4	1.37	1.52	1.48	1.38	1.29	1.43	1.43	1.32	1.44	1.45	1.32
	1.5	1.49	1.61	1.56	1.51	1.40	1.51	1.51	1.42	1.52	1.53	1.44
	1.6	1.61	1.71	1.64	1.63	1.51	1.59	1.59	1.53	1.60	1.61	1.55
Site potential	1.7	1.73	1.80	1.72	1.76	1.62	1.68	1.68	1.64	1.68	1.69	1.67
(N%)	1.8	1.85	1.89	1.80	1.88	1.74	1.76	1.76	1.74	1.76	1.77	1.78
	1.9	1.97	1.99	1.88	2.01	1.85	1.84	1.84	1.85	1.84	1.85	1.90
	2.0	2.09	2.08	1.96	2.13	1.96	1.93	1.93	1.96	1.92	1.93	2.01
Sensitivity score (%/%)		1.20	0.94	0.78	1.25	1.12	0.84	1.02	1.14	0.80	0.79	1.15

Table 8. Nitrogen offtake (kg/ha) of spring barley varieties as influenced by site yield potential (t/ha. Data are fitted values from linear regressions of variety N offtake against the mean N offtake of all varieties at each site. The sensitivity score for N offtake is the coefficient of the linear regression.

		Chalice	Chariot	Delibes	Derkado	Extract	Ferment	Landlord	Livet	Optic	Prisma	Tankard
	5.0	77	74	67	75	67	61	65	68	73	73	67
	5.5	84	81	77	81	74	71	74	75	80	79	76
	6.0	91	89	87	86	82	81	84	83	87	85	85
Site potential (t/ha)	6.5	98	96	97	92	89	90	93	90	94	92	93
	7.0	105	103	107	97	96	100	102	97	101	98	102
	7.5	112	110	117	102	103	110	111	105	108	104	111

8.0	120	117	127	108	110	120	121	112	115	110	120
Sensitivity score (kg/t)	14	15	20	11	14	20	19	15	14	13	17

Table 8 shows how variety N offtake changed according to site fertility. At low yielding sites, Ferment had the lowest N offtake (61-71 kg/ha) and Chalice had the highest offtake (77-84 kg/ha). At high yielding sites, Dekardo, Extract and Prisma had the lowest offtakes (102-110 kg/ha) and Delibes had the highest offtake (117-127 kg/ha). The offtakes for Delibes, Ferment and Landlord were the most responsive to an increase in site fertility. By contrast, offtakes for Derkado and Prisma were the least responsive to changes in site fertility.

Economic analysis

Five examples below provide an indication of the economic benefits or disbenefits of choosing particular varieties at sites that were high or low in yield or grain N. Data for yield and grain N % were taken from site potentials of 5.5 t/ha (low) and 7.5 t/ha (high) in Tables 5 and 6, and from site potentials of 1.5 N % (low) and 1.7 N % (high) in Table 7. Crop values are based on the prices for yield value and N % premiums as indicated in the Materials and Methods. The examples refer to current RL included in this study, though other now redundent varieties may have had better yield or grain N.

Example 1. *If choice is between any variety to improve yield and income,*

then, at either a low or high yielding site:

a) a modest yield improvement of 0.4t/ha = benefit of £28.0/ha

b) a good yield improvement of 0.8t/ha = benefit of £56.00/ha

Example 2. *If choice is between varieties of similar average grain quality (N %) to improve yield and income e.g. Chalice, Optic and Prisma (mean grain N % of 1.67-1.71,*

then,	a) at low yielding sites:		and,	b) at high yielding sites:	
	Chalice at 5.8 t/ha	= £406/ha		Chalice at 7.7 t/ha	= £539/ha
	Optic at 6.1 t/ha	= £427/ha		Optic at 7.4 t/ha	= £518/ha
	Prisma at 5.5t/ha	= £385/ha		Prisma at 7.3 t/ha	= £511/ha

Therefore appropriate choice could provide benefits of up to £42/ha depending on site yield potential (note: Optic had a relativley low grain N %, especially at low yielding sites, and could provide an additional premium).

Example 3. *If choice is between any variety to improve grain N % and premium. Assuming that desired market is for low grain N% at <1.8%,*

then, a) at low yielding sites:

i) a modest improvement of 0.1 % less N = additional premium of £5/t

ii) a good improvement of 0.2 % less N = additional premium of £10/t

and, b) at high yielding sites:

i) a modest improvement of 0.07 % less N = additional premium of £3.50/t

ii) a good grain improvement of 0.15 % less N = additional premium of £7.50/t

Therefore appropriate variety choice could provide benefits between £7.50 to £10.00/t

Example 4. *If choice is between varieties of similar yield to improve grain N % and premium e.g. Chariot, Landlord and Prisma (mean yield 6.6-6.7 t/ha),*

then, a) at low yielding sites:

Chariot at 1.78 %N = premium of £16/t

Landlord at 1.67 %N = premium of £21.50/t

Prisma at 1.69 %N = premium of £20.50/t

and, b) at high yielding sites:

Chariot at 1.80 %N = no premium

Landlord at 1.75 %N = premium of £17.50/t

Prisma at 1.68 %N = premium of £21/t

and, c) at low grain N sites:

Chariot at 1.61 %N = premium of £24.50/t

Landlord at 1.53 %N = premium of £28.50/t

Prisma at 1.53 %N = premium of £28.50/t

and, d) at high grain N sites:

Chariot at 1.80 %N = no premium

Landlord at 1.73 %N = premium of £18.50/t

Prisma at 1.77 %N = premium of £16.50./t

Therefore appropriate choice could provide benefits of up to £5.50/t. In some cases the variety choice could determine whether a premium was gained or lost i.e. ± £15.50.

Example 5. *If choice is between any variety to maximise income based on yield and grain N % e.g. a comparison of Chariot, Landlord, Optic and Prisma,*

then, a) at low yielding sites:

Chariot at 5.4 t/ha and 1.78 %N	=	value of £464.40/ha
Landlord at 5.3 t/ha and 1.67 %N	=	value of £484.95/ha
Optic at 6.1 t/ha and 1.56 %N	=	value of £591.70/ha
Prisma at 5.5 t/ha and 1.69 %N	=	value of £497.75/ha

All varieties achieved a premium. However, the yield and grain N % of Optic provided a significant economic advantage of between £93-£127/ha over the other varieties.

and, b) at high yielding sites:

Chariot	at 7.2 t/ha and 1.80 %N	=	value of £504.00/ha
Landlord	at 7.5 t/ha and 1.75 %N	=	value of £638.80/ha
Optic	at 7.4 t/ha and 1.73 %N	=	value of £654.90/ha
Prisma	at 7.3 t/ha and 1.68 %N	=	value of £664.30/ha

Chariot narrowly failed to make a premium and had a significantly lower value than the other varieties. Optic lost its advantage at the high yielding site and Prisma benefitted from a relativley low N %.

Discussion

Our results show where opportunities may exist to benefit from variation between varieties in yield and grain N %. We suggest that variety choice can be used to improve crop value in spring barley by considering how varieties respond to changes in site potential for yield and grain N. Growers targeting a specific end use for their grain, for example a distilling or malting market with a specific grain N requirement, are likely to benefit by increased opportunities for gaining a premium. For example, in top graded malting varieties, a characteristically low grain % N is likely to attract a better premium than a high grain nitrogen variety and the former is more likely to meet the maltsters' specification on those sites that are close to the threshold of acceptance. An ecomonic analysis indicated how appropriate variety choice could improve yield and/or grain N with an increase in income of up to £10/t or £50/ha.

The performance of a variety can be considered as a function of its average value (across sites) and its sensitivity to changing site conditions. Thus, the estimates from regression analyses should be of more practical use than variety averages or sensitivity scores alone because their combined value allows each variety to be more closely matched to site conditions (Tables 5-8). For example, the less yield sensitive Chalice or Optic may be preferable to the more responsive, but lower yielding, Landlord or Ferment at the most fertile sites (Table 5). Opportunities for financial gains from the variety approach should be greatest at those sites that are consistently above or below average for yield or grain N, or where variation between varieties is large.

Variety choice depends on many factors, including grain market and agronomic characteristics. Growers are often limited in this choice. The requirements of maltsters and the likely size of the premium associated with a particular variety are often the dominant force. In some areas, avoiding a late maturing variety, or one that might suffer severe ear loss, can also be dominant forces. However, we suggest that the varietal approach can still be adopted even when choice is restricted in that variety ranking can be adjusted according to site fertility or potential for grain N. Table 9 summarises the variety profiles for yield and grain N. These descriptors would be approporiate for Cereals Recommended Lists.

Table 9. Variety profiles based on yield and grain N compared to other varietites across sites.

Variety	Profile
Chalice	*Yield:* above average across all sites *Grain N:* close to average at low grain N sites and above average at high N sites; high sensitivity
Chariot	*Yield:* close to average, although performs less well at better sites *Grain N:* consistently above average, especially at low N sites
Delibes	*Yield:* average at low yielding sites, above average at high yielding sites; very high sensitivity *Grain N:* average at low N sites, average at high N sites; low sensitivity
Derkado	*Yield:* average at low yielding sites, poor at high yielding sites; low sensitivity *Grain N:* average at low N sites, above average at high N sites; high sensitivity
Extract	*Yield:* low at poor sites, responds well to an increase in site yield potential *Grain N*: relatively low across all sites, and especially at low N sites
Ferment	*Yield:* close to average across all sites *Grain N:* slightly above average at low N sites, below average at high N sites; low sensitivity
Livet	*Yield:* low at poorest sites, responds well to an increase in site yield potential; very high sensitivity *Grain N:* low across all sites, but especially at low N sites
Prisma	*Yield:* close to site average, although performs less well at better sites *Grain N:* slighlty above average at low N sites, below average at high N sites; low sensitivity
Optic	*Yield:* very good at low yielding sites, average at high yielding sites; very low sensitivity *Grain N:* above average at low N sites, average at high N sites; low sensitivity
Tankard	*Yield:* close to site average, but tends to do better at high yielding sites *Grain N:* below average at low N sites, average at high N sites

A procedure for ranking varieties according to their relative performance at different sites is shown in Table 10A and B. Catagory I indicates those varieties that are most suited to site conditions; with good or above average performance. Catagory III indicates the lowest ranking varieties, i.e. below average performance. Catagory II are intermediate and represent average performance. Table 10A is used to make variety choice based on the yield potential of a site and Table 10B is used when choice is dictated by grain N potential of a site. For example, if sowing a combination of Chariot and Landlord, then the latter is best placed in the higher yielding fields with Chariot in the lower yielding fields. A combination of Optic and Chalice would benefit from placing Optic in less fertile fields and Chalice in the higher yielding fields. When growing a combination of Chariot and Prisma, it would be preferable to place Prisma, rather than Chariot, in those fields that were marginal for malting. Of the current RL varieties Chalice would appear to be a good choice at the better malting sites, whilst Optic or Prisma would be better at the marginal malting sites. A variety such as Extract could provide opportunities for very good grain N (i.e. low N %) across all sites, with added value of high yields at the most fertile sites.

Table 10A. Ranking varieties according to yield performance at sites of high and low yield potential.

	High yielding site (> 6.5 t/ha)	Low yielding site (< 6.0 t.ha)
Catagory I, above average or good yield	Delibes Tankard Livet Chalice Extract	Optic Chalice
Catagory II, average performance	Landlord Ferment	Prisma Tankard Chariot Delibes Derkado
Catagory III, below average or poor yield	Optic Prisma Chariot Derkado	Livet Extract Landlord Ferment

Table 10B. Ranking varieties according to grain N % at sites with potential for low or high grain N.

