YIELD BENEFIT FROM AUTUMN CONTROL OF APHIDS AND BARLEY YELLOW DWARF VIRUS ON WINTER BARLEY

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Summary The spread of barley yellow dwarf virus in autumn on early-sown barley can be reduced by controlling its aphid vectors with insecticides applied from late October to mid-November. The yield benefits are described from a series of field experiments in SW England between 1978 - 1980. These indicate the relationship y = 0.64 x, where y = % yield benefit from one spray of demeton-S-methyl and x = % tillers with BYDV symptoms in spring. Assuming a potential yield of 4.5 t/ha at £85/t, and a treatment cost of £9/ha, treatment would have a 50% probability of being cost effective when disease incidence is greater than 5%. In most parts of the UK such severe attacks are occasional, and a prediction system is needed.

Résumé La dissémination du virus de la Jaunisse Nanissante de l'Orge en automne sur les semis précoces d'orge peut être réduite en combattant ses vecteurs aphidiens au moyen des insecticides appliqués vers la fin octobre ou à la mi-novembre. Les augmentations de rendements obtenues dans une série d'essais au champ réalisés dans le sud-ouest de l'Angleterre entre 1978 et 1980 sont décrites. Elles donnent le rapport y = 0.64 x, ou y = % augmentation de rendement d'une pulvérisation à déméton-S-méthyl et x = % talles montrant des symptômes du VJNO au printemps. En admettant un rendement potential de 4.5 t/ha à £85/t, et une coûte de traitement de £9/ha, les traitments n'auraient une probabilité de 50% d'être rentables que si la fréquence éventuelle de la maladie était plus de 5%. Dans la plupart des régions du Royaume-Uni, de telles attaques sévères n'ont lieu que de temps en temps, et il faut un système de prévision.

INTRODUCTION

Several reports show that the autumn application of insecticides to control the aphid vectors of barley yellow dwarf virus (BYDV) on winter-sown barley can sometimes reduce virus infection and increase yield (Plumb, 1977; Horellou & Evans, 1979; Kendall & Smith, 1981a). However, the relationship between disease incidence and yield has not been well established in the UK, nor are the yield benefits from insecticide treatment defined in terms of a disease threshold above which control becomes economically worthwhile.

In this paper the yield benefits from the autumn control of BYDV on early-sown winter barley are described.

Table 1

% BYDV infected tillers and yield (t/ha) on untreated and insecticide treated plots at trial sites in SW England

Sowing date	cv	Unsprayed control % BYDV	Unsprayed control Yield	Insecticide sprayed % BYDV	Insecticide sprayed Yield	Yield increase over control
22/9/78	M.Otter	1.20	7.89	0.50*	8.54	+ .65
4/10/78	M.Otter	0.13	3.42	0.15	3.30	- .12
2/10/78	Igri	10.00	6.81	1.00	7.57*	+ .76
26/9/79	Sonja	0.30	8.13	0.06*	8.14	+ .01
26/9/79	Sonja	0.30	8.13	0.03*	8.45	+ .32
11/10/79	Sonja	0.35	5.98	0.18*	6.35*	+ .37
5/9/79	Athene	0	5.81	0	5.71	- .10
20/9/79	Athene	0	5.55	0	5.57	+ .02
4/10/79	Athene	0	5.45	0	5.58	+ .13
28/9/79	Igri	34.70	6.06	1.30*	6.93*	+ .87
16/10/79	Igri	0.24	7.53	0	6.92	- .61
13/9/79	Hoppel	0.33	6.45	0	6.29	- .16
2/10/79	Hoppel	0	6.36	0	6.61	+ .25
17/10/79	Hoppel	0	4.68	0	4.74	+ .06
21/9/79	Sonja	1.13	3.88	0.61	4.26	+ .38
2/10/79	Sonja	0.91	5.83	0.16	5.80	- .03
17/10/79	Sonja	0.03	6.63	0.03	7.02	+ .39
12/9/80	Sonja	71.40	3.85	18.20*	5.64*	+ 1.79
12/9/80	Sonja	71.40	3.85	4.60*	5.70*	+ 1.85
24/9/80	Sonja	18.30	4.88	2.50*	5.62*	+ .74
24/9/80	Sonja	18.30	4.88	0.70*	5.98*	+ 1.10
19/9/80	Igri	48.50	3.82	0.20*	4.85*	+ 1.03
19/9/80	Igri	48.50	3.82	0*	4.82*	+ 1.00
1/10/80	Igri	18.30	4.93	0.20*	5.46*	+ .53
1/10/80	Igri	18.30	4.93	0.10*	5.61*	+ .68
24/9/80	Sonja	8.10	4.19	0.80	4.41	+ .22
24/9/80	Sonja	8.10	4.19	0.20	4.66	+ .47

* significantly better than unsprayed (P = 0.05)

MATERIALS AND METHODS

The data were obtained from a series of spray timing trials done at Long Ashton Research Station and elsewhere in SW England between 1978 and 1980. All trials included 2 - 4 sowings of barley at intervals from early September to mid-November. The different sowings were drilled side by side in large unreplicated areas. All treatments were replicated within each sowing in a randomised block design. Demeton -S-methyl (244g a.i./ha in a volume of 225 l/ha at 2 bar pressure) was used as a standard treatment.

BYDV infection was assessed in late April or May by counting tillers showing symptoms in 1 m^2 sample areas, and all plots were taken to yield irrespective of disease incidence.

Data are included only from crops sown before mid-October because later sowings in our trials have had fewer than 0.1% plants infected with BYDV and have shown no significant yield response to insecticide treatment. Also, only results obtained from single sprays of demeton-S-methyl applied between late October and mid-November have been used, since this has been the optimum period for treatment, giving the best control of aphids and subsequent BYDV infection and the best yield responses (Kendall & Smith, 1980, 1981b).

RESULTS AND CONCLUSIONS

Table 1 compares BYDV infection and yield for untreated and insecticide treated plots. Treatment significantly increased yield on all trials where disease incidence on unsprayed plots resulted in > 10% tillers infected. In only one trial did a significant increase in yield occur with < 10% infection (Cultivar Sonja sown 11 Oct. 1979, Table 1).

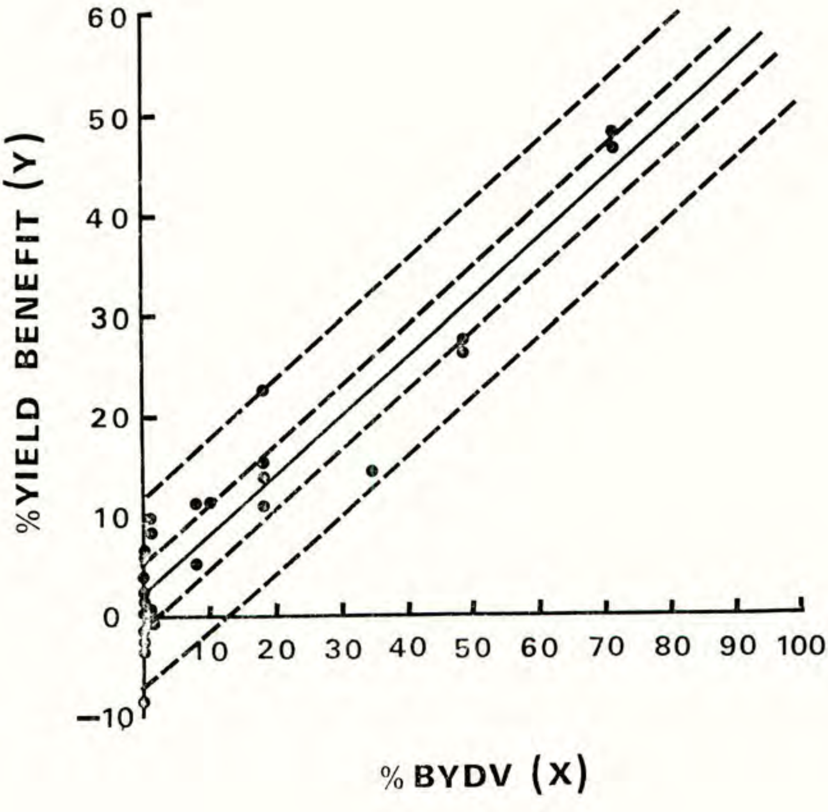
Yield increases calculated as a percentage of the unsprayed yield correlated well with the amount of BYDV on untreated plots (Fig. 1: $y = 0.59x + 1.96$ S.E.(y) $\pm$ 4.9, r = 0.941; where y is % yield benefit, and x is % tillers infected with BYDV). The intercept of this regression on the y-axis is not significantly different from zero (the origin), so for practical purposes the relationship shown in Fig. 1 can be recalculated and simplified, without significant loss of accuracy, to $y = 0.64x$ S.E. (y) $\pm$ 5.0 (r = 0.958).

This regression line can be used to estimate the economic value of insecticide treatment, and hence a disease threshold where spraying becomes worthwhile. Such thresholds also depend on yield potential, crop value, and treatment costs. For example, assuming a potential yield for winter barley of 4.5 t/ha, an average price for feed barley of £85/t, and insecticide cost, including application, of £9/ha, it follows that the minimum yield increase to offset the cost of insecticide treatment would be about 0.1 t/ha or 2.5%. Reference to Fig. 1 shows that a single insecticide treatment could be cost effective (i.e. $y \geq 2.5\%$) when crop infection is $\geq 1\%$, but the probability of achieving this remains below 50% until the incidence of BYDV is > 5%, and below the 95% confidence limit until > 18% of tillers become infected.

The incidence of BYDV varies greatly from year-to-year in most regions in the UK. For example, on winter barley crops at Long Ashton BYDV infection has only exceeded 1% in two years and 5% in one year since 1976 (Kendall & Smith, 1981c). This emphasises the need for a system to predict and monitor disease outbreaks, so that the needless use of insecticides can be avoided.

Figure 1

Percentage yield increase on insecticide-treated plots over unsprayed (y) in relation to % tillers infected with BYDV (x) on untreated plots. Regression line: $y = 0.59x + 1.96$ S.E.(y) $\pm$ 4.9 ($r = 0.941$); 50% and 95% confidence limits (broken lines).



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ASSESSMENT OF LOSSES CAUSED BY STEM-BASE AND ROOT DISEASES IN CEREALS

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Summary Symptoms and assessment methods for eyespot (*Pseudocercosporella herpotrichoides*), sharp eyespot (*Rhizoctonia cerealis*), *Fusarium* diseases and take-all (*Gaeumannomyces graminis* var. *tritici*) of cereals are described.

The relationship between yield loss and slight, moderate and severe eyespot and take-all in winter wheat has been established at several sites in 1974-80 by comparing the yields of a large number of individual tillers (for eyespot) or plants (for take-all) exhibiting a range of disease severities.

Slight infection by either disease was found to have no effect on yield. Equations relating percentage yield loss to the percentage of stems or roots with moderate and severe infection of eyespot and take-all have been used to estimate national crop losses from assessments carried out in ADAS winter wheat disease surveys from 1975-80.

Similar work is in progress for eyespot of winter barley and sharp eyespot and *Fusarium* diseases of winter wheat and winter barley.

Resumé On décrit les symptômes et les méthodes d'appréciation du piétin-verse (*Pseudocercosporella herpotrichoides*), de la rhizoctonie (*Rhizoctonia cerealis*), des fusarioses et du piétin échaudage (*Gaeumannomyces graminis*) des céréales.

Le rapport entre les pertes de rendement et le piétin-verse en forme légère, modérée et sévère ainsi que le piétin échaudage chez les céréales d'hiver a été constaté sur plusieurs terrains au cours de la période 1974-80 en comparant les rendements d'un grand nombre de talles individuelles (pour le piétin-verse) ou de plantes (pour le piétin échaudage) manifestant toute une gamme de gradations phytopathologiques.

On a constaté qu'une infection légère par l'une ou l'autre maladie n'avait aucune incidence sur les rendements. On a employé des équations rapportant les pertes de rendement exprimées en pourcentage au pourcentage des tiges ou des racines infectées d'une manière sévère et modérée par le piétin-verse et le piétin échaudage, pour l'estimation des pertes nationales des cultures à partir d'appréciations effectuées lors des enquêtes au sujet du blé d'hiver menées depuis 1975 jusqu'à 1980 par l'ADAS (le service de développement et de consultation agricoles).

Des études pareilles sont en cours relatives au piétin-verse chez l'orge d'hiver et à la rhizoctonie, ainsi qu'aux fusarioses, chez le blé d'hiver et l'orge d'hiver.

INTRODUCTION

Stem-base and root invading fungi are among the most important pathogens of winter cereals and the resulting diseases can be a constraint to the attainment of optimum yields and to the practice of continuous cereal cropping. Annual Agricultural, Development and Advisory Service surveys of cereal diseases to assess their relative importance were begun for spring barley in 1967 (King 1972, 1977b) and for winter wheat in 1970 (King, 1977a) but the latter did not include assessments of stem-base diseases until 1975. Take-all (*Gaeumannomyces graminis* var. *tritici)* was included in the winter wheat surveys in the years 1977-79.

In 1974, work began at this laboratory on diagnosis and assessment methods, and and on establishing the relationship between yield loss and severity of eyespot (*Pseudocercosporella herpotrichoides*), sharp eyespot (*Rhizoctonia cerealis*), *Fusarium* diseases and take-all of winter wheat. Equations relating disease severity to yield loss are required in order to estimate national crop losses from survey results and have been obtained for eyespot and take-all using single tiller and plant assessment methods respectively (Clarkson, 1981; Polley and Clarkson, 1980). Work is still in progress on sharp eyespot and *Fusarium* on winter wheat and all stem-base diseases of winter barley.

DIAGNOSIS

Standard techniques of visual observation, microscopy, isolation and culturing were employed to correlate the various disease symptoms with their causal pathogens; descriptions of symptoms are given below.

Eyespot

Oval, light brown lesions, usually with little distinction between the margin and the central area, can be found on leaf sheaths in winter and spring. The fungus penetrates successive leaf sheaths eventually forming the characteristic eyespots on the lower internodes of the culm. Lesions often have black stromatic pustules in their centre and, in cases of severe infection, may girdle and weaken the stem causing straggling or lodging in a crop. Prematurely ripened ears (whiteheads) containing shrivelled grain may result from eyespot infection. Infected stems usually contain grey mycelium of *P. herpotrichoides*.

Sharp Eyespot

On young plants, lesions of sharp eyespot are generally more pronounced than those of eyespot and have more prominent dark brown borders. The centre of lesions on the leaf sheaths may rot leaving a shredded area surrounded by a dark brown margin.

On mature plants, lesions are easily identified by their sharply defined dark brown borders and cream coloured central area. They are often asymmetric and coalesce into large multiple lesions girdling the stem and occurring up to a height of *c*. 40 cm above ground level (higher than eyespot lesions) although regular, elliptical lesions can occur on the lower internodes, particularly in cases of slight infection. Purplish-brown mycelium may occur in the centre of lesions but is not a good diagnostic feature unless examined microscopically. Paler forms of the dark-brown bordered lesions are often present on the leaf sheaths of infected shoots. Severe infection can cause lodging and premature ripening and brown sclerotia of *R. cerealis* may be present between the leaf sheath and stem (Pitt, 1964) or within the stem lumen (Clarkson and Griffin, 1977) where they may be accompanied by white sclerotial initials and white-grey mycelium.

Fusarium

During tillering, *Fusarium* infection is seen as a general brown discolouration or striping on the outer leaf sheaths at the base of the plant, sometimes developing into a true 'water-soaked' foot-rot.

The most common symptom encountered on older plants in surveys is nodal infection (*F. nivale)* in which the lowest nodes have a dark brown or purple discolouration, often totally girdling the stem, with yellowing of the associated leaf sheath. *F. nivale* has also been isolated from brown or black, streak-like, internodal lesions but other species, e.g. *F. culmorum, F. avenaceum* and *F. graminearum*, may sometimes be implicated. Oval lesions similar to eyespot but with a pink or orange discolouration are sometimes found and have yielded *F. culmorum* and/or *P. herpotrichoides*. Mature plants with a true brown foot rot have rarely been seen in survey samples.

Take-all

Take-all can attack the roots of cereal plants from the seedling stage onwards causing a characteristic root blackening. Severe infection reduces the size of the root system due to rotting and the crown roots may appear to be thickened with adhering soil. Stem bases of mature plants may have a matt or sooty black appearance due to the presence of black plate mycelium, revealed by stripping away the lowest leaf sheaths; the latter may contain perithecia of *G. graminis*.

Under adverse conditions for plant growth, the disease accentuates the effects of stress resulting in patches appearing in crops which are sparsely populated with stunted plants, often with prematurely ripened heads, and are prone to invasion by weeds. Whiteheads usually contain small, shrivelled grain and, particularly in a wet season, may show secondary infection by external sooty moulds (e.g. *Cladosporium* spp.). Lodging is not usually associated with take-all infection, although it can occur in rye.

Precise identification of the causal pathogen of root infection requires microscopic examination, culturing and pathogenicity testing in the laboratory to distinguish between varieties of *G. graminis* and other root invading fungi, e.g. *Phialophora* spp. (Clarkson and Polley, 1981).

ASSESSMENT

The following assessment keys have been used for stem-base and root diseases in surveys and yield loss studies at growth stages 75 to 92 (Zadoks *et al*, 1974).

Eyespot and Sharp Eyespot

Individual shoots are assessed according to the key used by P.R. Scott and T.W. Hollins, Plant Breeding Institute (pers. comm.):

0, healthy;

1, slight eyespot: one or more lesions girdling in total less than half the stem circumference OR one or more lesions on leaf sheath, not penetrating to stem;

2, moderate eyespot: one or more lesions girdling in total at least half the stem circumference;

3, severe eyespot: one or more lesions girdling in total at least half the stem circumference AND tissue softened so that lodging would readily occur.

Fusarium

Initially, individual shoots were assessed according to the degree of stem girdling by nodal and internodal lesions irrespective of causal species. This was found to be unsatisfactory because of associations between particular species and symptom types, and the following key, based solely on the incidence of symptom type, is now used:

a, healthy;

b, nodal infection: dark brown/purple discolouration on lower nodes, usually with yellowing of associated leaf sheath;

c, internodal infection: vertical, streak-like, brown or black lesions or discolouration on lowest internodes;

d, nodal and internodal infection: both types of symptom occurring on same shoot.

A further category may be necessary to accommodate a true *Fusarium* foot-rot.

Take-all

Washed roots of whole plants are assessed under water against a white background, using an illuminated magnifier, according to ADAS key no. 1.5.1 (Anon., 1976):

0, healthy;

1, slight: root lesions present on up to 25% of the root system;

2, moderate: lesions present on 25% to less than 75% of the root system;

3, severe: lesions present on 75% to 100% of the root system. Stem base is often blackened.

The moderate category may be subdivided as follows (*cf.* Shipton, 1972):

moderate I : lesions present on 25% to less than 50% of the root system;

moderate II : lesions present on 50% to less than 75% of the root system.

Several other methods for take-all assessment have been described which can be used for particular studies and have been reviewed by Clarkson and Polley (1981).

YIELD-LOSS ESTIMATION

The method employed in this work involves the comparison of the mean yield and yield component values of large numbers of single plants (for take-all) or tillers (for other diseases) in different disease assessment categories with healthy plant or tiller yield.

Samples of 500-1,000 plants or tillers are taken at random along diagonal transects of infected commercial crops carefully chosen to avoid complications due to the presence of moderate or severe levels of stem-base or root diseases not being assessed. Field trial plots may also be used.

In the work described below, suitable crops were located, mainly in East Anglia and south-east England. After sampling, the ears from each plant or individual tiller were threshed separately and the grain dried, weighed and counted. The mean percentage loss in grain yield per ear for each disease category was then calculated by comparison with the yield of healthy plants or tillers (Table 1).

Eyespot

Clarkson (1981) found that grain yield per ear of winter wheat was not reduced by slight eyespot but was reduced by 10% and 36% by moderate and severe eyespot respectively. The effect of disease on the components of yield was assessed independently: moderate and severe eyespot reduced grain number per ear by 8% and 29% respectively and 1000-grain weight by 5% and 15% respectively. Healthy tillers showed no compensation for yield loss in ears of eyespot-infected tillers on the same plant.

The yield-loss/disease severity equation is thus: $y = 0.1x_1 + 0.36x_2$, where y = percentage yield loss, x_1 = percentage of moderately infected tillers and x_2 = percentage of severely infected tillers.

Similar work is in progress on winter barley eyespot; results so far from two sites indicate that the range of yield losses encountered may be similar to that in winter wheat (J.D.S. Clarkson, unpubl.).

Sharp Eyespot

Single tiller assessments of sharp eyespot of winter wheat in 1980 (J.D.S. Clarkson and R.J. Cook, unpubl.) suggested that slight and moderate infection had only small effects on yield but that severe infection reduced yield per ear by *c*. 22%, with most of the effect being on grain number per ear rather than on 1000-grain weight. These data are only provisional and must be interpreted with caution as data from other years has yet to be included before a yield loss formula can be derived with confidence.

Fusarium

Similar studies on *Fusarium* infection of wheat stem bases have not yet clarified the associated yield losses, which have varied considerably between sites (J.D.S. Clarkson, unpubl.). Losses due to nodal infection have ranged from 0 to 15%, to internodal infection from 0 to 47% and to dual infection from 0 to 41%; the mean figures given in Table I must, therefore, be interpreted with caution. Work is still continuing on this disease and should probably include more detailed assessment of the severity of the various symptoms associated with infection by *Fusarium* spp.

Take-all

Polley and Clarkson (1980) found that slight take-all in winter wheat had no effect on yield per plant; moderate infection caused a reduction of 15.6% with more of the effect being on 1000-grain weight than on grain number per plant. Severe take-all reduced yield per plant by between 53.1% and 61.6%, the uncertainty here being caused by plants splitting into component tillers during root washing. Plants with severe take-all in stunted patches showed a significantly greater yield loss than severely affected plants in areas of apparently normal growth. This may have been due to a combination of an earlier attack within the patches and the consequent ease with which severely infected plants from these patches split up during root washing. For this reason, the yields of severely affected plants were adjusted on the assumption that all reduction in tiller number was caused by plants splitting during assessment.

Table 1

Mean percentage loss in grain yield per ear for three severity (or symptom) categories of stem-base and root diseases of cereal crops sampled between 1975 and 1980

Disease	Host	No. sites sampled	Disease category Slight	Moderate	Severe	Reference
Eyespot	WW	8	- 0.1	9.8**	36.1**	Clarkson (1981)
Eyespot*	WB	2	1.1	16.1	39.3	Clarkson (unpubl.)
Take-all[1]	WW	8	0.6	15.6**	53.1**	Polley & Clarkson (1980)
Sharp Eyespot*	WW	7	5.0	6.5	21.7	Clarkson & Cook (unpubl.)
			symptom type b	c	d	
Fusarium*[2]	WW	5	0.6	6.0	12.5	Clarkson (unpubl.)

WW = Winter wheat; WB = Winter barley.

* = Provisional data, investigations still in progress.

** = Significantly different from healthy plant or tiller yields at P=0.001 (provisional data not analysed).

1 = Data expressed as percentage yield loss per plant.