	A good malting site (grain N up to 1.6%)	Marginal for malting (grain N up to 1.8%)
Catagory I, grain N likely to be lower than average (best choice for low grain N market)	Livet Extract Tankard	Extract Livet Optic Ferment Prisma Tankard
Catagory II, average grain N	Chalice Optic Ferment Prisma Derkado Landlord	Delibes Landlord
Catagory III, grain N likely to be higher than average (most risky choice for low grain N market)	Delibes* Chariot	Derkado* Chariot Chalice

*These varieties would be favoured for high N grain distilling markets.

Table 10 could be incorporated in to Decision Support Systems (DSSs) along with site descriptors or records of field yield, grain N or N offtake. The rank order of varieties can be adjusted as new varieties are introduced. Three of the varieties reported here (Chariot, Delibes and Derkado) were included in the study by Cranstoun and Hoad (1997): Delibes has retained its comparative advantage and Derkado its comparative disadvantage at high yielding sites, and both are now intermediate for yield at the low yielding sites. Chariot yielded relatively well in low yielding situations, as reported before.

Intuitively, the relationships between yield or grain N % and offtake are postive, but some varieties have exceptionally high or low values for yield or grain N about the fitted relationships (Fig. 1). Although average yield was conservative at each level of grain N across variety *x* site combinations (Fig. 2B), groupings or clusters of varieties appear to be more appropriate than linear functions for describing relationships between yield and grain N across varieties (Fig. 2A). It is clear that that Chariot and Derkado utilise their N offtake differently to other varieties (Fig. 1, Table 4A and B). Chariot's low yield and high grain N in relation to N offtake is consistent with the view that this variety is a relatively efficient scavenger for soil and/or fertiliser N (Cranstoun and Hoad, 1997). Our results suggest that Derkado also has relatively high N scavenging ability. By contrast, Chalice and Delibes can be characterised by their relatively high N offtake. And Extract has relatively low N offtake.

Some varieties are more likely to exceed a malting threshold than others at margin malting sites and/or when given the same rate of nitrogen fertiliser. As well as matching more closely varieties to site potential for yield and grain quality there is scope for variable cost savings by adjusting N fertiliser according to scavenging ability. To counteract the scavenging efficiency of varieties such as Chariot it is likely that a small downward adjustment should be made to the optimum nitrogen rate (e.g. up to 20 kg N/ha). Current work at SAC on N use in spring barley should provide more precise recommendations for adjusting N rates in efficient N scavengers.

Our results indicate that the scientific background to N scavenging and the efficiency of N utilisation (e.g. nitrogen harvest index) would be worthwhile research areas. This should include wider testing for inherent differences in N offtake and partitioning of N between vegetative parts and the grain. The 'Community Structure in Barley' project at SAC (SOAEFD Project 629712) is investigating the physiological basis for differences in N use and yield sensitivity between varieties that have high N offtake and/or high N scavenging ability. This work would benefit from an investigation of functional relationships between root systems and above ground biomass; especially the extent of root systems in relation to N supply, as influenced by soil factors such as compaction and moisture supply.

In an analysis of winter wheat Foulkes *et al.* (1998) identified changes in N offtake of different varieties according to their date of introduction. Varieties introduced in the late 1980's appeared less efficient at aquiring soil nitrogen than those introduced in the early 1970's. However, the later introductions were better at recovering fertiliser N than older varieties and had higher levels of yield, optimum fertiliser and grain N offtake at optimum N. Foulkes *et al.* (1998) suggests that genetic improvement in yield of UK varieties has been associated with an increase in N offtake with the conservation of N %. In spring barley, Ellis and Marshall (1998) showed that average grain N in response to N supply (under a nutrient culture system) was influenced by varietal differences in size and N % of individual grains within ears and between stems. An examination of the environmental factors and management practices that influence N distribution between stems and within ears would be appropriate.

Defining a field in terms of yield or grain N potential is a key step in matching varieties to site conditions. In most cases, several years' data will be required to account for the effects of crop rotation, climatic conditions and management practices on the yield and grain N at each site. As well as soil and fertiliser N supply, seasonal factors such as radiation post-anthesis and length of grain filling period affect the relationship yield and grain N%. Consequently, a potentially high or low yielding site could have a high or low grain N depending on the dilution of N by grain filling. Mean N offtake at each site may be a useful guide to identifying those sites that are marginal for good yields or low/high grain N. For example, unless climatic conditions result in excessive dilution of grain N, a field with a high mean N offtake (e.g. >105 kg/ha) will result in medium to high yield and grain N. By contrast, unless N dilution is excessive or very poor then low mean N offtake will result in both low yield and low grain N. Those sites that are intermediate in N offtake (e.g. > 85 kg/ha, < 105 kg/ha) will need to be more clearly defined in terms of other limiting factors that affect yield and malting premiums. These sites are represent the widest spread of yield and grain N, but they are also the sites most likely to provide opportunities for good yields of low grain N % malting barley.

To date the nitrogen data base is small and some of the varieties are redundant. Updating the data base for more relevant varieties should provide recommendations for choosing sites and adjusting N according to variety characteristics. The procedures described in this study should be applicable to other cereals, especially winter wheat and winter barley. Benefits of the variety approach could be assessed by further examination of winter wheat *x* site fertility data in Cereals Recommended List (e.g. NIAB, 1999).

Concluding remarks

1. Regression analysis and a combination of variety averages and sensitivity scores provide a means to match more closely variety characteristics to site conditions.

2. Varieties can be ranked according to their yield or grain N % at different sites.

3. A variety approach should provide opportunities to increase yields and reduce the risk of losing grain quality premiums, as well as adjusting N fertiliser according to variety.

4. To counteract the scavenging efficiency of varieties such as Chariot and Derkado it is likely that a small downward adjustment should be made to its optimum nitrogen rate.

5. Implementation of data from this type of study is likely to be rapid: and results will be of use in Decision Support Systems and variety profiles for Cereals Recommended Lists.

6. A similar variety approach could be assessed in winter barley and winter wheat.

7. The physiological basis for nitrogen scavenging ability and variety differences in N use and partitioning would be worthwhile research areas. This would lead breeders and growers to better matching of varieties to field circumstances and market requirements.

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Annexe 1

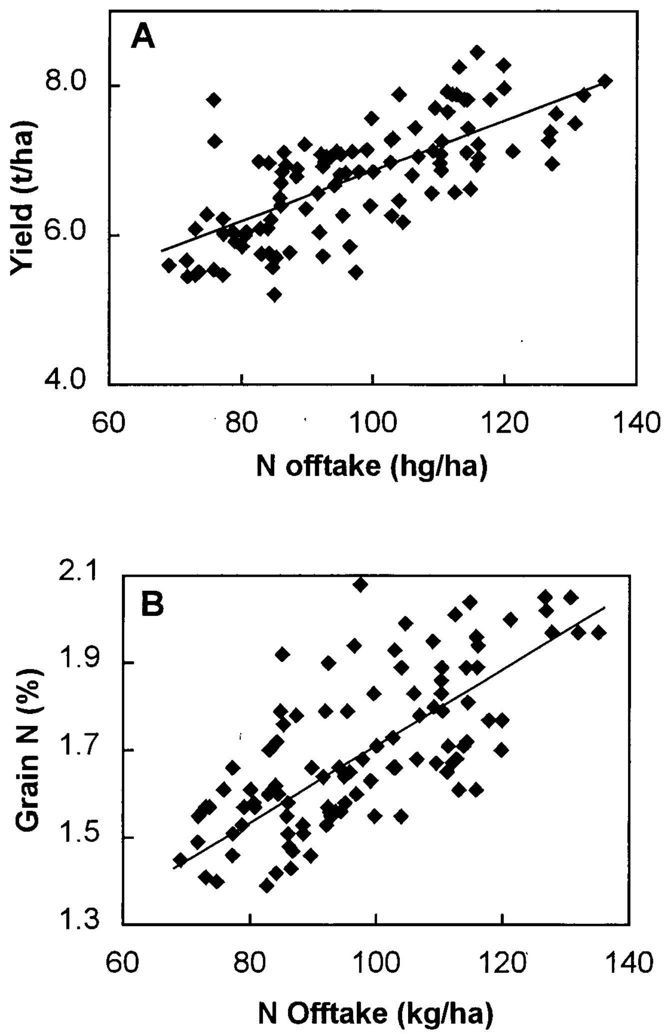

Figure 3. (A) Relationship between yield and N offtake across all variety *x* site combinations; $y = 3.50 + 0.034x$, $r^2 = 50.2\%$, $P < 0.001$, $n = 106$. (B) Relationship between grain N and N offtake across all variety *x* site combinations; $y = 0.84 + 0.0088$, $r^2 = 52.7\%$, P , 0.001, $n = 106$.

HGCA

PROJECT REPORT No. 200

THE USE OF FUNGICIDE SEQUENCES TO MAXIMISE THE CONTROL OF EYESPOT IN CEREALS AND MINIMISE THE RISK OF SHARP EYESPOT

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Price £3.50

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THE USE OF FUNGICIDE SEQUENCES TO MAXIMISE THE CONTROL OF EYSPOT IN CEREALS AND MINIMISE THE RISK OF SHARP EYESPOT

by

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This is the final report of a nine month project which started in February 1998. The work was funded by a grant of £15,633 from HGCA (Project No. 1088).

CONTENTS

1. ABSTRACT

This project report describes the results of a one year field trail carried out to investigate the control of common eyespot and sharp eyespot. Controlling one disease may allow another disease to colonise the clean stem base and one aim of this project was to investigate if controlling common eyespot would lead to an increase in sharp eyespot and if this could be suppressed.

Previous work on common eyespot has shown that the two most effective fungicides with activity against common eyespot have different optimum timings of application. Prochloraz works best when applied during the period of mid tillering to the start of stem extension. Cyprodinil works best when applied later at the second node stage of stem extension. Both fungicides cause an initial suppression of the eyespot population, but levels of eyespot then increase again. Successful treatment depends on getting a large enough initial reduction in the population coupled with a more sustained period of reduction before the eyespot population recovers. This project aimed to establish if using the two fungicides in sequence at their optimum timings would allow for a longer period of reduction and hence a more successful eyespot treatment.

The project found the most effective treatment for common eyespot control of those evaluated in the trial was cyprodinil applied at GS 32 as a single full dose treatment. Splitting this dose of cyprodinil between GS 30 and GS 32 was not as effective as the single full rate application. Prochloraz applied at full dose rate at GS 25 also reduced the levels of eyespot assessed at the end of the season. Splitting the prochloraz treatment between GS 25 and GS 31 did not improve eyespot control.

Splitting the eyespot treatment and applying half dose rate prochloraz at GS 25 and half dose rate cyprodinil at GS 32, so that each was applied at it's optimum timing, was not as successful at reducing visual eyespot as cyprodinil either as a single full dose application at GS 32 or as a split treatment as GS 30 and GS 32. PCR analysis, however, shows lower levels of eyespot DNA in the prochloraz followed by cyprodinil treatment than in these other treatments, which may support the theory that better eyespot control could be achieved by using both products at their optimum timing than could be achieved using either one straight. The yield from this split treatment of prochloraz and cyprodinil was also higher than cyprodinil applied on its own.

Analysis of the eyespot DNA present showed that the R strain was the dominant strain at the site and that the W strain of eyespot was only present at very low levels. In this trial eyespot was not seen until the crop was heading with no eyespot present at the critical time for making an eyespot spray choice, of stem extension. This shows how a threshold approach to treating this crop would not have been successful, and also demonstrates how the fungicides worked well as protectants in reducing final eyespot levels in the plots.

Sharp eyespot levels in the trial were very low, but there was a small increase in sharp eyespot levels following the most successful eyespot treatments and there was a negative correlation between sharp eyespot and common eyespot at the end of the season. A sequence of azoxystrobin sprays were applied and, of the timings evaluated, the spray applied at GS 32

was the most successful at reducing sharp eyespot as well in increasing yield and reducing lodging.