2 = Data expressed as percentage yield loss due to b) nodal, c) internodal, d) nodal + internodal infection respectively.

Cultivars used : Eyespot (WW):- Maris Hunstsman (3), Champlein (2), Mega, Hobbit, Flanders.

Eyespot (WB):- Sonja, Maris Otter.

Take-all (WW):- Maris Huntsman (2), Flanders (2), Armada (2) Mardler (2).

Sharp Eyespot (WW):- Mardler (2), Hobbit (2), Armada, Kinsman, Maris Huntsman.

Fusarium (WW):- Champlein, Flanders, Hobbit, Maris Huntsman, Mega.

Table 2

National mean percentage of winter wheat stems infected by stem-base and root diseases, ADAS surveys 1975-80

	Eyespot			Take-all*			Sharp Eyespot		*Fusarium* spp.
	Slight	Moderate	Severe	Slight	Moderate	Severe	Slight + Moderate	Severe	
1975	6.8	2.5	1.8	-	-	-	2.5	0.1	21.8
1976	3.3	1.1	0.4	-	-	-	8.0	0.3	17.0
1977	10.6	4.4	1.7	8.9	1.6	1.3	7.9	0.6	31.1
1978	12.1	5.0	2.0	29.8	8.1	2.4	6.7	0.5	-
1979	5.8	1.8	1.3	24.9	7.1	3.1	5.8	0.3	39.0
1980	5.6	1.8	0.2	-	-	-	15.2	2.7	28.0
Mean	7.4	2.8	1.2	21.2	5.6	2.3	7.7	0.75	27.4

\- Not surveyed

* Data expressed as percentage of plants infected.

The percentage yield loss, y, = 0.156 x_1 + 0.531 x_2, where x_1 is the percentage of moderately infected plants and x_2 is the percentage of severely infected plants, is therefore a minimum estimate.

CROP LOSSES

Although there are disadvantages to using single plant or tiller assessment methods (Polley and Clarkson, 1980; Clarkson, 1981), the range and magnitude of yield losses encountered using these techniques are comparable to those found by other workers using various methods for establishing different amounts of disease. Therefore, it seems reasonable to apply the yield loss/disease severity formulae derived from the work described above to the national disease incidence data for stem-base and root diseases in winter wheat recorded in ADAS surveys (Table 2) in order to obtain an estimate of national winter wheat crop losses (Table 3).

Table 3

Estimated national percentage yield losses in winter wheat due to eyespot and take-all, ADAS surveys 1975-80

	1975	1976	1977	1978	1979	1980	Mean
Eyespot	0.9	0.3	1.1	1.2	0.7	0.3	0.75
Take-all	-	-	0.9	2.6	2.8	-	2.1

\- Not surveyed

Estimated losses due to eyespot in winter wheat in 1975-80 ranged from 0.3% to 1.2% with a mean of 0.75% and were thus similar to those caused by *Septoria* diseases for the same period, were greater than losses due to yellow rust (*Puccinia striiformis*) or brown rust (*P. recondita*) but less than those due to mildew (*Erysiphe graminis* f.sp. *tritici*) (King, 1977a; J.E. King, unpubl.). Estimated losses due to take-all in winter wheat in 1977-79 ranged from 0.9% to 2.8% with a mean of 2.1% and were thus seemingly greater than those due to *Septoria* and the rust diseases and almost as high as losses due to mildew in the same years.

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THE USE OF SPRING BARLEY CULTIVAR MIXTURES AS A TECHNIQUE FOR THE CONTROL OF POWDERY MILDEW

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Summary Six spring barley cultivars were grown for two years as pure stands and all possible two-way and three-way mixture combinations. The mixtures generally outyielded their expected values and often the highest yielding component cultivar. This appeared to be largely due to disease control. Fungicide treatment of pure stands produced slightly higher yields than untreated mixtures, but with less consistency. The cost-benefit ratio was in favour of untreated mixtures in this situation.

Fungicide treatment of mixtures produced no extra advantage, partly because mixing and fungicide treatment provided a similar function, i.e. disease control, and partly because the cultivars used were moderately or highly resistant.

Strategies for integrating cultivar mixtures and fungicides are discussed to try to point towards a flexible and cheap system for providing consistently high-yielding crops that would reduce selection on the pathogen for host pathogenicity and fungicide insensitivity.

Six variétés d'orge ont été cultivées pendant deux ans à l'état pure, ainsi que tous les mélanges possible combinant deux et trois variétés. Le rendement des mélanges a généralement dépassé les valeurs attendues et il a souvent été supérieur à celui du composant de plus fort rendement. Il est apparu que le contrôle des maladies en est largement responsable. Les variétés pures ayant subi un traitement fongicide ont un rendement légèrement supérieur mais moins régulier que celui des mélanges non traités. La comparaison des prix de revient a été en faveur mélanges non traités, dans la situation décrite.

Le traitement fongicide des mélanges n'apporte aucun avantage supplémentaire en partie car le mélange et le traitement fongicide assure une function similaire, le contrôle des maladies, et en partie parceque les cultivars utilisés sont moyennement à fortement resistants.

Les stratégies pour l'utilisation conjointe des mélanges de variétés et des fongicides sont discutées afin d'essayer de faire resortir un système souple et peu couteux pour assurer un rendement élevé avec régularité et qui reduirait la sélection des pathogènes pour leur virulence vis à vis des plantes hôtes et pour l'insensibilité aux fongicides.

INTRODUCTION

Wolfe and Barrett, (1980 and in press) and Wolfe et al. (1981) pointed out some advantages of mixing barley cultivars with different resistance genes for the control of powdery mildew (*Erysiphe graminis* f. sp. *hordei*) and other diseases. For example, the often large degree of disease control obtained with mixtures correlates well with increased yield relative to the components grown alone. Secondly, the simplicity of the system allows for the rapid introduction of changes in mixture composition as new, higher yielding and more resistant varieties become available, and for designing mixtures for particular areas or purposes. The consequent provision of diversity between mixtures is an essential requirement for increasing the likelihood that the mixtures will remain effective during their commercial life. Thirdly, the low variability of mixture yields reduces the problem of predicting performance of particular cultivars for use in a particular place in a future season. Variations of this system are now being developed on a large scale in the UK, Denmark and the Netherlands; experimental development is in progress in other countries, particularly in eastern Europe.

Similar considerations for improving the durability of fungicides led Wolfe (1981) to consider various ways of integrating cultivar and fungicide use to achieve adequate disease control and improved durability of both host resistance and fungicide, all at low cost. This paper reviews preliminary results from an experiment with six spring barley cultivars to determine their potential for use in mixtures with, or without, conventional fungicide treatment, or a partial treatment to provide integrated control.

METHODS AND MATERIALS

The six spring barley cultivars, Atem, Claret, Egmont, Goldmarker, Simon and Triumph, were the highest yielding cultivars on the National Institute of Agricultural Botany Recommended List for 1980: they differ in some of the mildew resistance genes that they carry, although there are a number of common genes. Together with all of their 15 possible two-way combinations and 20 possible three-way combinations, they were grown in standard 4.1m x 1.2m plots at the Plant Breeding Institute in 1980 and 1981. In 1980, additional plots were treated with half-rate fluotrimazole (750ml product per ha), followed by full-rate tridemorph (700ml product per ha), for control of powdery mildew; in 1981, this treatment was changed to full-rate triadimenol seed treatment (150g product per 100kg seed). In 1981, in an additional treatment, all seed lots that were sown comprised a mixture of one third of the seed treated with triadimenol at normal field rate, mixed with two thirds of untreated seed. All the plots were surrounded by a 1.2m guard of spring rye, to reduce spore transfer between plots, in both years.

Disease assessments were made on a 0 (no disease) to 9 (complete disease cover) scale on the whole plot. The values obtained were squared to provide approximate percentage disease cover. Powdery mildew was common in both years, although none of the six varieties was highly susceptible; yellow rust (*Puccinia striiformis*) was severe in 1981, but only on the cultivar Simon. Yields were obtained from whole plots, using a small plot combine harvester.

RESULTS

a) Untreated mixtures

From the overall means (Table 1) the untreated three-way mixtures provided a yield response which was both high and stable when compared with two-way mixtures and, particularly, with the single cultivars. The remarkable overall performance of the three-way mixtures can be further illustrated by the distribution of the mixture yields relative to those of the components. Out of the total of 40 comparisons of three-way mixtures with their components over the two years, 21 exceeded the highest yielding component, only five were between the lowest and mid component value, and none yielded less than the lowest yielding component. Of the 30 two-way mixture comparisons, 11 exceeded the higher yielding component, and only two yielded less than the lower yielding component.

Table 1
Mean yields (t/ha) and variances of six spring barley cultivars grown as pure stands, all possible 2-component and all possible 3-component mixtures in 1980 and 1981. No fungicide treatment

	1980		1981	
Composition	Mean yield	Variance	Mean yield	Variance
Pure stands	6.7	0.9	6.4	0.4
2-way mixtures	7.0	0.4	6.8	0.2
3-way mixtures	7.1	0.2	7.1	0.3

In Table 2, yields and mildew infection, averaged for the two years, are compared for the six individual cultivars and for each group of 10 three-way mixtures to which a particular cultivar contributes. For example, in the first line, the average yield of pure stands of Triumph over the two years was 7.5 t/ha, whereas that of the 10 three-way mixtures that contained Triumph was 7.3 t/ha. Triumph was the only cultivar whose mean yield exceeded that of the mixtures containing it (though only by 3%). Indeed, all mixtures outyielded the remaining cultivars grown as pure stands, again underlining the consistent high performance of mixtures compared with single cultivars.

Table 2
Mean yields (t/ha) over 1980 and 1981 of six spring barley cultivars and the groups of 10 3-way mixtures to which each was common, together with the maximum average mildew infection (no fungicide treatment)

	Pure stands		3-way mixtures	
Cultivar	Yields	Mildew	Yields	Mildew
Triumph	7.5	0.8	7.3	2.1
Egmont	6.8	11.8	7.2	4.1
Claret	6.7	2.9	7.0	2.7
Atem	6.7	0.1	7.1	2.2
Goldmarker	5.8	9.8	7.0	3.3
Simon*	5.7	4.1	6.9	2.5
Overall mean	6.5	4.9	7.1	2.8
% mix/pure			109	57

*severely infected by yellow rust in 1981

From Table 2, the mixtures provided an overall reduction in mildew infection. This did not occur in the Atem and Triumph groups since more than half of those mixture components were more susceptible than Atem or Triumph. It appears (Table 2) that the yield increases due to mixing are not closely correlated with the reduction in powdery mildew infection. This is because yield performance in mixtures is also a function of yield potential in pure stands, which is evident from the close correlation between the two columns of yield data in Table 2. For example, Egmont mixtures, although considerably less infected by mildew than Egmont itself, did not show a dramatic improvement in yield because most of the other component cultivars in these mixtures had a lower yield potential than Egmont itself. Mixtures involving Simon performed consistently and remarkably well in both years showing that the overwhelming effect of the yellow rust infection in 1981 on this cultivar was also considerably reduced when it was protected in mixtures.

b) Fungicide treated mixtures: normal treatment rates

A comparison of the yields of pure stands between Tables 3 and 2 shows that, with the exception of Atem, all cultivars responded to fungicide application for mildew control. The yield increase of Simon treated with fungicide was relatively small, because the yellow rust infection was less well controlled than the mildew infection by the fungicide used. The large response of Triumph was surprising since there was little mildew sporulation on untreated plots of this cultivar. However, the resistance reaction of Triumph consists of large necrotic lesions on the leaves, which were much less evident on fungicide-treated plots. This suggests that the reaction is energy dependent (see Smedegaard-Petersen, 1980) and that, despite the guard rows, there may have been considerable local transfer of spores between plots. If so, this suggests that on a large scale, mixture performance would be relatively better in terms of disease control and yield, than in the experimental system described.