2. SUMMARY

A complex of diseases can infect the stem base of wheat and as common eyespot is the more damaging disease many studies have concentrated on controlling this pathogen. Other studies have observed, however, that where eyespot is controlled sharp eyespot tended to increase, successfully colonising the clean tissue from which common eyespot had been controlled. The aim of this study was to develop a fungicide program that would control common eyespot without increasing the risk of sharp eyespot. This was done by following the diseases both through visual assessments and by using DNA probes through out the season following sprays with the fungicides prochloraz, cyprodinil and azoxystrobin. The use of PCR in this way has proved a useful tool in tracking common eyespot epidemics through a season and this project aimed to apply the same techniques to track sharp eyespot and follow the progress of the two diseases together.

Prochloraz and cyprodinil are the two fungicides used to target common eyespot in wheat but they have little or no activity against sharp eyespot. Azoxystrobin on the other hand does have activity against sharp eyespot but no activity against common eyespot. By using the fungicides both in sequence and as mixes it was hoped that control of both diseases would be achieved. Azoxystrobin was therefore applied at a range of timings with the aim of establishing if it would reduce sharp eyespot levels and to determine the optimum timing for this.

Previous work on common eyespot has shown that prochloraz and cyprodinil have different optimum timings of application. Prochloraz has been shown to give the largest reduction in eyespot levels when applied during the period of mid tillering to the start of stem extension. Cyprodinil works best when applied later at the second node stage of stem extension. Both fungicides cause an initial suppression of the eyespot population, but levels of eyespot then recover again. Successful treatment depends on getting a large enough initial reduction in the population coupled with a longer period of reduction before the population recovers. This project aimed to establish if using the two fungicides in sequence at their optimum timings would allow for a longer period of reduction and hence a more successful eyespot treatment.

The most effective treatment for eyespot control of those evaluated in the trial was cyprodinil applied at GS 32 as a single full dose treatment. Splitting this dose of cyprodinil between GS 30 and GS 32 was not as effective as the single full rate application. Prochloraz applied at full dose rate at GS 25 also reduced the levels of eyespot assessed at the end of the season at GS 71. Splitting the prochloraz treatment between GS 25 and GS 31 did not improve eyespot control.

One aim of the work was to investigate if applying cyprodinil at it's optimum time of application for eyespot control of GS 32 as a split treatment with prochloraz, also applied at it's optimum time of application (GS 25 - 30). Visually this treatment was not as successful at reducing eyespot as cyprodinil, either as a single full dose application at GS 32 or as a split

treatment as GS 30 and GS 32. The PCR analysis however showed lower levels of eyespot DNA in the prochloraz followed by cyprodinil treatment than in these other treatments, which may support the theory that better eyespot control could be achieved by using both products at their optimum timing than could be achieved using either one straight. The yield from this split treatment of prochloraz and cyprodinil was also higher than that in the straight or split cyprodinil treatments. The result would support further work being done to confirm, or otherwise, the theory that splitting the treatments at their optimum timings would improve eyespot control.

Sharp eyespot levels in the trial were very low, but a reduction in sharp eyespot was seen following an application of azoxystrobin. Despite levels of sharp eyespot being so low there was a negative correlation between sharp eyespot and common eyespot levels at the end of the season. There was a small but not significant increase in sharp eyespot levels following the most successful treatments to control common eyespot and this increase was reduced by tank mixing azoxystrobin with the eyespot treatment. A sequence of azoxystrobin sprays were applied and, of the timings evaluated, the spray applied at GS 32 was the most successful at reducing sharp eyespot as well in increasing yield and reducing root lodging.

This finding is important as it emphasises the importance of correctly identifying stem base pathogens. Treatment for common eyespot if, in fact, sharp eyespot was the problem would make a sharp eyespot infection worse. Where common eyespot is the dominant pathogen then at present a sharp eyespot treatment (azoxystrobin) is probably not merited as the cyprodinil plus azoxystrobin mix would still require the addition of a triazole fungicide for foliar disease protection at GS 32. The resultant three way mix required to target foliar diseases, common and sharp eyespot would unlikely to be cost effective.

Analysis of the eyespot DNA present using the PCR technique showed that the R strain was the dominant strain at the site and that the W strain of eyespot was only present at very low levels. This is now felt to be typical of the situation in the UK where most sites surveyed have either only the R strain or, if a mixed population, the R strain dominating. Only a very few sites in the UK have any significant level of the W strain. The W strain is more easily controlled with fungicides and tends to show symptoms earlier in the season. The R strain typically infects later and increase rapidly, and this is thought to be the reason why thresholds for eyespot treatment no longer work. In this trial eyespot was not seen until the crop was heading with no eyespot present at the critical time for making an eyespot spray choice at stem extension. This trial demonstrated how a threshold approach to treating this crop would not have been successful, and also demonstrated how the fungicides worked well as protectants in reducing final eyespot levels in the plots.

3. INTRODUCTION

A complex of diseases infects the stem base in wheat of which common eyespot, caused by the organism *Pseudocercosporella herpotrichoides,* is the most common and the most damaging. Sharp eyespot, *Rhizoctonia solani*, also attacks the stem base as do several Fusarium species of fungi. All these diseases can weaken the stem base and reduce uptake, reducing yields and causing shrivelled grains and white heads. In severe cases they can also causes lodging, further reducing both yield and quality.

Common eyespot, *Pseudocercosporella herpotrichoides,* causes much larger yield losses than the other disease in the stem base complex. The severity of disease development as a result of infection by common eyespot is determined by agronomic as well as environmental factors, and is greatest under cool, moist conditions and where wheat and / or barley is grown in close rotation. Eyespot is conventionally controlled in winter wheat crops with a fungicide spray at early stem extension between growth stages Zadoks 30 to 32 (Anon, 1987, Burnett *et al.*, 1998), often applied as a split treatment.

In the asexual form the eyespot fungus survives in the soil in crop debris, where it can persist for more than a season so that a two year break from cereals is required for effective rotational control. Eyespot is worse where cereals are grown continuously or in short rotations. Conidia are spread to the host plant by rain splash where the mycelium penetrates the coleoptiles or leaf sheaths of the host plant. Infection is localised at the stem base; it seldom infects above the second node and does not colonise leaf or root tissue. The infection can proceed through several leaf layers to eventually penetrate the stem. After infecting the stem the characteristic eye or pupil shaped lesion can form. Surrounding tissue becomes discoloured. The development of the disease is favoured in the UK by mild, wet weather in winter and cool damp weather in spring. Eyespot is most severe in early-sown crops and can be reduced in high risk fields by late sowing and crop rotation (Cook *et al.*, 1993).

The sexual stage of the eyespot fungus is now suspected to more significant than it was in the past. Over recent seasons first wheat crops that would not be perceived to be at risk from the asexual, trash borne phase of eyespot have sometimes been severely affected by eyespot. The cause of these infections can be the airborne, sexual stage of the fungus. Airborne apothecia are produced on surrounding trash, stubble or crops and can then blow into and infect first wheat crops. Conditions which favour apothecia discharge are cool temperatures of 3-8°C and high rainfall. Standing stubble and set aside are common sources of the sexual stage, as is rye grass pasture land.

There are two species of eyespot which commonly occur in the UK, one the W strain is highly pathogenic on wheat, but less so on barley and on rye, the second the R strain is equally pathogenic on wheat, barley and rye (Scott *et al.*, 1975). The sexual stages of these two strains have recently been reclassified as two distinct species, *Tapesia yallundae* (W strain) and *Tapesia acuformis* (R strain). The R strain is the most common in the UK and is present at much greater levels that the W strain at most sites. The W strain is only present in significant proportions at a very few sites (Novartis Crop Protection Ltd. pers. comm.)

Recent work showed that there is a strong correlation between eyespot levels and yield (HGCA Project Report 150). Trials carried out by SAC before this, in the course of an HGCA funded project looking at the biology and control of eyespot (Project No. 0015/1/91), also found that there was a significant association between eyespot levels and yield. Although lodging was also associated with yield loss, the correlation was not as strong as that between eyespot and yield. There was also a significant correlation between eyespot and lodging (Burnett & Oxley, 1996, Burnett *et al.*, 1998).

Control of eyespot

Eyespot is conventionally controlled in winter wheat crops with a fungicide spray at early stem extension between growth stages Zadoks 30 to 32 (Anon, 1987, Burnett *et al.*, 1998), often applied as a split treatment. Previous work has identified prochloraz and cyprodinil as the two most effective fungicides for control of common eyespot and resultant yield benefit.

Work carried out at SAC (HGCA Project Report 150) showed that both fungicides were more effective at controlling the W strain than the R strain. The greater efficacy of the two fungicides against the W strain in that study concurs with reports in the literature. Prochloraz has been reported to control the W strain better than the R strain (Bateman *et al.*, 1986) and cyprodinil showed better control of the W strain in work carried out in France (Migeon *et al.*, 1995).

HGCA Project Report 150 reports that cyprodinil gave a more persistent reduction in R strain eyespot, in both seasons the project, ran than prochloraz and although control of the R strain with prochloraz was initially good the population often recovered. Recovery of the R strain population was slower after cyprodinil treatment in both seasons. The PCR technology used in the project demonstrated that fungicide treatments work by reducing the levels of both strains present. Control was temporary, and the populations recovered, so the key to effectively reducing the degree of visual symptoms and the damage to the plant at the end of the season, is timing the fungicide application to achieve the longest respite from the disease possible.

Treatment too early or too late allowed the populations to recover, and visual eyespot symptoms to develop to severe levels despite the treatment. Prochloraz applied too early led to a recovery of the W population that eventually exceeded the levels in the untreated controls. Control of the R strain had to be made early with prochloraz. Application too late did not significantly reduce the R strain eyespot levels after application. Cyprodinil could give large reductions in R and W strain eyespot, but the populations could recover fast, particularly the W strain, so again it was evident that cyprodinil used late could reduce the populations over the remainder of the season.

Prochloraz therefore has to be used early in the season, during tillering, for maximum effect on eyespot levels. Cyprodinil works best if applied after the start of stem extension. Spraying outside the optimum window could allow the eyespot populations to recover following treatment even if initial reductions in eyespot were achieved. Prochloraz applied too late did not reduce the eyespot population sufficiently to affect the levels at the end of the season. In contrast cyprodinil applied too early achieved an initial reduction that was not be maintained until the end of the season. The findings of the work would suggest the potential for using sequences of fungicides to achieve season long control of the eyespot pathogen.

Control of eyespot therefore remains a compromise between targeting the site of infection at early stem extension where this part of the plant is still exposed, but not going in so early that the eyespot populations can recover and eventually exceed the initial disease prognosis.

The use of thresholds

As treatment decisions have to be made early in the season if eyespot is to be targeted, disease risk assessment and prediction has been the aim of many research projects, with the objective of determining a threshold level of eyespot early enough in the season to identify crops where control of eyespot would be economic. Some schemes have relied on weather data, but this does not allow for the loss of lesions that either die out or are shed with the outer leaves and never penetrate the stem. The ADAS scheme for identifying crops at risk of eyespot was based on assessing the number of stems infected at the start of stem extension and recommending treatment if an incidence of more than 20% is found (Anon, 1987, Jones, 1994)).

Eyespot assessment in the spring, however, has long been recognised as an unreliable indicator of subsequent disease progress (Scott and Hollins, 1978). Hughes et al., 1999 demonstrated the fallibility of this threshold method and concluded that while it would identify correctly those crops that passed the threshold at stem extension as being those that would benefit from treatment is would miss all those that had not passed the threshold but would go on to develop serious infections. In view of the changes in fungicides, in wheat cultivars and in the pathogen population itself since the currently recommended threshold was devised it clearly needs to be updated.