Table 3
Mean yields (t/ha) over 1980 and 1981 of six spring barley cultivars and the groups of 5 2-way mixtures and 10 3-way mixtures to which each is common: all fungicide-treated for mildew control

Cultivar	Pure stands	2-way mixtures	3-way mixtures
Triumph	8.5	7.7	7.5
Egmont	7.7	7.4	7.4
Claret	7.3	7.2	7.2
Atem	6.7	7.1	7.3
Goldmarker	6.9	7.0	7.2
Simon	6.2	7.2	7.3
Mean	7.2	7.3	7.3
Variance	0.6	0.2	0.2

Fungicide treatment of the mixtures produced, overall, a slight increase in yield, insufficient to pay for the cost of treatment, although again, the yield variance was less than that between single cultivars. The advantage was greatest for mixtures involving Atem and Simon, but did not occur for Triumph mixtures, because of dilution by other cultivars of the high yield potential of fungicide-treated Triumph.

c) Fungicide treated mixtures: partial treatments

A comparison of yields of pure cultivars shows that, with the exception of Simon, they all yielded similarly well with the partial fungicide treatment (Table 4) as with fungicide treatment at the normal rate (Table 3). The lack of improvement with Simon probably occurred because of the relatively late development of the severe yellow rust infection. At this stage, the amount of fungicide per unit leaf area was probably declining, and the incidence of infection on the untreated plants was sufficient to overcome the remaining protection on the small proportion of treated plants.

Table 4

Mean yields (t/ha) in 1981 of six spring barley cultivars and the groups of 5 2-way mixtures and 10 3-way mixtures to which each is common: 1/3 of all seed sown was treated at the normal field rate with triadimenol, the remainder was untreated

Cultivar	Pure stands	2-way mixtures	3-way mixtures
Triumph	8.2	7.3	6.9
Egmont	7.6	7.4	7.1
Claret	7.7	7.4	7.0
Atem	6.8	7.4	7.2
Goldmarker	7.2	7.0	7.0
Simon*	5.7	6.6	6.8
Mean	7.2	7.2	7.0
Variance	0.8	0.4	0.4

*severely affected by yellow rust

The outstanding performance of partially treated pure plots compared with those treated conventionally may be because these plots were themselves acting as mixtures of one-third highly resistant (i.e. treated) and two-thirds partially resistant (i.e. untreated) plants. This assumes that fungicide-insensitive forms of the pathogen were not being selected to any great extent on the treated plants, since if they had occurred, they would have been able to grow on both untreated and treated plants. From other evidence, from this trial and elsewhere, it seems likely that forms of the mildew pathogen with insensitivity to triadimenol combined with pathogenicity for each of the cultivars except Goldmarker, is likely to be rare (Fletcher and Wolfe, this volume).

If this hypothesis is correct, then it is not surprising that the cultivar mixtures with partial fungicide treatment did not yield more than the pure stands with partial treatment, although they did show greater consistency, evident from the variances. The relatively poor performance of the three-way mixtures with partial treatment is largely due to the group of Triumph mixtures. It is possible that in these mixtures, large numbers of spores non-pathogenic on Triumph were liberated, so that the yield of the highest yielding component, that is Triumph itself, was depressed by the operation of the resistance reaction.

DISCUSSION

The results obtained, together with those described by Wolfe (1981) suggest that different strategies of integrating cultivar mixtures with fungicides may be required for different cultivar combinations. Such strategies need to be flexible in order to combine the needs of short-term economic crop production with reduced selection on the pathogen to enhance the durability of the cultivar and fungicide components. The use of mixtures of cultivars that are moderately or highly resistant under severe disease pressure, and of others that are moderately or highly resistant under low disease pressure, and which do not therefore require fungicide treatment, can reduce the total exposure of fungicides to the pathogen. For other mixtures, different strategies are required. The three major strategies can be generalised as follows:

a) Mixtures of largely resistant cultivars

Since mixtures of resistant cultivars appear to be highly cost effective in terms of mildew control and yield stability, they may be generally preferred to cultivation of either single cultivars or mixtures treated with fungicide. There may be a case, however, for considering among this group, two-way mixtures with partial fungicide treatment, since these might be useful in selecting matching cultivar components for specific purposes.

In retrospect, it may be argued that fungicide treatment of a single cultivar such as Triumph would have provided the best profit margin since it provided the highest overall yield by a considerable margin. It outyielded fungicide-treated mixtures involving Triumph because two-thirds of the components of that group had lower yield potential than Triumph. However, because of the popularity and increased monoculture of this cultivar, the effectiveness of its mildew resistance may be starting to decline, so that it could no longer be safe to continue to predict such outstanding performance. The use of Triumph as a mixture component with other high-yielding resistant cultivars may be a more reliable strategy for the future.

b) Mixtures of largely susceptible cultivars

The system of partial treatment suggested may be more effective generally when applied to mixtures of cultivars whose susceptibility is such that mixing alone cannot slow down the epidemic sufficiently to eliminate the major effects of disease. Such an example is provided by Wolfe (1981). However, selection of the pathogen for fungicide insensitivity would be further reduced if, instead of applying the fungicide to a random proportion of the mixed seed, it was applied to one component cultivar in one season, and to different components in subsequent seasons.

c) Mixtures with single susceptible components

The third general possibility is for mixtures which contain single or few susceptible components. In such cases, the best strategy may be to treat only the susceptible component(s) so that the size of the pathogen population is markedly reduced.

Because of the vulnerability to selection within powdery mildew populations of both cultivar components and fungicides when they become popular and widely used, it is important that urgent consideration should be given to larger scale application of the strategies suggested above, in order to try to reduce such vulnerability while maintaining consistent high levels of yield at low cost.

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NOTES

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PREDICTION OF THE ECONOMIC NEED FOR A FUNGICIDE PROGRAMME ON WINTER WHEAT AND THE EFFECTS OF THIS PROGRAMME ON SOME PARAMETERS OF GRAIN QUALITY

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Summary A scheme utilising nine agronomic factors to predict the cost-effective use of a fungicide programme involving triadimefon/carbendazim followed by triadimefon/captafol for winter wheat based on 84 trials results over 3 years, is described and its accuracy evaluated. The effects of this programme on various grain quality parameters over a range of cultivars at 3 sites are given. Grain size, thousand grain weight, specific weight, and milling quality were all improved by treatments. Hagberg falling number was unaffected and in some instances grain protein was decreased. The effects of these quality variations by treatment on acceptability for the end use are discussed.

Résume Le but du projet examiné ci-après est d'étudier, à l'aide de neuf facteurs agronomiques, la rentabilité d'un programme de traitement fongicide employant du triadimefon/carbendazime suivi de triadimefon/captafol. Le projet est basé sur les résultats de 84 essais obtenus sur blé d'hiver durant 3 années. Sont rapportés les effets de ce programme sur les qualités de grain de différentes variétés implantées sur 3 zones. Grosseur du grain, poids de mille grains, poids spécifique et qualité meunière ont été améliorés par les traitements. Le nombre décroissant de Hagberg ('Hagberg falling number') n'a pas varié et dans certains cas, les protéines du grain ont diminués. Les effets de ces variations dans la qualité du grain par les traitements sont examinés en vue de l'acceptation du projet.

INTRODUCTION

The high value of winter wheat in recent years has created major changes in production techniques. The intensive use of technology has increased yield to above 10 tonnes/ha. High yielding production systems provide a strong incentive to protect crops against losses from pests and diseases. Most important cereal diseases can be effectively controlled with currently available fungicides at relatively low cost. However, the routine prophylactic use of fungicides to maximise or at least maintain output is in question with regard to the need to maintain profitability, and to rationalise pesticide usage (Jenkins and Lescar 1980). In addition there are available in the U.K. disease monitoring and forecasting systems to help determine, by means of disease thresholds, the necessity for fungicide usage. The latter systems are particularly well developed with regard to barley disease, especially barley mildew (*Erisyphe graminis*), but are less well defined for wheat diseases such as mildew (Erisyphe graminis), rusts (Puccinia spp), eyespot (Pseudocercosporella) herpotrichoides) and Septoria spp and the interaction of several of these diseases together in a crop. In northern France, Lescar (1980) concluded that more than 50% of routine fungicide applications in 1978 were not economically worthwhile. The ITCF has therefore, developed a risk assessment scheme to forecast the disease risk and predict the economic benefit of fungicide usage on wheat (Lescar 1981; Maumené 1981). The objective of the work reported here was to test a modified version of the fungicide prediction scheme used in France, on trials carried out with a specific fungicide programme on wheat in the U.K. during the last 3 years and to evaluate the usefulness of such a scheme for U.K. conditions.

The aim of the cultivar/fungicide programme trials was to study the interaction between soil, cultivar and a fungicide programme when grown in large plots. They were primarily designed to demonstrate these relationships to farmers and investigate their effects on yield and grain quality. Improvements in grain quality could be of additional benefit in economic terms whereas with the prediction scheme yield is taken as the only criterion for judging the value of a crop protection treatment.

METHODS AND MATERIALS

1) Prediction Scheme

A risk assessment table (Table 1) was devised for the prediction scheme, based on the agronomic, cultural and geographic factors in the ITCF scheme. In addition to the scores attributed to previous crop, sowing date, crop density and susceptibility of soil to drought, some other factors were included to maintain the theoretical maximum score total at 15 points. A score was given to the incidence of wheat diseases for a locality, or even a specific field, according to local knowledge and experience. Fertilizer usage, particularly nitrogen, was included as evidence exists relating the response to fungicide usage with increased nitrogen application (Harris 1979; Stevens and Nuttall 1980). Cultivars were scored using a system based upon disease susceptibility ratings given by NIAB (NIAB 1978, 1979, 1980 and 1981) and correlating these ratings with response to routine fungicide treatments in previous trials (Priestley 1980; Priestley and Bayles 1981). Soil type was additionally classified according to the land use capability grading (Ordnance Survey). The fixed score constant of 7 was added to the final total in accordance with the French system. A threshold score of 10 points was then used; if the rating achieved a score of 10 or more, routine treatment was predicted to be economically justified; a score of less than 10 required crop monitoring and treatment according to disease thresholds.

A total of 84 results from trials carried out in the U.K. between 1978 - '80 was examined, involving the use of the following two-spray fungicide programme compared with an untreated control:- 125g ai triadimefon + 250g ai carbendazim as a w.p. (Bayleton BM®) per hectare applied @ GS 30 - 32 (Zadoks et al 1974) followed by 125g triadimefon + 1300g captafol as a w.p. (Bayleton CF®) per hectare applied @ GS 39 - 59. Of these 84 results 54 came from Bayer U.K. Ltd., of which 28 are also reported in further detail under the cultivar/fungicide interaction section of this paper. The remaining results examined were from the independent sources of MAFF (27), Norfolk Agricultural Station (2) and Kenneth Wilson Ltd. (1). The results from Bayer U.K. trials were sited at 24 locations and the independent trials at 15.

Using Table 1, a prediction score was obtained and based on the costs given below, this was then compared with the yield response to the fungicide treatment achieved and assessed for cost-efficiency. The break-even was determined by obtaining the increased return from the yield response achieved and subtracting the chemical cost, cost of application and 2% of untreated yield level, an arbitrary measure of wheeling damage incurred. Over the three year period, the following costs were used for 1978/'79 and 1980 respectively - wheat £95 and £100/t; triadimefon/carbendazim £16.02 and £19.07/ha; triadimefon/captafol £17.52 and £22.00/ha and application £3.70 and £3.70/ha.