This threshold was developed when the W strain of eyespot predominated whereas the R strain is now more common. The fungicides most commonly used on wheat over the last 20 years were members of the DMI group which act differentially on the two strains, and are far more effective in controlling the W strain. This may be one reason why the R strain now predominates throughout the UK. The R strain often infects later and then increases fast which may make it less suitable for meeting the threshold criteria. The wheat strain tends to cause more cell browning as it infects the stem and therefore may have been easier to assess as a visual threshold. HGCA Project Report 150 found that in one season there was a significant correlation between W strain levels at stem extension and the final levels at the end of the season, indicating how thresholds may have been more effective when the W strain was the dominant strain of eyespot in the UK.

Identifying crops at risk form eyespot requires further study. At present taking account of other risk factors such as sowing date and previous cropping would seem to be a more successful approach to identifying crops that would benefit from an eyespot spray, than would the use of thresholds.

Diagnostics

PCR technology now means that it is possible to detect and quantify the amount of fungal DNA present in the stem base. HGCA Project Report 150 investigated the use of PCR technology to assess eyespot levels. Until that time eyespot infections could only be quantified visually. Visual differentiation between other diseases of the stem base such as sharp eyespot and Fusarium was often difficult. In addition it was only possible to differentiate between the two eyespot strains using conventional mycological techniques which were often not definitive and could not quantify the levels of each pathotype present. Techniques developed at the John Innes Centre enable the type and quantity of each pathotype to be determined by extracting the pathogen DNA from the host tissue (Nicholson & Rezanoor, 1994) and it became possible to study the differential effect that different fungicides had on the eyespot pathotypes. It was also possible to plot the levels of each pathotype throughout the season and to study how they fluctuated following fungicide application.

The findings were that this technology was a useful tool when researching treatment efficacy as it was possible to chart the initial efficacy of the fungicides following application, and the duration of control. However, the levels of DNA measured were variable between plots even within treatments and the differences between treatments were only occasionally significant. Eyespot is patchily, rather than evenly, distributed in fields (N. McRoberts, pers. comm.) and the variation in the PCR results may be a factor of the sampling required to reduce variation between plots.

Another problem identified was that in very severely infected stems the levels of fungal DNA actually fall as the dead stem can no longer support the pathogen. This means that PCR results should always be taken together with visual assessments so that one can aid the interpretation of the other. ELISA (enzyme linked immunosorbent assay) technology also exists to measure eyespot levels in the plants. Commercial work at SAC has shown that this has the advantage of measuring total eyespot (whether dead or alive) and thereby overcomes this effect of low levels of fungal DNA being found in severe lesions, seen late in the season with PCR technology. The disadvantage is that it is less sensitive and does not differentiate between R and W strains.

Although diagnostics for eyespot have proved a useful research tool they have not, however, improved the accuracy of a threshold approach to treatment or been helpful in determining a new one.

Sharp eyespot

Sharp eyespot is caused by the soil borne fungus *Rhizoctonia solani*. The fact that it is ubiquitous in soils and also has a very wide host range means that there is no form of rotational control. All cereal crops can be affected, but as with other stem base diseases spring crops tend not to be severely affected. Winter wheat is the most susceptible of the cereals and there is no form of varietal resistance. The disease tends to be favoured by cool, dry conditions and therefore some fields are more prone to the disease than others.

Sharp eyespot causes symptoms very similar to those of common eyespot. The disease infects through outer leaf sheaths and causes eye-like lesions which have a much more defined edge and paler centre than those of common eyespot. Early in the season the lesions may have a more shredded appearance on the leaf sheaths than common eyespot. Mature lesions on the stem with sharp eyespot often contain a purplish mycelial growth which can be scraped off and later in the season flat sclerotia or resting bodies forms against the stem and between leaf sheaths. Lesions have a slightly oblique shape are often seen as multiple lesions extending far up the stem. As with the other stem base diseases, sharp eyespot reduces uptake through the stem and as a consequence can cause shrivelled grains, reduced yields and whiteheads as well as weakening the stem so that lodging is more likely. It is generally perceived to be less damaging than common eyespot in terms of yield losses.

Objectives

A complex of diseases can infect the stem base of wheat and as common eyespot is the more damaging disease many studies have concentrated on controlling this pathogen. Other studies have observed, however that where eyespot is controlled sharp eyespot tended to increase, successfully colonising the clean tissue from which common eyespot had been controlled. The aim of this study was to develop a fungicide program that would control common eyespot without increasing the risk of sharp eyespot. This was to be done by following the diseases both through visual assessments and by using DNA probes through out the season following sprays with the fungicides prochloraz, cyprodinil and azoxystrobin. The use of PCR in this way has proved a useful tool in tracking common eyespot epidemics through a season and this project aimed to apply the same techniques to track sharp eyespot and follow the progress of the two diseases together.

Prochloraz and cyprodinil are the two fungicides used to target common eyespot in wheat but they have no activity against sharp eyespot. Azoxystrobin on the other hand does have activity against sharp eyespot but no activity against common eyespot. By using the fungicides in sequence and in mixes it was hoped that control of both diseases would be achieved. Azoxystrobin was therefore applied at a range of timings with the aim of establishing if it would reduce sharp eyespot levels and to determine the optimum timing for this.

One aim of the work was to investigate if applying cyprodinil at it's optimum time of application for eyespot control of GS 32 as a split treatment with prochloraz also applied at it's optimum time of application (GS 25 - 30) would allow for a longer period of reduction in the eyespot population and hence a more successful eyespot treatment.

4. MATERIALS AND METHODS

The field trial was carried in 1998 by superimposing plots in a commercial crop of winter wheat (variety Riband) on a site in East Lothian. The crop was a second wheat. Plots were 40 m^2 and were laid out in randomised blocks. There were four replicates of the treatments. Fungicide treatments were applied using a hand-held Cooper Pegler CP3 sprayer calibrated to deliver a water volume of 200 l/ha at a pressure of 2.5 bars. The plots were not over sprayed with fungicides later in the season to eliminate foliar disease development. Except for fungicides the trial areas received the same inputs as the surrounding commercial crop.

Visual assessments for stem base diseases were carried out according to the four point scales below, on 25 separate plants from each plot (prior to growth stage 31) or tillers after this growth stage.

Score	Description
0	No symptoms
1	Lesions affecting less that 50% of stem circumference
2	Lesions affecting over 50% of stem circumference
3	Lesions affecting over 50% of stem circumference AND tissues softened so that lodging would readily occur.

A stem base disease percentage index was then calculated for each disease using the following

$$\frac{((\text{no. slightly infected stems})+(\text{no. moderately infected stems x 2})+(\text{no. severely infected stems x3}))\text{x4}}{3}$$

The stem base diseases common eyespot, sharp eyespot and Fusarium spp. were assessed visually at each sampling. The quantity of eyespot and sharp eyespot DNA was also quantified at each assessment. Lodging (percentage of each plot leaning at more than 45 degrees) and yield (tonnes per hectare corrected to 85% moisture content) were assessed at harvest. The sampling dates and crop growth stages and the spray programmes evaluated, are detailed in Table 1, 2 and 3.

Table 1.
Spray programmes evaluated 1998
Treatment regimes 1 - 15

	GS 25 25 Feb 98	GS 30 21 April 98	GS 31 28 April 98	GS 32 11 May 98
1.	-	-	-	-
2.	Prochloraz 0.9 l/ha	-	-	-
3.	-	-	-	Cyprodinil 1.0 kg/ha
4.	-	Prochloraz 0.45 l/ha	-	Cyprodinil 0.5 kg/ha
5.	-	Cyprodinil 0.5 kg/ha	-	Prochloraz 0.45 l/ha
6.	Prochloraz 0.45 l/ha	-	Prochloraz 0.45 l/ha	-
7.	-	Cyprodinil 0.5 kg/ha	-	Cyprodinil 0.5 kg/ha
8.	Prochloraz 0.45 l/ha + Azoxystrobin 0.5 l/ha	-	-	-
9.	-	-	-	Cyprodinil 0.5 kg/ha + Azoxystrobin 0.5 l/ha
10.	Azoxystrobin 1.0 l/ha	-	-	-
11.	-	Azoxystrobin 1.0 l/ha	-	-
12.	-	-	Azoxystrobin 1.0 l/ha	-
13.	-	-	-	Azoxystrobin 1.0 l/ha
14.	-	-	-	-
15.	-	-	Cyprodinil 0.5 kg/ha	Azoxystrobin 0.5 l/ha

Full commercial doses for the products used were as follows:-

Active ingredient	*Product*	*Manufacturer*	*g a.i./ha*
Prochloraz	Sportak 45	AgrEvo	405
Azoxystrobin	Amistar	Zeneca	250
Cyprodinil	Unix	Novartis	1000

Treatments applied by CO^2 knapsack sprayer in 200 - 250 litres of water/ha at 200 -300 kPa
Zadoks growth stages (Tottman & Broad, 1987).

Table 2.
SAMPLING SUMMARY

Assessment date	Treatments for visual assessment	Treatments for PCR assessment
Assessment 1	1, 14	1,14
Assessment 2	1, 2, 6, 8,10, 14	1, 14
Assessment 3	1, 2, 4, 5, 6, 7, 8, 10, 11, 14	1, 2, 4, 5, 6, 7, 8, 10, 11, 14
Assessment 4	1, 2, 4, 5, 6, 7, 8, 10, 11, 12, 14	1, 14
Assessment 5	1 to 14	1 to 14
Assessment 6	1 to 14	1, 14
Assessment 7	1 to 14	1 to 14

Table 3.
Assessments dates and growth stages 1998

Assessment	Sampling date	Growth stage
Assessment 1	17 Feb 98	21/22
Assessment 2	15 Apr 98	30
Assessment 3	06 May 98	31
Assessment 4	20 May 98	33/37
Assessment 5	23 Jun 98	59
Assessment 6	20 Jul 98	71/73
Assessment 7	28 Aug 98	90

Detection of *Pseudocercosporella herpotrichoides* and *Rhizoctonia solani* in wheat stem base tissue by PCR

PCR diagnostics were used to study the progress of the eyespot and sharp eyespot epidemics, in conjunction with the visual assessments. At each sampling date, 25 stem bases were chosen at random from each of four replicate plots. Early in the season, prior to stem extension, one stem base was defined as being one plant, but later samples took the form of 25 tillers from different plants. Roots (also the crown root and seed coat if still attached) were removed close to the crown and the stem base was cut to 2 - 3 cm in length. The upper part of the plant and any remaining leaf laminae were discarded. Tissue was rinsed in tap water followed by distilled water, transferred to plastic weighing boats, covered in clingfilm then frozen at -80°C until freeze-drying could be carried out. Samples were removed from the -80°C freezer, still frozen, then placed on the freeze-dryer for 48h (the clingfilm was pierced first). The tissue was removed to plastic storage boxes containing silica gel and stored at -80°C until DNA could be extracted.

Prior to DNA extraction, the freeze-dried weight of each pooled 25 stem base-sample was recorded. The sample was transferred to a pestle and mortar and ground in liquid nitrogen to a fine flowable powder. This was removed to a centrifuge tube and DNA extracted using a commercially available kit designed for plant DNA extraction (Nucleon Phytopure, Scotlab Ltd, Coatbridge, Strathclyde). Final re-suspension of the DNA was made in 500μl TE (tris-EDTA buffer pH 8.0) in plastic eppendorf tubes. Primers were applied to aliquots of the samples for detection of W- and R-strain *P. Herpotrichoides* and *Rhizoctonia solani.* A competitive PCR technique was used at the John Innes Centre, Norwich which enables quantification of PCR products; details of the competitive PCR process used have been submitted for a patent application and are therefore confidential. Results were expressed as μg fungal DNA per unit dry weight of stem base and used to quantify the amount of each fungus pathotype present at each sampling date.

5. RESULTS

Table 4.
Visual eyespot
% Incidence GS 22-37, % Index GS 59 - 90

		Growth stage of assessment						
Treatment	Treatment / growth stage	21/22	30	31	33/37	59	71/73	90
T1	UT	5.25	9.75	9.50	7.75	22.3	51.7	53.7
T2	P/25	*	7.25	8.00	8.75	14.0	35.7	47.0
T3	C/32	*	*	*	*	5.3	26.7	53.3
T4	P/30 + C/32	*	*	10.2	5.75	6.7	32.7	50.0
T5	C/30 + P/32	*	*	7.50	5.00	11.7	42.0	50.0
T6	P/25 + P/31	*	9.67	9.25	9.75	16.3	35.7	51.3
T7	C/30 + C/32	*	*	6.50	3.75	15.0	32.0	59.0
T8	P +A/25	*	2.75	8.25	8.75	22.7	48.0	55.3
T9	C+A/32	*	*	*	*	7.0	38.7	59.3
T10	A/25	*	4.00	5.75	5.75	22.0	50.3	55.0
T11	A/30	*	*	6.25	3.00	23.0	51.0	57.7
T12	A/31	*	*	*	3.50	20.3	47.3	53.0
T13	A/32	*	*	*	*	19.0	50.7	55.7
T14	UT	6.50	6.75	9.00	8.25	30.0	42.7	50.3
T15	C/31+A/32	*	*	*	3.00	13.7	50.0	55.7
SED		0.990	1.696	2.683	1.241	6.20	10.72	13.69
P		0.253	0.004	0.757	<0.001	0.008	0.314	1.000

Code	*Active ingredient*	*Product*
P	Prochloraz	Sportak 45
A	Azoxystrobin	Amistar
C	Cyprodinil	Unix

Single products applied at full rate, tank mix or split application products applied at half rate each

Eyespot was assessed visually to be present in the trial at very low levels until flag leaf emergence (GS 33 - 37) and did not exceed an incidence of 10% until the heads were fully emerged in the crop (GS 59). By the end of the season the index was over 50% in nearly all treated and untreated plots which represented a serious eyespot epidemic. The cyprodinil treatments applied at GS 32 (treatment numbers T3 and T9) gave the largest significant reduction in eyespot levels at GS 59. This reduction was still apparent visually at GS 71/73 when full rate cyprodinil (T3) gave the largest reduction in eyespot compared to the untreated plots. The treatments with half rate cyprodinil applied (T7 and T9) were not as good at this timing as the full rate cyprodinil. All the prochloraz and cyprodinil treatments gave some reduction in eyespot compared to the untreated. At GS 90 stems were dying off and eyespot lesions at this time were very advanced and usually included symptoms of Fusarium so differences between treatments were not visually apparent

Table 5.
Visual Sharp eyespot
% Incidence GS 22-37, % Index GS 59 - 90

		Growth stage of assessment						
Treat ment	Treatment / growth stage	21/22	30	31	33/37	59	71/73	90
T1	UT	8.25	0	1.25	1.00	1.67	1.00	0.33
T2	P/25	*	0	0.50	0.25	0.67	1.00	0.67
T3	C/32	*	*	*	*	2.67	2.33	1.00
T4	P/30 + C/32	*	*	0.50	0.50	1.00	0.33	2.00
T5	C/30 + P/32	*	*	0.25	0.25	3.33	4.00	2.33
T6	P/25 + P/31	*	0	0.50	0.25	1.00	2.67	1.67
T7	C/30 + C/32	*	*	0.25	0.00	1.67	4.00	5.33
T8	P +A/25	*	0	0.00	2.75	3.00	3.33	1.00
T9	C+A/32	*	*	*	*	0.67	0.33	0.33
T10	A/25	*	0	0.00	0.00	1.33	4.00	1.00
T11	A/30	*	*	0.75	0.00	0.33	1.33	0.67
T12	A/31	*	*	*	0.00	1.33	1.33	1.33
T13	A/32	*	*	*	*	1.00	0.67	0.00
T14	UT	5.25	0	0.50	0.25	3.00	2.00	0.33
T15	C/31+A/32	*	*	*	3.00	0.67	1.00	0.00
SED		7.246	-	0.428	1.619	1.189	1.636	1.168
P		0.693	-	0.199	0.586	0.213	0.211	0.007

Code	*Active ingredient*	*Product*
P	Prochloraz	Sportak 45
A	Azoxystrobin	Amistar
C	Cyprodinil	Unix

Single products applied at full rate , tank mixed or split application products applied at half rate each.

Sharp eyespot was assessed visually to be present at extremely low levels throughout the season. Initial lesions present at tillering were shed with the lower leaves and after this timing levels only just exceeded 5% in the worst affected plots. Differences between treatments were never significant but tended to be higher in those treatments that had shown common eyespot control (T3 to T9).

Table 6.
Visual Fusarium
% Incidence GS 22-37, % Index GS 59 - 90

Treat ment	Treatment / growth stage	21/22	30	31	33/37	59	71/73	90
		Growth stage of assessment						
T1	UT	12.0	11.5	16.8	16.0	30.0	58.3	51.3
T2	P/25	*	15.5	17.2	18.2	32.3	59.3	41.3
T3	C/32	*	*	*	*	26.0	48.3	44.7
T4	P/30 + C/32	*	*	15.5	11.8	41.3	54.0	44.7
T5	C/30 + P/32	*	*	14.7	9.75	24.7	50.3	49.0
T6	P/25 + P/31	*	15.0	17.2	14.8	33.7	59.0	49.0
T7	C/30 + C/32	*	*	17.5	9.25	21.7	46.0	49.7
T8	P +A/25	*	11.8	14.2	17.0	30.0	58.3	51.3
T9	C+A/32	*	*	*	*	26.0	53.3	50.0
T10	A/25	*	12.0	12.0	13.2	32.0	62.3	51.3
T11	A/30	*	*	16.2	8.00	29.0	54.7	48.0
T12	A/31	*	*	*	9.00	27.7	57.0	51.3
T13	A/32	*	*	*	*	24.0	46.7	45.7
T14	UT	14.8	15.0	15.8	14.5	29.0	57.0	51.7
T15	C/31+A/32	*	*	*	12.0	26.7	51.0	41.0
SED		5.089	0.439	1.989	1.963	7.71	5.56	8.54
P		0.608	0.395	0.204	<0.001	0.696	0.111	0.977

Code	*Active ingredient*	*Product*
P	Prochloraz	Sportak 45
A	Azoxystrobin	Amistar
C	Cyprodinil	Unix

Single products applied at full rate , tank mixed or split application products applied at half rate each.

Fusarium levels in the plots increased steadily throughout the season until watery ripe (GS 71 - 73). At the GS 33/37 assessment the split cyprodinil treatments and the azoxystrobin treatments at GS 30 and 31 (T5, T7, T11 and T12) gave a significant reduction in Fusarium levels. Differences later in the season were not significant but the lowest levels of Fusarium at GS 71/73 were found in the full rate cyprodinil treatment (T3), in the split cyprodinil treatment (T7) as well as in the latest azoxystrobin treatment (T13).

Table 7.
Lodging and yield

Treatment	Treatment / growth stage	Growth stage of assessment Lodging %	Yield t/ha
T1	UT	48.8	3.67
T2	P/25	75.0	3.75
T3	C/32	48.8	4.59
T4	P/30 + C/32	31.8	4.73
T5	C/30 + P/32	62.5	4.39
T6	P/25 + P/31	63.8	3.93
T7	C/30 + C/32	42.5	4.57
T8	P +A/25	60.0	3.74
T9	C+A/32	22.0	5.42
T10	A/25	69.5	3.82
T11	A/30	28.8	4.98
T12	A/31	28.8	4.89
T13	A/32	25.0	5.21
T14	UT	63.8	3.76
T15	C/31+A/32	27.5	5.23
SED		12.31	0.172
P		<0.001	<0.001

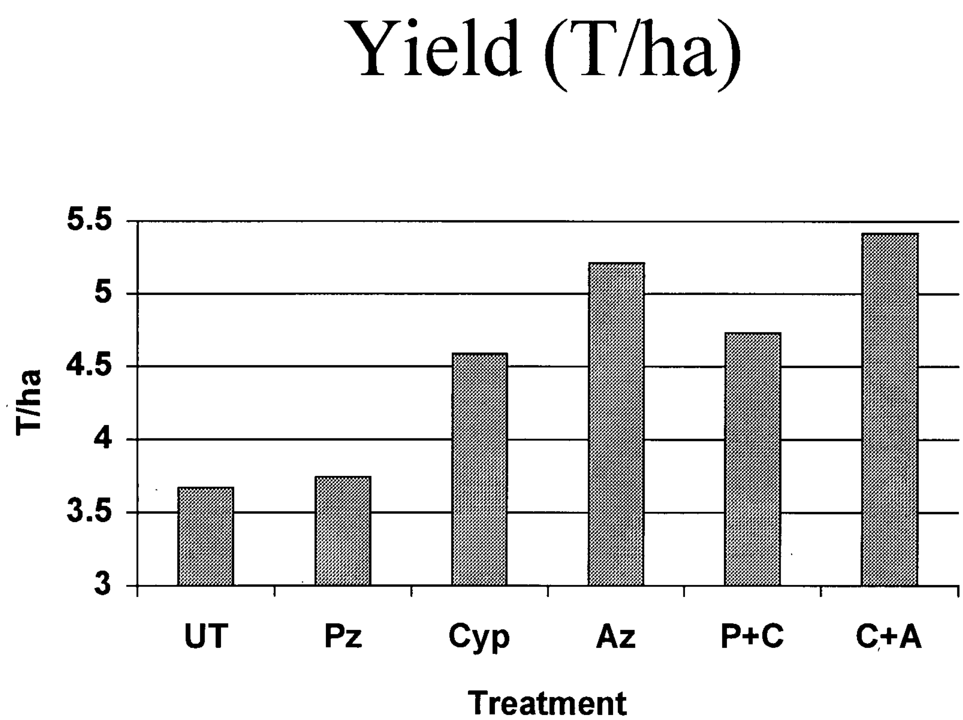
Code	*Active ingredient*	*Product*
P	Prochloraz	Sportak 45
A	Azoxystrobin	Amistar
C	Cyprodinil	Unix

Single products applied at full rate, tank mixed or split application products applied at half rate each.

There were high levels of root lodging in the trial at the end of the season. All the azoxystrobin treatments significantly reduced this, with the later applied treatments showing the largest reduction in lodging.

Yields were low as plots were not over sprayed to control foliar disease. Azoxystrobin showed the largest yield increase over the untreated and this increase was greatest at the GS 32 application (T13). The cyprodinil treatments T3, T4 and T7 also gave yield increases of around a tonne (Figure 1).

Figure 1



The highest yielding treatment was the cyprodinil and azoxystrobin tank mix applied at GS 32. Cyprodinil at GS 32 and prochloraz followed by cyprodinil also increased yield.