Table 1

Risk assessment table for winter wheat to advise the need for routine fungicide programmes of triadimefon/carbendazim followed by triadimefon /captafol

Previous crop	Risk score
Peas, potatoes, oilseed rape	+3
Wheat, grass	+2
Sugar beet, barley	+1
Maize	0
Cultivars	
Hobbit, Sentry	+3
Armada, Brigand, Copain / Hustler, Mardler, Virtue	+2
Aquila, Atou, Maris Freeman / Kinsman, Rapier	+1
Bounty, Bouquet, Flanders / Flinor, Kador, Norman, Prince	0
Maris Huntsman	-1
Avalon	-2
Sowing date	
Before 15 October	+2
15 - 31 October	+1
1 - 24 November	-1
After 25 November	-2
Cultivations	
Plough	+1
Tines/disc	0
Shallow	-1

Locality disease risk	Risk score
High	+1
Moderate	0
Low	-1
Land classification grade	
1	+2
2	+1
3	0
4	-1
Susceptibility of soil to drought	
High	+1
Medium	0
Low	-1
Fertilizer (N) usage	
High > 150kg/ha	+1
Medium 100 - 150kg/ha	0
Low < 100kg/ha	-1
Crop density	
High (> 250 plants or 550 tillers/m^2)	+1
Normal/low	-1
Add fixed score	+7
Total =	

2) Cultivar/fungicide interaction trials

In the trials carried out at Feltwell, Norfolk 1979 and 1980 on organic soils and at Parham, Suffolk 1980 on a mineral soil the treatments (F+) were applied by grower machines at the following application dates:-

	Feltwell '79	Feltwell '80	Parham '80
triadimefon + carbendazim	17 5 '79	14 4 '80	23 4 '80 + chlormequat/choline chloride
triadimefon + captafol	26 6 '79 + pirimicarb	26 6 '80 + pirimicarb	12 6 '80 + pirimicarb

These treatments were compared with control (Fo) which received no fungicide, aphicides or growth regulators.

The formulations and rates of use of the fungicides were triadimefon 125g + carbendazim 250g/ha and triadimefon 125g + captafol 1300g/ha. The cultivars treated are referred to in Table 3. The addition of growth regulator and aphicide at some treatments could have influenced the results and are taken into account in the financial calculations in Table 6.

At Feltwell 1980 the cultivar Armada inadvertently received an additional triadimefon + captafol treatment on 12 6 '80. Plots were unreplicated and greater than 200m^2 in size. Yields were taken using a Wintersteiger small plot combine at Feltwell and a commercial combine at Parham using an in-trailer weighing device.

Grain samples were taken at harvest for quality assessments. Hagberg, protein and endosperm texture tests were conducted by the millers RHM (Agriculture) Ltd.

The means of treated and untreated have been compared using a paired sample t test. This assumes that the samples are taken from populations having a normal distribution.

RESULTS

1) Prediction Scheme

On examining the 84 results, 68 were predicted to require the two spray programme having been rated at 10 points, or above while 16 rated less than 10 points and so would have been predicted to require disease monitoring and a 'wait and see' approach to fungicide application. Table 2 indicates the results in terms of the cost-efficacy and the breakdown into those trials carried out by Bayer U.K. Ltd. and those from independent sources. Fig. 1 shows the spread of individual results when the prediction score is related to the degree of yield response.

The overall accuracy of the prediction score was 90% although the scheme, because it used retrospective trials site evidence rather than commercial usage experience, was weighted heavily (4:1) in favour of high prediction scores and economic response. With the relatively fewer cases predicting a non cost-effective response from routine treatment, the accuracy was 94%.

Table 2

Prediction of the economic need for a fungicide programme on winter wheat
Analysis of trials results 1978 - '80

Prediction score category	Number of Predictions			
	Total in each category	Correct	Incorrect	% Accuracy
Bayer results				
10+	46	44	2	96%
<10	8	7	1	88%
TOTAL	54	51	3	94%
Independent results				
10+	22	17	5	77%
<10	8	8	0	100%
TOTAL	30	25	5	83%
Bayer and Independent results				
10+	68	61	7	90%
<10	16	15	1	94%
TOTAL	84	76	8	91%

2) Cultivar/fungicide interaction trials

Disease At Feltwell '79 mildew was the major disease which occurred throughout the season at high levels from the spring onwards. At Feltwell '80 mildew occurred in the spring but did not develop to high levels late in the season, however ear diseases such as *Septoria nodorum* and *Botrytis/Alternaria* were prevalent. The crops at Parham '80 did not suffer unduly from early disease but late season diseases such as brown rust (*Puccinia recondita*) occurred on the susceptible varieties and there were marked improvements in green leaf areas from treatment.

Yield At Feltwell '79 not all varieties were taken to yield because of crop lodging and or/resultant bird damage. The results from the three sites are given in Table 3 having been corrected to 16% moisture content.

Fig 1. Analysis of Prediction scores in relation to economic response to fungicide treatment

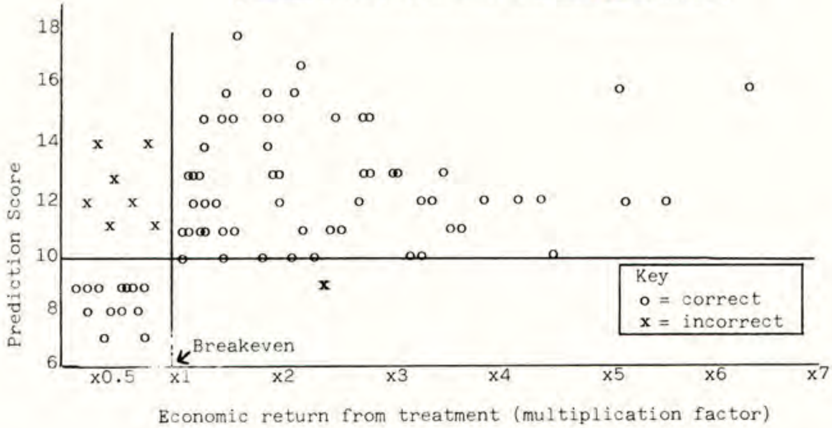

Table 3

Yield and yield increment in t/ha on the cultivar/fungicide interaction trials

Cultivar	Feltwell '79		Feltwell '80		Parham '80	
	Fo	F+	Fo	F+	Fo	F+
Aquila	N/A		–		–	
Armada	5.1	+1.8	4.5	+3.1	7.2	+1.6
Avalon	–		5.1	+1.5	8.3	+0.9
Bounty	–		4.1	+2.0	8.0	+1.3
Bouquet	–		–		7.0	+1.8
Brigand	–		4.0	+2.4	8.5	+1.9
Copain	–		–		7.5	+1.2
Flanders	N/A		4.7	+1.5	7.4	+2.0
Hobbit	N/A		–		8.8	+1.3
Maris Huntsman	N/A		5.0	+1.4	7.2	+2.5
Hustler	2.6	+2.7	–		–	
Kador	3.6	+2.3	6.5	+1.1	7.6	+1.8
Kinsman	3.0	+1.8	–		–	
Mardler	3.0	+1.6	3.2	+2.4	9.5	+1.3
Pageant	–		4.0	+1.9	–	
Prince	–		5.1	+1.3	7.2	+1.2
Rapier	N/A		–		–	
Sentry	–		–		8.1	+1.0
Mean	3.6	+2.00**	4.6	+1.9**	7.9	+1.5**
% increase		56		41		19

N/A = not assessed for yield

– = cultivar not included in this trial

** = significant difference between Fo and F+ at p = 0.01

Fo = Untreated control

F+ = crop protection including the fungicide programme

Grain quality Treatment increased both the percentage of grain being retained on a 2.8mm sieve and thousand grain weight and these increases varied according to site, season and cultivar.

Specific weights were improved with treatment by a relatively small amount with the mean % increased between sites varying from 2 to 9%. However these increases raised the number of cultivars which reached the intervention standard (HGCA 1980) from 23 on the untreated over the 3 sites to 31 with treatment. The number in the bread making category was increased from 21 to 27. The results of these assessments and of the Hagberg falling number tests are summarised in Table 4.

At Feltwell '79 where there was a high level of early season mildew, treatment showed a slight but inconsistent increase in grain protein. Conversely, in 1980 at both Feltwell and Parham grain protein was decreased with treatment where late season diseases were the major problem. However, protein yield per unit area was markedly increased with treatment as can be seen in Table 4.

Table 4

The effect of a crop protection programme on grain quality of winter wheat, mean of all cultivars

	Feltwell '79		Feltwell '80		Parham '80	
	Fo	F+	Fo	F+	Fo	F+
No. of cultivars	10		10		13	
Grain > 2.8mm (%)	25	49**	47	66	83	88
% increase		96		42		6
1000 grain wt (g)	27	34*	32	39**	47	50**
% increase		26		23		6
Specific wt (kg/hl)	66	72*	71	76	81	82
% increase		9		8		2
Intervention standard:-						
No. of cv. in bread category	3	7	5	7	13	13
No. of cv. in bread and feed category	4	8	6	10	13	13
Hagberg Falling Number	296	213	270	286	329	310
% grain protein	11.8	12.0	13.3	12.1*	11.1	10.6**
% increase (decrease) in protein		2		(8)		(5)
Protein yield in t/ha	0.42	0.67**	0.61	0.79**	0.88	1.00**
% increase in protein/ha		60		30		14

* = significant difference between Fo and F+ at p = 0.05
** = significant difference between Fo and F+ at p = 0.01

Fo = Untreated control
F+ = crop protection includ-ing fungicide programme

Hard/soft differential tests, a measure of the extraction rate of endosperm were only carried out from Feltwell '80 but they serve to indicate an area where more information should be obtained in future work. There was a consistent improvement in the hardness qualities of the cultivars with treatment to the extent that on the control only 3 of the 10 cultivars were classified as hard, whereas with treatment this increased to 6. The results of this assessment are summarised in Table 5.

Table 5

The effect of a crop protection programme on endosperm texture (hard/soft differential test) at Feltwell 1980

	Fo	F+
Mean of 10 cultivars	3.4	6.7**
% increase		97.0
No. of 'hard' cultivars	3	6

** = significant difference between Fo and F+ at p = 0.01

Fo = untreated control
F+ = crop protection including fungicide programme

The effect of treatment on costs and returns can be seen in Table 6. The costings were based on 1980 pesticide prices and wheat at £100 per tonne. Fixed costs were standardised at £321 per ha. The returns shown only take account of yield and are not adjusted according to quality as there would be too many non-quantifiable variables.

Table 6

Economics based on yield only (at 1980 prices)

	Feltwell '79		Feltwell '80		Parham '80	
	Fo	F+	Fo	F+	Fo	F+
Variable costs/ha	64	107	77	121	235	286
Gross margin/ha	296	453	383	529	555	654
Added value/ha		157		146		99
Total cost/t of output	107	76	87	68	70	65
Profit (loss)/t of output	(7)	24	13	32	30	35
Profit (loss)/ha	(25)	134	60	208	237	329

Fo = untreated control
F+ = crop protection including the fungicide programme

DISCUSSION

1) Prediction Scheme

The results indicate that the Prediction Scheme can be used to define more accurately than hitherto those winter wheat crops which will benefit from the routine fungicide programme involving triadimefon/carbendazim followed by triadimefon/captafol. Such a scheme could be utilised to supplement existing disease monitoring and forecasting projects, and therefore be of benefit in rationalizing fungicide usage in an effective and responsible manner.