Table 10.
W strain PCR analysis
(Fungal DNA (ng per mg plant dry weight)

		Growth stage of assessment						
Treat ment	Treatment / growth stage	21/22	30	31	33/37	59	71/73	90
T1	UT	0	0	0	0	0	0.0012	0.0008
T2	P/25	0	0	0	0	0	*	0.0004
T3	C/32	0	0	0	0	0	*	0.0008
T4	P/30 + C/32	0	0	0	0	0	*	0.0001
T5	C/30 + P/32	0	0	0	0	0	*	0.0008
T6	P/25 + P/31	0	0	0	0	0	*	0.0004
T7	C/30 + C/32	0	0	0	0	5.0×10^{-5}	*	0.0015
T8	P +A/25	0	0	0	0	1.6×10^{-4}	*	0.0010
T9	C+A/32	0	0	0	0	5.0×10^{-5}	*	0.0015
T10	A/25	0	0	0	0	8.2×10^{-5}	*	0.0055
T11	A/30	0	0	0	0	5.0×10^{-5}	*	0.0084
T12	A/31	0	0	0	0	5.0×10^{-5}	*	0.0080
T13	A/32	0	0	0	0	5.5×10^{-4}	*	0.0251
T14	UT	0	0	0	0	4.9×10^{-4}	0.0031	0.0055
SED						-	0.00244	0.00514
P						-	0.470	0.001

Code	*Active ingredient*	*Product*
P	Prochloraz	Sportak 45
A	Azoxystrobin	Amistar
C	Cyprodinil	Unix

Single products applied at full rate , tank mixed or split application products applied at half rate each

Levels of W strain eyespot were very low in the trial. No W strain was detected until GS 59 and levels remained very low until the end of the season. Levels of DNA measured were very variable and one treatment was analysed as having higher levels at the end of the season which gave an apparently higher value for T13.

Table 9.
R strain PCR analysis
(Fungal DNA (ng per mg plant dry weight)

		Growth stage of assessment						
Treatment	Treatment / growth stage	21/22	30	31	33/37	59	71/73	90
T1	UT	0	0	0	0	0	0.0722	0.1919
T2	P/25	0	0	0	0	0	*	0.0863
T3	C/32	0	0	0	0	0	*	0.1264
T4	P/30 + C/32	0	0	0	0	0	*	0.0480
T5	C/30 + P/32	0	0	0	0	0	*	0.1851
T6	P/25 + P/31	0	0	0	0	0	*	0.1637
T7	C/30 + C/32	0	0	0	0	0.0003	*	0.0715
T8	P +A/25	0	0	0	0	0.0033	*	0.0592
T9	C+A/32	0	0	0	0	0.0030	*	0.0406
T10	A/25	0	0	0	0	0.0091	*	0.1213
T11	A/30	0	0	0	0	0.0036	*	1.0589
T12	A/31	0	0	0	0	0.0051	*	0.1766
T13	A/32	0	0	0	0	0.0002	*	0.2009
T14	UT	0	0	0	0	0.0001	0.050	0.1262
SED						0.00202	0.0500	0.222
P						0.001	0.678	0.008

Code	*Active ingredient*	*Product*
P	Prochloraz	Sportak 45
A	Azoxystrobin	Amistar
C	Cyprodinil	Unix

Single products applied at full rate , tank mixed or split application products applied at half rate each.

R strain eyespot was not detected in the plots at measurable levels until GS 59. Levels between plots at this time were very variable with the untreated plots showing lower levels of R strain eyespot than many of the treated plots. At the end of the season T11 was the only treatments with significantly higher levels than the other plots. Differences between other treatments were not significant but the split cyprodinil treatments tended to have lower levels than the other treatments.

6. DISCUSSION

Eyespot control

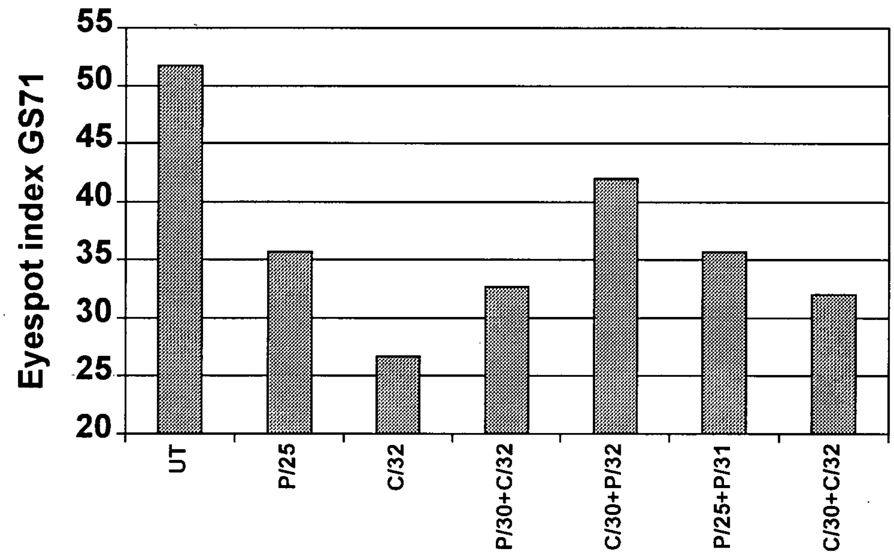
Eyespot levels were reduced by fungicide treatment and full rate cyprodinil gave the largest reduction in eyespot levels when applied at GS 32 (Figure 2.). Prochloraz also reduced eyespot levels at GS 71 when applied either as a single application at GS 25 or when applied as a split or tank mixed treatment at half rate. Prochloraz has been shown to give comparable control to cyprodinil if applied at it's optimum timing of GS 25 - 30 (HGCA Project 150). It reduced eyespot levels in this trial but did not, however, perform as well in this seasons trial as it had done in previous years. The season in which the trial was conducted meant that there was a period of several months from tillering until stem extension. This growth pattern meant that prochloraz was applied in February at GS 25 and GS 30 was not reached until 21 April. The eyespot infection did not occur until the crop was heading which again is later than is typically seen and may have reduced the efficacy of this very early treatment, which in more typical epidemics has been seen to perform better.

Cyprodinil performed better at eyespot control as a single full rate spray than it did in half dose rate tank mixes or as a split treatment applied at GS 30 and 32. Splitting the prochloraz treatment at GS 25 and GS 31 (Treatment 6) did not increase the eyespot control that resulted from a single full dose of prochloraz applied at GS 25 (Treatment 2).

Previous work on the optimum timings of cyprodinil and prochloraz (HGCA Project Report 150) showed that cyprodinil was best applied at GS 32 and prochloraz at GS 25 - 30. This project therefore investigated if applying these fungicides in sequence at their individual optimum timings would improve eyespot control. Treatment 4 had prochloraz applied at GS 30 and cyprodinil at GS 32, Treatment 5 had cyprodinil applied at GS 30 and prochloraz at GS 32 and Treatment 7 had cyprodinil applied at both timings. The eyespot levels at GS 71 are shown in Figure 2.

Figure 2.

Eyespot control from cyprodinil and prochloraz treatments

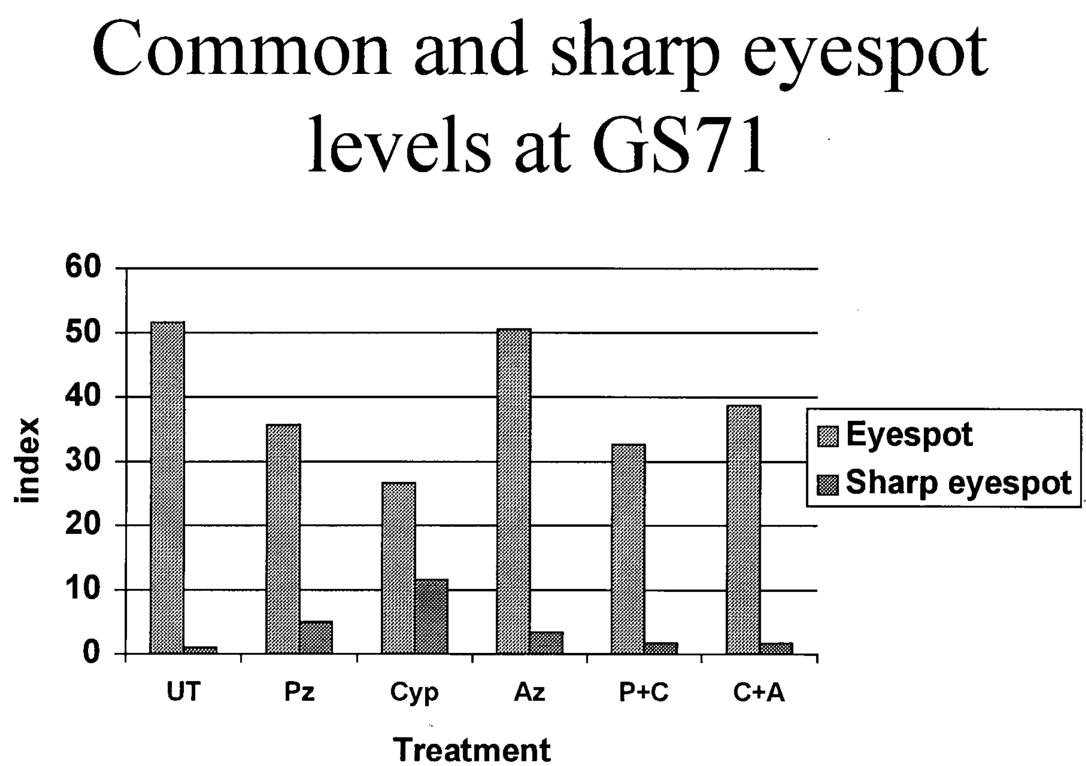


Reversing the treatments and applying cyprodinil and prochloraz away from their optimum timings lead to a significant decline in eyespot control when compared to treatment 4, where prochloraz was applied at GS 30 and cyprodinil at GS 32. This treatment did not however improve on the eyespot control achieved by applying cyprodinil at half rate at both these timings, and non of the split treatments matched the level of control achieved by applying a single full rate of cyprodinil.

Sharp eyespot control

Observations from previous eyespot studies have shown that treatments that clean the stem base of one disease can lead to an invasion of a second disease, colonising the empty stem. Sharp eyespot can therefore increase in severity where common eyespot is controlled, and in this trial azoxystrobin was used to try to reduce sharp eyespot infection. Sharp eyespot levels in the trial were very low at the beginning of the assessment period and dropped to zero during at GS 30 as lesions present on the leaf sheaths at tillering were shed. Sharp eyespot did reinfect at GS 31 but even by the end of the season levels in the plots were typically around 1% incidence, with a maximum of around 5% incidence. Levels of sharp eyespot were never high enough to quantify using the PCR technique.

Figure 3.



The results in figure 3 show that azoxystrobin (Az) had no effect on the common eyespot assessed visually at GS 71. Cyprodinil (Cyp) applied at GS 32 gave the largest reduction in common eyespot and there was a small increase in sharp eyespot when compared to the untreated control. This would support the theory that controlling common eyespot can lead to an increase in sharp eyespot. The addition of azoxystrobin to the cyprodinil suppressed this rise in sharp eyespot, although common eyespot levels also rose as the rate of cyprodinil was reduced so that this reduction in sharp eyespot could be partly due to the rise in common eyespot. There was a negative correlation between common eyespot levels in all plots at GS 71 and sharp eyespot levels at the same time ($r = -0.270$, $P = 0.005$) which would also support the theory that sharp eyespot is more likely to infect where common eyespot levels are reduced. Sharp eyespot levels in the trial were so low however that this work would have to be repeated to validate this theory.