2) Cultivar/fungicide interaction trials

Although economic yield response was the only parameter used for establishing a prediction for the value of a fungicide programme, grain quality also has a bearing on return, depending on acceptability for the end use, be it for seed, Intervention, milling or home grown feed. The trials at Feltwell in 1979 and 1980 and at Parham in 1980 showed that the treatments improved grain size, 1000 grain weight and specific weight. The improvement in specific weight caused more of the samples to reach the intervention standard for either bread making or feed. With regard to bread making and milling quality, treatment did not impair Hagberg falling number, but improved the extraction rate of flour in terms of the hard/soft differential, and more cultivars were classified as 'hard'. Although unaffected in 1979, percentage grain protein was decreased by treatment in 1980. This could be a disadvantage for bread making quality. However, the total amount of protein produced per hectare was markedly increased in both seasons, which could be of benefit in home grown feed production. Variability in market forces made it difficult to quantify these parameters accurately in financial terms.

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EVALUATION OF FUNGICIDE TREATMENTS FOR CONTROL OF BARLEY NET BLOTCH CAUSED BY *PYRENOPHORA TERES*

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Summary Propiconazole, prochloraz and fenpropimorph were the most effective of nineteen fungicides in glasshouse tests against net blotch of barley (Pyrenophora teres). Carbendazim-generating fungicides were not effective as protectants, and increased disease when applied after infection. Sporulation was enhanced by sprays containing carbendazim-generating fungicides or triadimefon. Fungicidal treatments of infected seed had little effect on subsequent disease development. Outdoor timing experiments on pot-grown plants showed best disease control and yield increases from single sprays applied between GS30 and GS32; GS39 sprays were also beneficial. In field experiments on winter barley two sprays of propiconazole applied at GS31 - 32 (April - May) and GS39 (June), were particularly effective in controlling net blotch and increasing yield; two-spray programmes involving other fungicides at GS39 also controlled net blotch and increased yields substantially, but single sprays were less effective.

INTRODUCTION

Barley net blotch, caused by Pyrenophora teres, has been known as a minor disease of barley in the United Kingdom for many years. However, much net blotch was seen in winter barley crops in south-west England during autumn 1979, and the disease spread further in 1980 and 1981. Initial sources of infection are barley seed and straw debris from diseased crops and infected volunteer barley plants (Jordan, 1981). Debris is probably the main source of inoculum that leads to severe autumn disease.

In Europe, net blotch is known to cause grain yield losses of 10 - 40%. Rintelen (1969) reported that infection on spring barley before tillering decreased yield by 30 - 40% on diseased shoots, whereas infection between tillering and flowering reduced plant yield by 10%. Smedegard-Petersen (1974) found that in Denmark, net blotch decreased yields of spring barley by diminishing grain size and weight. Jordan (1981) reported that on winter barley, severe disease during tillering decreased the number of grains per ear and grain weight.

Attempts to control the disease by cultural treatments such as stubble burning and deep ploughing have reduced its incidence where the source of infection was diseased straw debris (Piening, 1968). Seed treatments used to control other diseases may have some effect but seem not to have been evaluated.

Foliar sprays have been used to control the disease in the field. Shipton (1966) obtained a 65% yield increase, attributable to control of net blotch, with repeated sprays of maneb from the 3-leaf stage. Jordan (1981) obtained partial control of a severe net blotch infection and a 23% yield increase on winter barley with a single spray of propiconazole at flag leaf emergence.

There is no published information on the selection of fungicides and on the timing of treatment for net blotch control. We examined the action of many fungicides in glasshouse tests. The most active materials were included in an outdoor pot experiment and in field experiments, in which applications at different stages of crop development were compared.

MATERIALS AND METHODS

Glasshouse spray tests. Tests were done on potted winter barley plants, cv. Sonja. Commercial formulations were applied at manufacturers' recommended spray concentrations for field application at 250 l/ha (Table 1). Materials were sprayed to maximum retention to 3-week-old seedlings with 3 fully expanded leaves, rotated in a spray cabinet. The n.m.d. of droplets produced by the compressed air atomiser was *ca* 30 µm.

(i) Protectant/eradicant action Ten pots of barley plants were sprayed with each fungicide and allowed to dry (4h). The sprayed plants and a further 30 pots of seedlings were then inoculated with a conidial suspension of *P. teres* and incubated in large polyethylene frames in a glasshouse. Further batches were sprayed with fungicide after 3 or 5 days and when dry, returned to the polyethylene frames. Plants sprayed with fungicides containing triadimefon were incubated in separate frames to reduce vapour effects. Disease was assessed on all plants 14 days after inoculation by estimating the leaf area affected by net blotch lesions.

(ii) Antisporulant action Severely diseased potted barley plants at GS30 (Zadoks, Chang & Konzak, 1974) were sprayed with fungicide in 10-pot batches 2 weeks after inoculation. When the deposits had dried, 10 diseased leaves were cut from each batch, the lesioned areas measured with a ruler then incubated in closed, moistened petri dishes for 3 days at 18°C. The leaves were then suspended in 10 ml distilled water, shaken vigorously for 60s on a Rotomix agitator, and the spores in four 1 ml samples counted with a Sedgewick Rafter counting cell.

Immediately after the initial sampling, all plants were subjected to 40 mm simulated rain, in a cabinet where mains water was forced through nozzles 3m above the plants. Leaves were then excised and treated as above.

Evaluation of seed treatment. Diseased barley seed, cv. Hoppel, was treated in a mini-Rotostat seed treater, with nine commercial treatments at manufacturers' recommended concentrations (Table 4). Fifty pots each containing 5 treated seeds were grown in the glasshouse (8°C minimum temperature). At the 3-leaf stage, 25 pots from each treatment were randomised in large polyethylene frames, and moistened diseased straw segments, bearing mature perithecia of *P. teres*, were positioned vertically in each pot. All pots were sprayed daily with distilled water. The lesioned leaf area on the youngest fully expanded leaf when diseased straws were introduced, was estimated 2 weeks later. The remaining 25 pots from each treatment were grown in isolation for 6 weeks. Presence or absence of net blotch symptoms on prophylls was recorded.

Outdoor pot experiment. Propiconazole was applied to plots of 100-pots of net blotch-diseased winter barley, cv. Hoppel, at GS30, GS32, GS39 or on all three occasions, with unsprayed plots left for comparison. Each plot was surrounded by winter wheat buffer areas, and the 5 treatments replicated in 3 randomised blocks. Disease and green leaf areas were assessed in May and June. At harvest, three 10-pot batches from each plot were threshed in a Wintersteiger Labor ear thresher; the grain number, ear weight and thousand grain weight was recorded.

Field experiments. Fungicides were applied at the manufacturer's recommended concentrations (Table 1) for application at 250 l/ha to 3 or 4 replicates of 20m x

2m plots with an Oxford Precision Sprayer. Diseased and green areas were estimated as percentages on the two youngest fully expanded leaves on each of 10 tillers/plot.

Trial 1 (Yanleigh, Avon), was done on a diseased crop of Sonja winter barley, sown in October 1980, where net blotch was the only disease prevalent in the spring and summer.

Trial 2 (Newquay, Cornwall), was done on winter barley, var Igri, sown on 21 October 1980, where net blotch and leaf blotch (Rhynchosporium secalis) were prevalent in the spring and summer. Both trials compared fungicide applications at GS31 - 32 with applications at GS39.

RESULTS

Glasshouse tests.

(i) Protectant/eradicant action Propiconazole, prochloraz, fenpropimorph, carbendazim + tridemorph + maneb, chlorothalonil, carbendazim + maneb, maneb and triforine + mancozeb, when applied before inoculation with P. teres, each completely prevented disease development, whereas benomyl and carbendazim were not effective (Table 2). With the exception of benomyl, carbendazim, thiabendazole and thiophanate-methyl, where more disease developed on sprayed plants than on unsprayed plants, all fungicides tested as protectants reduced disease.

Propiconazole and prochloraz also prevented disease when applied 3 days after inoculation. These two fungicides and fenpropimorph decreased disease by more than 75% when applied 5 days after inoculation.

(ii) Antisporulant action Nine of the fungicides suppressed sporulation from diseased leaves to some extent, and propiconazole, prochloraz, fenpropimorph and iprodione decreased sporulation both before and after periods of simulated rain (Table 3). More sporulation occurred on leaves treated with thiophanate methyl, carbendazim and triadimefon + carbendazim than on unsprayed leaves. Following simulated rain, sporulation was also enhanced by benomyl, carbendazim + tridemorph + maneb, captafol, chlorothalonil and triadimefon.

(iii) Effects of seed treatment P. teres causes lesions on the prophylls of seedlings grown from infected seed (Jordan, 1981). Several of the seed treatments decreased markedly the number of diseased seedlings, although none gave complete control (Table 4). When seedlings were subjected to inoculum from infected straw debris, the seed treatments had little or no effect.

Outdoor pot experiments. Single applications of propiconazole at either GS30 or GS32 greatly suppressed the upward spread of disease, an effect maintained until harvest. Applications made at GS39, when disease was already severe on the upper leaves, increased the duration of green areas on the flag leaves and leaf 2, but were less effective than the earlier applications. Best disease control was obtained from the three-spray programme.

All fungicide treatments increased plot yields. Of the single applications, the spray applied at GS30 was the most effective (15% yield increase) and the GS39 spray least (8% increase). Most yield was obtained from plots that received all 3 sprays (Table 5).

Field experiments. Results of field experiments are shown in Tables 6 and 7. In Trial 1, plots treated with propiconazole at GS31 - 32 gave lower amounts of net blotch and more yield and grain weight compared with untreated plots or plots sprayed with triadimefon (Table 6). Second sprays of several fungicides gave further reductions in disease but enhanced yield only when propiconazole was used in the first spray. A GS31 spray of propiconazole + carbendazim increased yields markedly in Trial 2, but only when followed by a second spray (GS39) of propiconazole or of other fungicides (Table 7).

DISCUSSION

To be effective against net blotch, a fungicide must either protect the foliage from infection or destroy the inoculum available for new infection. The performance of the fungicides tested in this study differed considerably; several were effective protectants but only propiconazole, prochloraz and fenpropimorph had marked curative and antisporulant activities.

Of some importance is the finding in glasshouse experiments that applications of carbendazim-generating fungicides tend to exacerbate disease and stimulate sporulation by P. teres. Enhanced sporulation was also induced by fungicides that contain triadimefon. Stimulation by fungicides may be one reason why net blotch has recently become more severe in winter barley, for the barley area sprayed with carbendazim-generating fungicides and triadimefon has increased considerably during the past 5 years.

The relative performance of the different fungicides in field experiments correlated well with the glasshouse data; in both situations propiconazole was usually the most effective fungicide for net blotch control.

At present, there are no clear criteria for precise timing of sprays in relation to prevailing weather, disease thresholds and potential yield loss. Therefore, spray timing must be linked to crop development stages.

Field experiments for net blotch control in 1980 (Jordan, 1981) showed that single applications of propiconazole to diseased barley crops at flag leaf emergence increased yields by 17 - 23%. In the pot experiment (Table 5) where plots buffered with winter wheat minimised cross-infection between treatments, applications made between late tillering (GS30) and appearance of second node (GS32) gave good disease control until harvest and increased yields by 15%, whereas spraying at flag leaf emergence (GS39) increased yields by only 8%. This suggests that additional benefit may be gained from spraying before the flag leaf appears.

In 1981, the most effective control of net blotch in the field was obtained by two fungicide applications at GS31, and at flag leaf emergence (GS39). Differences in performance of the single sprays at flag leaf emergence between 1980 and 1981 may be due to differences in disease severity at the time of spray application; in 1981 there was more disease on the upper two leaves than in 1980, and this may have been more difficult to control by a single spray.