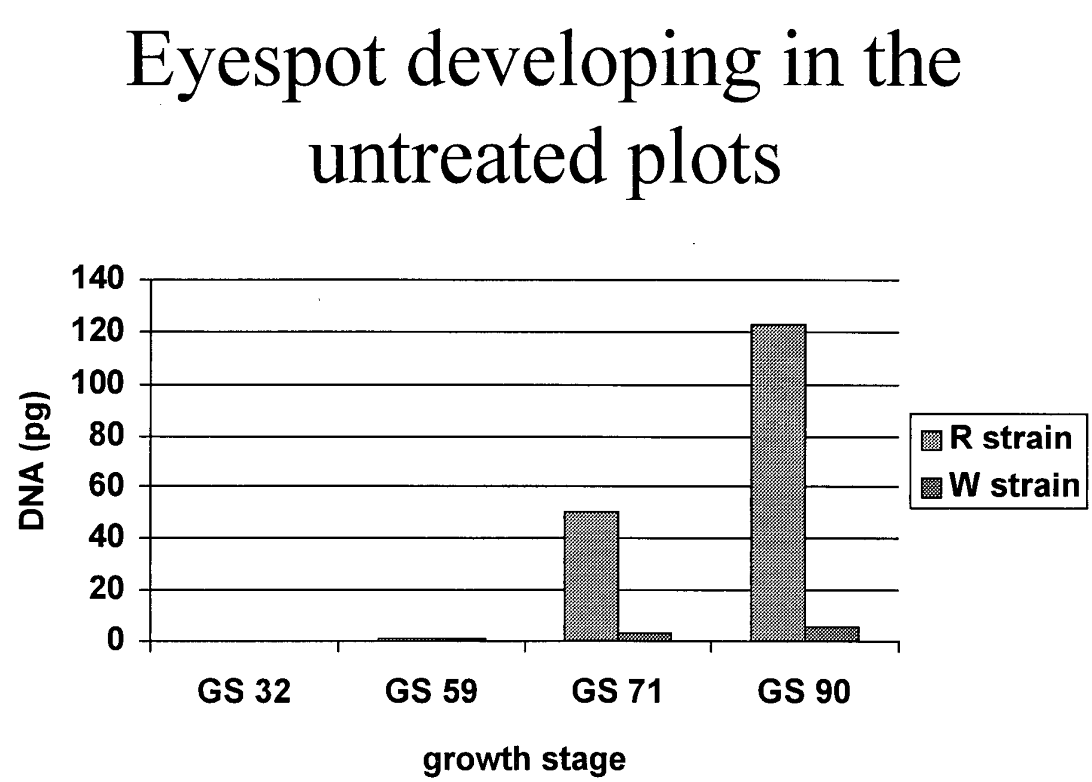
Fusarium

There was a positive association between visual eyespot levels and visual Fusarium levels at GS 71 ($r = 0.445$, $P < 0.001$) and GS 90 ($r = 0.685$, $P < 0.001$). This has been reported by other workers who have found *Microdochium nivale* and R strain eyespot are found associated more often than would be expected by chance (P. Nicholson, per. comm.), evidence that interactions do exist between the pathogens of the stem base.

PCR analysis

The PCR analysis allows the differentiation of the two eyespot strains that is not possible with visual assessments. Using the DNA probes the two strains were first detected at GS 59 in equal quantities. At the next assessment timings of GS 71 and GS 90 the R strain had increased rapidly to much higher levels than the W strain which remained at very low levels throughout the season. This is now thought to be typical of the situation throughout the UK where surveys have shown the R strain to be far more common at all but a very few sites than the W strain (Novartis Crop Protection Ltd, pers. com.).

Figure 4.



The variability of the PCR results meant that differences between treatments were seldom significant but several trends emerged over the season. In general the PCR assessments showed that treatment with either prochloraz or cyprodinil gave a reduction in fungal DNA levels measured at the next assessment. Previous work (HGCA Project 150) showed that eyespot levels always rose again after an initial reduction, and that the most successful treatments were those that could offer a sustained enough reduction in eyespot to allow for a yield improvement.

Figure 5 shows the levels of R strain DNA present at GS 90. Azoxystrobin did not reduce R strain levels compared to the untreated control. Prochloraz and cyprodinil did show a reduction in R strain DNA at this assessment timing. The split treatments or tank mixes showed larger reductions in fungal DNA. The treatment where prochloraz was applied at GS 30 and cyprodinil was applied at GS 32 (P+C) shows a larger reduction in R strain DNA, and this treatment was one of the highest yielding which could indicate more successful R strain control but this was not supported by the visual assessments which show the single full rates to be more successful.

Figure 5.

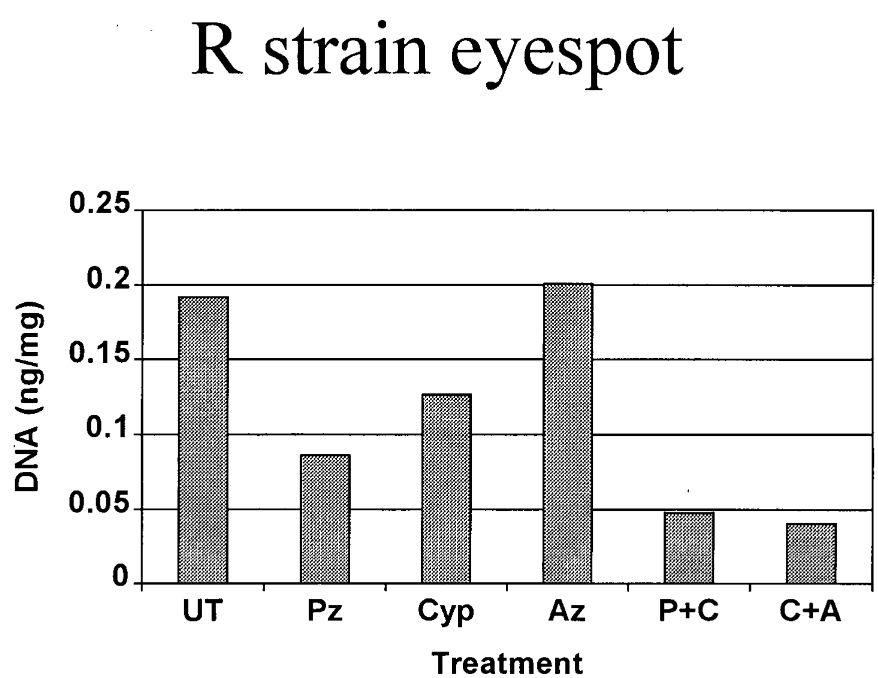
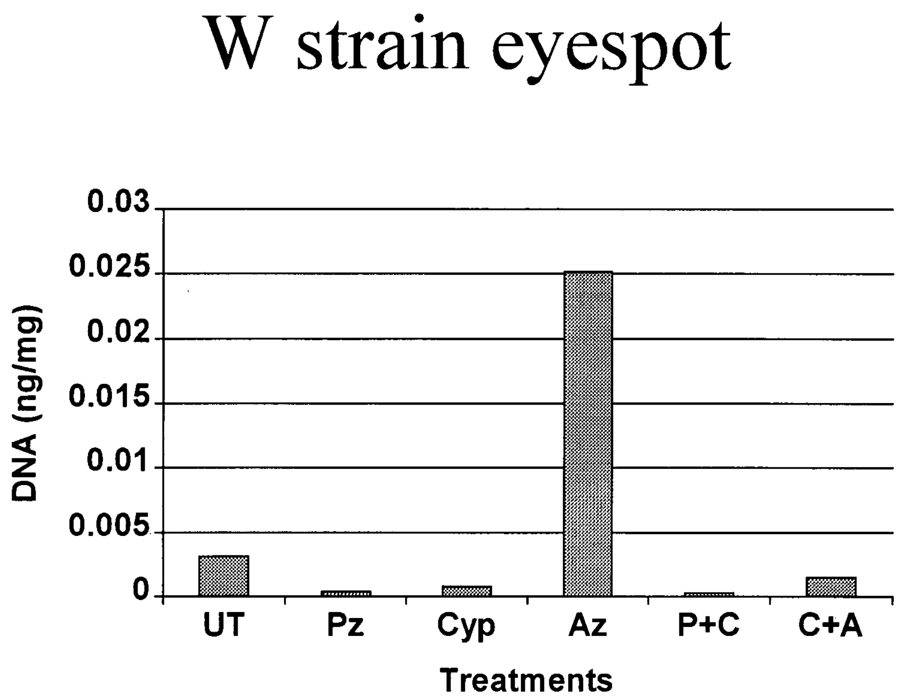


Figure 6 shows the levels of W type DNA at the end of the season. Again differences between treatments were seldom significant. Prochloraz and cyprodinil treatment did reduce W strain levels at GS 90. There were higher levels of W strain eyespot in the plots that were treated with azoxystrobin at GS 32, which probably shows the variability of the PCR technique rather than any significant treatment effect.

Figure 6.



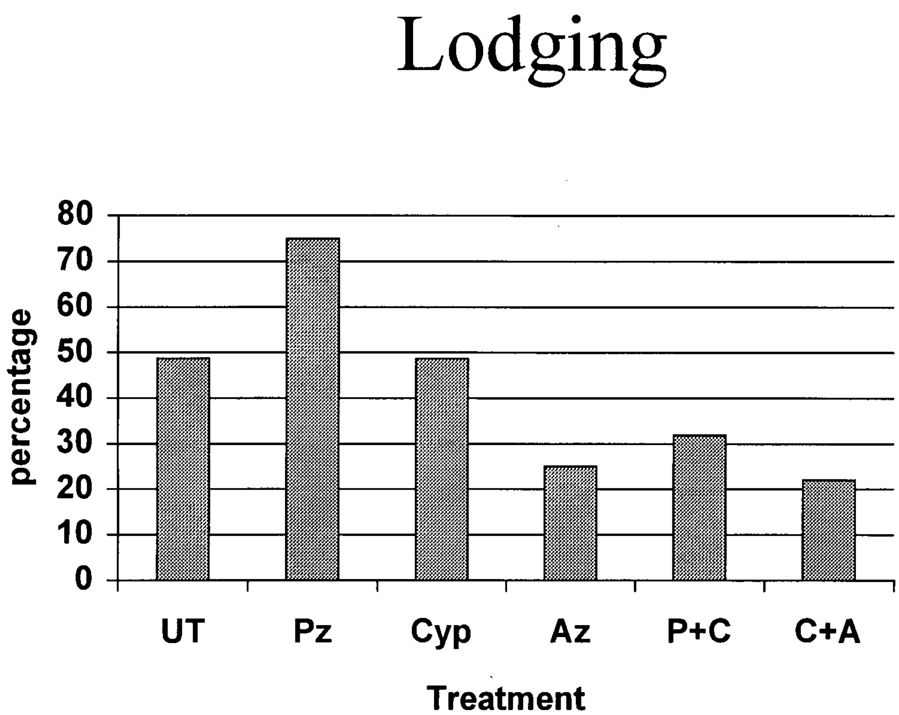
Again the treatment with prochloraz at GS 30 and cyprodinil at GS 32 had the lowest level of W strain eyespot as well as of R strain eyespot, compared to the other treatments.

PCR analysis is a useful tool to aid the interpretation of visual results, but because of the variability in the system results are best taken in conjunction with visual and other assessments rather than in isolation. One effect that has been documented in the past (HGCA Project Report 150) is that were eyespot lesions are very severe and plant tissue is dead or dying then fungal DNA also declines as the stem dies. This means that levels of DNA at the end of the season can be artificially low in plots where eyespot levels are high. This is typically seen with very low values of eyespot DNA in untreated plots where the stems are prematurely dead with eyespot lesions visible at severe levels, and clearly presents an inaccurate reflection of the eyespot in those plots. Limited resources and the expense of PCR analysis meant that analysis of all treatments was not made at GS 71, and had this been possible some of the variation seen at GS 90, just prior to harvest might have been avoided.

Lodging

There was significant levels of lodging prior to harvest in the trial. Prochloraz and cyprodinil as single full dose rate treatments did not reduce lodging compared to the untreated control, although as a split treatment with prochloraz applied at GS 30 and cyprodinil applied at GS 32 there was a reduction in lodging. Azoxystrobin gave reduced lodging as a single full dose rate treatment. Azoxystrobin tank mixed with cyprodinil applied at GS 32 gave the largest reduction in lodging (Figure 7).

Figure 7.



The season in which the trial took place was wet and as a consequence root development was shallow. The lodging that occurred was at the root rather than as a result of the stem lodging.. Prochloraz and cyprodinil have shown significant reductions in stem lodging (HGCA Project Report 150).

Thresholds

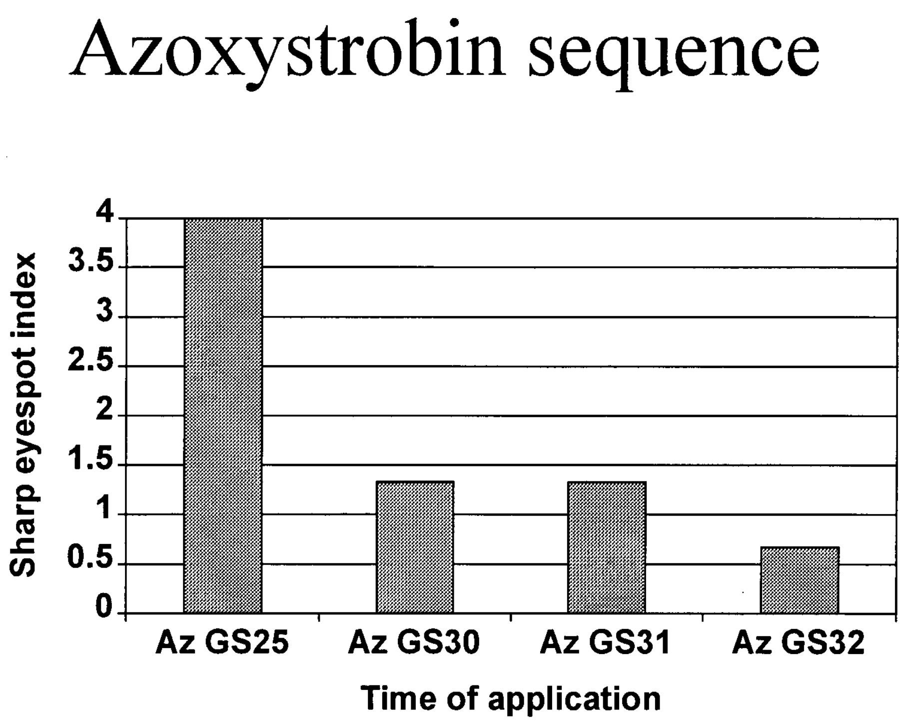
No eyespot was detected using PCR until GS 59. Visually at GS 30 - 31 levels of less than 10% incidence were recorded. This would not have been high enough to trigger the outdated 20% penetrating eyespot threshold used in the early 1980s. This bears out the findings of previous research that shows that the use of thresholds at stem extension are not helpful in predicting the severity of eyespot at harvest. HGCA Project Report 150 details previous work carried out at SAC which shows only a weak correlation between eyespot levels late in the season and those at harvest. There is some evidence to support the theory that the W strain may show a better correlation between levels at stem extension and those at harvest. In the early 80s the W strain was predominant in the UK, which maybe why thresholds used then used to be more successful in predicting which crops to treat. Recent surveys have shown that the R strain is now predominant throughout the UK (Novartis Crop Protection Ltd, pers. comm.)

In both this and previous projects (HGCA Project Report 150) total DNA at stem extension and at the end of the season do not correlate. This makes any attempt at determining a threshold at stem extension and before impossible, where a mixed R and W strain population is present, and it would appear that even early prediction of the W strain levels in an unmixed population would often be unsuccessful.

Azoxystrobin sequence

Within the treatments evaluated in the trial there was a sequence of azoxystrobin sprays applied at GS 25, 30, 31 and 32. Figure 8 shows the effect of timing on the sharp eyespot index at GS 71.

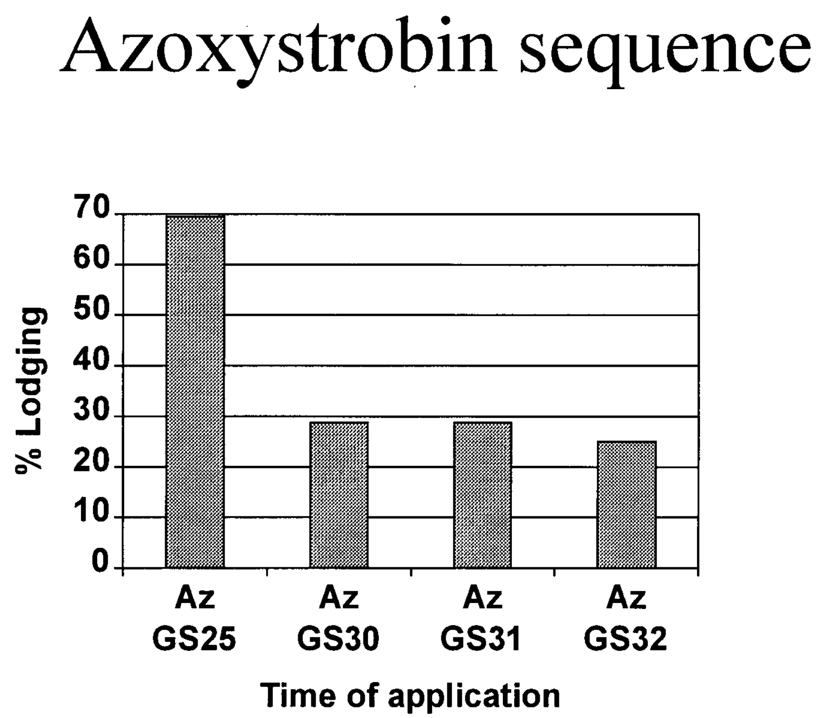
Figure 8. Azoxystrobin sequence and the effect on sharp eyespot index at GS 71



Sharp eyespot was best controlled by the azoxystrobin treatment at GS 32. The earlier the azoxystrobin was applied the poorer the level of control achieved.

Figure 9 shows the lodging reduction from azoxystrobin treatment. The trial season was wet and root establishment shallow and as a consequence the lodging seen at harvest was root rather than stem lodging.

Figure 9. Azoxystrobin sequence and the effect on lodging



The largest reduction in lodging was seen following the application of azoxystrobin at GS 32. The earlier treatments were progressively less effective. It is unknown why azoxystrobin has this effect on lodging.

Figure 10. Azoxystrobin sequence and the effect on yield

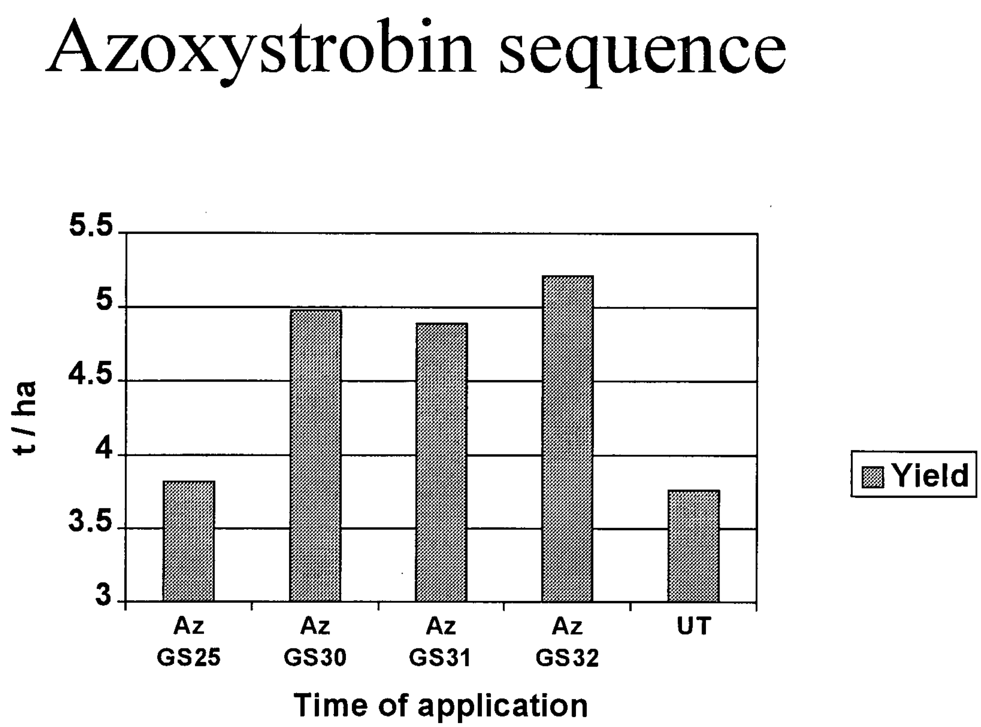


Figure 10 shows the effect of the azoxystrobin sprays on yield. The earlier the application the smaller the yield benefit. This yield benefit is most likely related to the control of foliar disease as well as the reduction in lodging rather than as a result of the sharp eyespot control, as levels of sharp eyespot in the trial were so low.

8. CONCLUSIONS

The most effective treatment for eyespot control of those evaluated in the trial was cyprodinil applied at GS 32 as a single full dose treatment. Splitting this dose of cyprodinil between GS 30 and GS 32 was not as effective as the single full rate application. Prochloraz applied at full dose rate at GS 25 also reduced the levels of eyespot assessed at the end of the season at GS 71. Splitting the prochloraz treatment between GS 25 and GS 31 did not improve eyespot control.

One aim of the work was to investigate if applying cyprodinil at it's optimum time of application for eyespot control of GS 32 as a split treatment with prochloraz also applied at it's optimum time of application (GS 25 - 30). Visually this treatment was not as successful at reducing eyespot as cyprodinil either as a single full dose application at GS 32 or as a split treatment as GS 30 and GS 32. The PCR analysis however shows lower levels of eyespot DNA in the prochloraz followed by cyprodinil treatment than in these other treatments, which may support the theory that better eyespot control could be achieved by using both products at their optimum timing than could be achieved using either one straight. The yield from this split treatment of prochloraz and cyprodinil was also higher. As discussed, too much emphasise should not be placed on the PCR results because of the variability inherent in this form of analysis but the result would support further work being done to confirm, or otherwise, the theory that splitting the treatments at their optimum timings would improve eyespot control.

Analysis of the eyespot DNA present using a PCR technique showed that the R strain was the dominant strain at the site and that the W strain of eyespot was only present at very low levels. This is now felt to be typical of the situation in the UK where most sites surveyed have either only the R strain or, if a mixed population, the R strain dominating. Only a very few sites have any significant level of the W strain. The W strain is more easily controlled with fungicides and tends to show symptoms earlier in the season. The R strain typically comes in later and increase rapidly, and this is thought to be the reason why thresholds for eyespot treatment no longer work. In this trial eyespot was not seen until the crop was heading with no eyespot present at the critical time for making an eyespot spray choice, of stem extension. This shows how a threshold approach to treating this crop would not have been successful, and also demonstrates how the fungicides worked well as protectants in reducing final eyespot levels in the plots.

Sharp eyespot levels in the trial were very low, but a reduction in sharp eyespot was seen following an application of azoxystrobin compared to earlier applications of this fungicide. Despite levels of sharp eyespot being so low there was a negative correlation between sharp eyespot and common eyespot levels at the end of the season. There was a small but not significant increase in sharp eyespot levels following the most successful treatments to control common eyespot and this increase was reduced by tank mixing azoxystrobin with the eyespot treatment.

This finding is important as it emphasises the importance of correctly identifying stem base pathogens as treatment for common eyespot if sharp eyespot was the problem would make a sharp eyespot infection worse. Where common eyespot is the dominant pathogen then at the moment a sharp eyespot treatment (azoxystrobin) is probably not merited as the cyprodinil plus azoxystrobin mix would still require the addition of a triazole fungicide for foliar disease protection at GS 32. The resultant three way mix required to target foliar diseases, common and sharp eyespot would be unlikely therefore to be cost effective.

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