The net blotch fungus is spread by both splash-borne and air-borne conidia, and as fungicides differ in their action against this disease, plots should be buffered to reduce cross contamination. The most effective buffering, in our experience, is winter wheat, but in farm fields this is impractical and barley buffers must be used. The decision to spray buffers or leave them unsprayed, will affect disease development in the experimental plots; the presence of much-diseased buffer areas sometimes results in a high coefficient of variation and masks treatment effects.

In one field trial, net blotch was the main disease, and in the other, leaf blotch was also important. In practice, most barley crops get more than one disease during the growing season. It will therefore be advisable to select a fungicide that controls the most prevalent disease and is also active against other diseases. The interactions between fungicides, diseases and other cultural practices, in relation to cost-effective disease control and yield enhancement need further examination.

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Table 1

Identity and amounts of foliar fungicides used

Fungicide	Product used (trade name)	Supplier	Formulation	Recommended application rate (per hectare)
Benomyl	Benlate	Dupont	50% w.p.	0.5 kg
Captafol	Sanspor	ICI	50% s.c.	2.8 l
Carbendazim	Bavistin	BASF	50% w.p.	0.5 kg
Carbendazim + maneb	Delsene M	Dupont	74% w.p.	2.5 kg
Carbendazim + tridemorph + maneb	Cosmic	BASF	53% w.p.	4.0 kg
Chlorothalonil	Bravo	Diamond Shamrock	40% e.c.	2.2 l
Fenpropimorph	Corbel/ Mistral	BASF/ May & Baker	75% e.c.	1.0 l
Iprodione	Rovral	May & Baker	50% w.p.	1.0 kg
Maneb	Manzate	Farm Protection	80% w.p.	2.0 kg
Prochloraz	Sportak	FBC	40% e.c.	0.5 l
Propiconazole	Tilt	Ciba-Geigy	25% e.c.	0.5 l
Propiconazole + carbendazim	A6117	Ciba-Geigy	-	1.0 kg
Thiabendazole	Storite	Merck, Sharp & Dohme	60% w.p.	0.5 kg
Triadimefon	Bayleton	Bayer	25% w.p.	0.5 kg
Triadimefon + captafol	Bayleton CF	Bayer	71.3% w.p.	2.0 kg
Triadimefon + carbendazim	Bayleton BM	Bayer	37.5% w.p.	1.0 kg
Tridemorph	Calixin	BASF	75% e.c.	0.7 l
Triforine + mancozeb	Saprol/ Dithane	Shell P.B.I.	19% e.c. + 80% w.p.	1.4 l + 2.0 kg

Table 2

Effect of fungicide timing on amount of disease (% leaf area) in glasshouse plants†

	Test (i) treatment	Application time (days after inoculation) 0*	3	5
a.	Propiconazole	0	0	5
a.	Prochloraz	0	0	4
c.	Fenpropimorph	0	1	1
d.	Triforine + mancozeb	0	14	18
d.	Chlorothalonil	0	21	17
b.	Carbendazim + tridemorph + maneb	0	2	16
d.	Triadimefon	4	13	9
d.	Triadimefon + captafol	2	13	12
e.	Triadimefon + carbendazim	8	11	5
f.	Thiophanate methyl	13	19	26
u.	Unsprayed	20		

	Test (ii) treatment	Application time (days after inoculation) 0*	3	5
a.	Propiconazole	0	0	21
b.	Propiconazole + carbendazim	1	2	27
d.	Maneb	0	24	38
g.	Iprodione	2	34	70
d.	Carbendazim + maneb	0	46	42
h.	Thiabendazole	21	58	67
d.	Captafol	10	49	42
d.	Tridemorph	2	23	36
j.	Benomyl	50	48	75
h.	Carbendazim	32	54	58
u.	Unsprayed	32		

Treatments with a letter in common are grouped for similar effects (P = 0.05):

a - 0,3<5,u; b - 0<3<5,u; c - 0<3,5<u; d - 0<3,5,u;

e - 0,3,5<u; f - 0<5,u; g - 0<3,u<5; h - u,0<3,5;

j - u,0,3,<5.

†Data analysed by logistic transformation and de-transformed.

*Fungicide applied 4h before inoculation.

Table 3

Effect of fungicides on spore release from net blotch lesions†

Test (i) treatment	Spores/cm^2 lesion no rain	+ rain	Test (ii) treatment	Spores/cm^2 lesion no rain	+ rain
Propiconazole	172 a	36 a	Propiconazole	122 a	139 b
Prochloraz	353 b	27 a	Propiconazole + carbendazim	156 a	57 a
Fenpropimorph	589 c	303 b	Maneb	392 b	1022 d
Triforine + mancozeb	593 c	848 c	Iprodione	1390 d	638 c
Chlorothalonil	1022 d	1624 e	Carbendazim + maneb	1085 c	1035 de
Carbendazim + tridemorph + maneb	2144 e	1444 e	Thiabendazole	1613 de	996 d
			Captafol	1596 de	1995 f
Triadimefon	2428 fg	1880 f	Tridemorph	1706 e	953 d
Triadimefon + captafol	2487 fg	1035 d	Benomyl	1840 e	1983 f
			Carbendazim	2143 f	1261 e
Triadimefon + carbendazim	2680 g	2004 f			
Thiophanate methyl	3535 h	2404 g			
Unsprayed	2273 ef	980 cd	Unsprayed	1670 e	1040 de

Mean values with a different following letter are significantly different (P = 0.05)

†Data analysed by square-root transformation and de-transformed.

Table 4

Effect of seed treatment on net blotch infection arising from diseased seed and from infected straw debris

Seed treatment	Product used (trade name)	Amount applied (g a.i./kg seed)	Diseased plants (%) seed	seed+debris
Triadiminol + fuberidazole	Baytan F.	1.5	3	65
Prochloraz	Sportak	2.0	8	68
Guazatine + imazalil	Murbenine Plus	2.2	7	63
Iprodione	Rovral	3.0	9	54
Nuarimol	Murox	2.2	8	51
Methoxyethyl mercury acetate	Panogen M	1.1	7	74
Methoxyethyl mercury acetate + triforine	Panogen M + Saprol	1.1+ 5.0	23	63
Phenyl mercury acetate	Agrosan D	1.2	13	58
Trivax (10%) + thiabendazole (2.5%) + imazalil (2.5%)	Experimental mixture	2.0	20	66
Untreated		-	25	63

Table 5

Effect of propiconazole sprays on net blotch and yield in infected potted barley plants outdoors

Growth stage when applied	Diseased leaf area (%) 1 April (leaf 5)	1 June (leaf 2)	Yield (85% DM) Grain Wt (g/100 ears)	Grain no. /ear	TGW (g)
GS30 (1 Feb)	4	6	182.1	40.4	45.3
GS32 (3 Mar)	5	12	178.3	38.6	46.3
GS39 (31 Apr)	45	1	171.0	38.4	44.8
GS30 + GS32 + GS39	3	1	185.7	38.3	48.6
Unsprayed	42	15	158.5	36.3	43.9
SED			5.9	1.3	1.3

Table 6

Net blotch control and yield, Trial 1 (Yanleigh, Avon, 1981)

Treatments GS32 (11 May)	GS39 (4 June)	Green leaf area (%) June Flag leaf	Leaf 2	Yield (t/ha)	TGW (g)
Propiconazole	propiconazole	91	67	4.42	58.4
Propiconazole	prochloraz	86	52	4.24	57.6
Propiconazole	fenpropimorph	69	37	4.38	58.7
Propiconazole	triadimefon	57	20	4.24	59.3
Propiconazole	carbendazim + tridemorph + maneb	62	11	4.39	56.6
Propiconazole	unsprayed	79	42	4.16	56.2
Triadimefon	propiconazole	90	56	3.96	56.1
Triadimefon	prochloraz	84	35	3.76	56.7
Triadimefon	fenpropimorph	66	18	3.47	55.6
Triadimefon	triadimefon	50	19	3.89	56.6
Triadimefon	carbendazim + tridemorph + maneb	55	18	3.88	54.8
Triadimefon	unsprayed	31	6	4.02	52.1
SED Min*		5.6	5.6	0.151	1.43
Max†		15.5	17.9		

*Applicable to means furthest from 50%; †Applicable to means nearest 50%.

Table 7

Disease control and yield, Trial 2 (Newquay, 1981)

GS31 (3 Apr)	GS39 (12 May)	Diseased leaf area (%)[†] Flag	Leaf 2	Yield (t/ha)	TGW (g)
Nil	propiconazole	10	16	6.16	42.3
Nil	prochloraz	10	8	6.07	43.5
Nil	fenpropimorph	9	15	5.93	43.4
Nil	carbendazim + tridemorph + maneb	11	16	6.32	44.6
Nil	triforine + mancozeb	5	10	5.81	43.1
Nil	triadimefon	10	19	6.12	43.2
Propiconazole + carbendazim	nil	9	16	6.26	45.0
Propiconazole + carbendazim	propiconazole	6	10	6.61	45.9
Propiconazole + carbendazim	prochloraz	5	11	7.15	48.5
Propiconazole + carbendazim	fenpropimorph	14	25	6.91	45.5
Propiconazole + carbendazim	carbendazim + tridemorph + maneb	10	14	7.14	47.2
Propiconazole + carbendazim	triforine + mancozeb	8	11	6.94	45.8
Propiconazole + carbendazim	triadimefon	11	26	6.52	44.8
SED		2	6	0.16	1.74

[†]combined net blotch and leaf blotch.

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CONTROL OF SEPTORIA SPP. IN WINTER WHEAT WITH CHLOROTHALONIL

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Summary A programme of replicated field trials has been carried out throughout Europe since 1978 to investigate the activity of chlorothalonil against leaf spot (*Septoria tritici*) and glume blotch (*Septoria nodorum*) of winter wheat. Effective control of these diseases has been obtained from one application of chlorothalonil at rates of 1000-1500 g a.i/ha applied during or shortly after ear emergence. The treatments have resulted in increases in yield over a wide range of conditions.

Trials to investigate optimal timing for chlorothalonil applications have indicated improved control from treatments made when the flag leaf is just visible. Trials in the United Kingdom have shown that chlorothalonil applied at this stage gives significantly better control of *Septoria* infection of the ear than applications made at full ear emergence.

Resumé Depuis 1978, un programme d'essais de plein champ, réalisés en petites parcelles à plusieurs répétitions, a été mis en place dans toute l'Europe. Le but de cet experimentation était d'étudier l'activité du Chlorothalonil contre les Septorioses des feuilles et des épis du blé d'hiver (*Septoria nodorum* et *Septoria tritici*).

La Septoriose a été parfaitement controlée avec le Chlorothalonil utilisé à des doses variant entre 1000 et 1500 grammes par hectare de matière active et appliqué à la sortie des épis ou juste aprés ce stade. Malgré des situations tres differentes, ces traitements ont toujours permis d'obtenir de fortes augmentations de rendement.

D'autres essais, dont l'objectif était d'étudier la periode optimum d'application du Chlorothalonil, ont montré que le controle le meilleur était obtenu avec des traitements effectués au stade "derniere feuille apparente". En Grande-Bretagne, les observations ont démontré que le Chlorothalonil appliqué à ce stade avait une efficacité sur la Septoriose des épis statistiquement superieure a celle des traitements effectués au stade "pleine émergence des épis".

INTRODUCTION

Chlorothalonil is a broad spectrum, non-systemic fungicide introduced in 1963 by the Diamond Alkali Co. (now Diamond Shamrock Corp.). The fungicidal properties of chlorothalonil were first described by Turner (1963). Since the introduction of chlorothalonil it has been developed for the control of a wide range of plant pathogens on major agricultural, vegetable, fruit and ornamental crops (Diamond

Shamrock Corp. 1981, Schauer 1977 and Wilson 1978).

Work is in progress to evaluate chlorothalonil for the control of the major cereal diseases, leaf spot (Septoria tritici) and glume blotch (S. nodorum) of winter wheat and leaf blotch (Rhynchosporium secalis) and net blotch (Pyrenophora teres) of barley.

This paper reviews results obtained from trials carried out in a number of European countries from 1978-1981 to examine the control of Septoria spp. in wheat.

METHODS AND MATERIALS

Chlorothalonil was applied as either a wettable powder (w.p.) formulation containing 75% a.i. or as suspension concentrate (s.c.) containing 500 g/l. a.i. Standard products used in the trials were applied as the commercially available products.

All the results presented were obtained from small plot trials with at least four replicates per trial. Individual plot sizes varied from country to country but with a minimum of 20 m^2.

Treatments were applied by knapsack sprayer in 200-400 litres of water per hectare at a pressure of 2-4 bar. Details of timing of the spray application are given in the text.

Disease assessments in the United Kingdom were made according to the Plant Pathology Laboratory Disease Assessment Keys (MAFF 1976). However, in 1980 when disease symptoms became confused with natural senescence assessments of the percentage of green leaf area were made. In other European countries assessments of percentage disease infection were also made although in Germany and Switzerland the BBA 1-5 or 1-9 scale for assessment of Septoria levels was used. Disease assessments were made 4-8 weeks after treatment as indicated in the text. Combine harvesters modified for the harvesting of small plots were used for yield measurements in all trials.

Many of the trials from which data is presented were treated overall with an MBC type fungicide for the control of Eyespot (Pseudocercosporella herpotrichoides) at an early stage of crop development. No other fungicides apart from those mentioned in the text were applied.

Crop growth stages are described using a decimal growth stage key (Zadoks et al 1974) although many of the trials were carried out using crop growth stages assessed according to the methods of Keller and Baggiolini (1954) or Large (1954).

RESULTS

France

Disease pressure due to Septoria spp. was generally low during 1979 and 1980. The trials were complicated by the presence of other diseases such as powdery mildew (Erysiphe graminis) and yellow rust (Puccinia striiformis). However, Tables 1 and 2 present data from sites where Septoria was the only disease of importance.

Table 1

Effect of chlorothalonil on *Septoria* in winter wheat in France, 1979. Mean of three sites

Treatment	Rate (g a.i./ha)	Septoria (% infection) leaf 2	ears
Chlorothalonil (w.p.)	1125	32	1.1
Chlorothalonil (s.c.)	1100	30	0.9
Carbendazim + maneb	300 + 2500	36	1.6
Untreated	-	58	4.8

Treatments applied at G.S. 59
Assessments carried out 4 weeks after treatment.

Table 2

Effect of chlorothalonil on *Septoria* and yield of winter wheat in France at Marche-Allouarde in 1980

	Rate (g a.i./ha)	Septoria (% infection) ears	Yield (kg./ha)	Yield (relative)
Chlorothalonil (s.c.)	1100	9.4	6334	109
Triadimefon + carbendazim	125 + 250	15.4	6349	109
Untreated		18.3	5812	100
LSD (p = 0.05)			N.S.	

Variety: Arminda. Treatments applied G.S. 59.
Assessments made 5 weeks after treatment

Germany

In a trial carried out in Northern Germany in 1978 application of chlorothalonil to winter wheat at full ear emergence gave a reduction in level of ear *Septoria* and a significant increase in yield (Table 3). The activity of chlorothalonil against *Septoria* under German conditions was further confirmed in a series of trials carried out in Bavaria in 1980 (Table 4). *Septoria* is normally severe in this region of Germany and the results clearly show the effectiveness of one application of chlorothalonil at 1100 g a.i./ha in reducing the level of ear *Septoria* and giving an appreciable increase in yield.

Table 3

Effect of chlorothalonil on *Septoria* and yield of winter wheat at Christinenthal, N. Germany in 1978

Treatment	Rate (g a.i./ha)	*Septoria* infection* ears	Yield (kg./ha)	Yield (relative)
Chlorothalonil (s.c.)	1100	2.6	6858	127
Captafol + halacrinate	1000 + 500	2.3	7128	132
Carbendazim	180	2.7	6264	116
Untreated	-	3.4	5400	100
LSD (p = 0.05)			680	
LSD (p = 0.01)			918	

Variety: Caribo. Treatments applied G.S. 61-69
*Assessment made 6 weeks after treatment according to BBA 1-5 scale. (1 = no infection, 2 = 0-10%, 3 = 10-25%, 4 = 25-50%, 5 = 50-100% infection.)

Table 4

Effect of chlorothalonil on *Septoria* and yield of winter wheat in Bavaria, S. Germany in 1980. Mean of five sites

Treatment	Rate (g a.i./ha)	*Septoria* infection* ears	Yield (kg./ha)	Yield (relative)
Chlorothalonil (s.c.)	1100	1.9	4746	117
Captafol	1680	1.9	4859	120
Captafol + triadimefon	1300 + 125	2.3	4702	116
Untreated	-	5.2	4042	100
LSD (p = 0.05)			153	

Treatments applied G.S. 59-69
*Assessments made 4-6 weeks after treatment according to BBA 1-9 scale (1 = no infection, 2 = 0-2.5%, 3 = 2.5-5%, 4 = 5-10%, 5 = 10-15%, 6 = 15-25%, 7 = 25-35%, 8 = 35-67.5%, 9 = 67.5-100% infection.)

Sweden

In a series of trials carried out in Sweden in 1980 *Septoria* disease levels on the ears of winter wheat were generally very low. However, treatment with chlorothalonil reduced the *Septoria* infection and produced yield increases which compared favourably with the standard product as indicated in Table 5.

Table 5

Effect of chlorothalonil on *Septoria* and yield of winter wheat in Sweden in 1980. Mean of five sites

Treatment	Rate (g a.i./ha)	*Septoria* (% infection) ears	Yield (kg./ha)	Yield (relative)
Chlorothalonil (s.c.)	1250	0.8	5902	107
Chlorothalonil (s.c.)	1000	0.7	5974	108
Benomyl	250	1.0	5762	104
Untreated	-	1.1	5514	100
LSD (p = 0.05)			265	

Treatments applied G.S. 47-59
Assessments made 6-8 weeks after treatment

Switzerland

Septoria is a serious problem in Switzerland in most years. Trials were carried out in which chlorothalonil was applied during ear emergence of winter wheat. The results indicated control of *Septoria* with considerable increases in yield. In these trials (Tables 6 and 7) there is an indication of a rate response to chlorothalonil in terms of yield increase. However, at all rates tested chlorothalonil was comparable with the standard products.

Table 6

Effect of chlorothalonil on *Septoria* and yield of winter wheat in Switzerland in 1979. Mean of two sites

Treatment	Rate (g a.i./ha)	*Septoria* (% infection) leaf 1*	*Septoria* (% infection) ears	Yield (kg./ha)	Yield (relative)
Chlorothalonil (s.c.)	1500	21	5	5850	111
Chlorothalonil (s.c.)	1000	50	8	5745	109
Benomyl + mancozeb	125 + 1920	71	16	5360	102
Untreated	-	76	20	5260	100
LSD (p = 0.05)				298	

Treatments applied G.S. 57-59
Assessments made 6-8 weeks after treatment
*leaf assessment at one site only

Table 7

Effect of chlorothalonil on *Septoria* and yield of winter wheat in Switzerland in 1980. Mean of three sites

Treatment	Rate (g a.i./ha)	*Septoria* infection leaf 1 (%)	*Septoria* infection ears*	Yield (kg/ha)	Yield (relative)
Chlorothalonil (s.c.)	1500	27	3.5	3810	116
Chlorothalonil (s.c.)	1250	25	3.7	3910	119
Chlorothalonil (s.c.)	1000	23	3.3	3700	113
Captafol	1200	31	4.3	3890	118
Untreated	-	50	6.3	3283	100
LSD (p = 0.05)				293	

Treatments applied G.S. 59-61
Assessments made 5-6 weeks after treatment (*ear assessment according to BBA 1-9 scale)

United Kingdom

The results of trials carried out in the United Kingdom in 1980 and 1981 are presented in Tables 8-10.

Weather conditions in 1980 were characterised by a drought period from April to mid-June followed by a period of persistently wet weather until mid-August. Conditions were not, therefore, conducive to the spread of *Septoria* until after ear emergence. However, *Septoria* spread rapidly at some sites in late July. By this stage the normal disease symptoms became confused with natural senescence although *Septoria* was the major contributing factor.

Table 8

Effect of chlorothalonil on % green leaf and yield of winter wheat at Burkham, Hampshire in the United Kingdom in 1980

Treatment	Rate (g a.i./ha)	% green leaf leaf 1	% green leaf leaf 2	Yield (kg/ha)	Yield (relative)
Chlorothalonil (s.c.)	1100	77	41	9333	107
Chlorothalonil (s.c.)	1000	78	36	9367	107
Captafol	1344	58	24	9417	107
Triadimefon + captafol	125 + 1300	72	35	9517	109
Untreated	-	52	4.4	8750	100
LSD (p = 0.05)				388	

Variety: Mardler. Treatments applied at G.S. 55
Assessments made 8 weeks after treatment

In contrast to 1980, weather conditions in 1981 were favourable to the spread of Septoria and severe disease pressure built up through the season.

Table 9

Effect of chlorothalonil on Septoria and yield of winter wheat at Alton, Hants. in the United Kingdom in 1981

Treatment	Rate (g a.i./ha)	Septoria (% infection) leaf 1	leaf 2	Yield (kg/ha)	(relative)
Chlorothalonil (s.c.)	1000	3.7	69.2	7070	108
Captafol	1344	2.3	71.6	7019	107
Triadimefon + captafol	125 + 1300	1.4	53.0	7196	110
Untreated		12.0	80.5	6539	100
LSD (p = 0.05)				391	

Variety: Bounty. Treatments applied G.S. 57
Assessments made 5 weeks after treatment

The data in Table 9 demonstrates control of Septoria on leaf 1 by chlorothalonil but only a slight reduction of disease level on leaf 2. However, this treatment applied at G.S. 57 did result in a significant yield increase compared to untreated. A further series of trials in 1981 examined the effect of timing of application on Septoria control by chlorothalonil (Table 10). This data shows the advantages of applying chlorothalonil at G.S. 37 rather than at later timings both in terms of disease control and yield increase. This is especially evident at the Pitney and Farleigh sites where Septoria levels built up rapidly early in the season. At the Zeals site where Septoria infections became established later most benefit was obtained from later applications. This site, however, was further complicated by late attacks of powdery mildew and brown rust (Puccinia recondita).

Table 10

Effect of timing on the control of Septoria by chlorothalonil at three sites in the United Kingdom in 1981

Site/treatment (g a.i./ha)	Timing of application	Septoria (% infection and assessment date) ears	ears	leaf 1	leaf 2	Yield (kg/ha)	(relative)
Pitney, Somerset		2/7	25/7	23/6	23/6		
Chlorothalonil 1000	GS 37	0.6c	2.3c	3.3b	28.9c	7649b	112
Chlorothalonil 1000	GS 45	0.3c	1.2c	3.6b	45.0b	7437b	109
Chlorothalonil 1000	GS 59	1.2b	3.5b	5.4b	72.6a	6998a	102
Untreated		2.3a	6.8a	10.1a	79.6a	6852a	100
Farleigh, Hampshire		3/7	28/7	3/7	3/7		
Chlorothalonil 1000	GS 37	0.1b	1.9c	4.4b	21.7c	5631cd	122
Chlorothalonil 1000	GS 45	0.0b	2.1c	6.2b	37.1b	5283bc	114
Chlorothalonil 1000	GS 59	0.6a	3.4b	11.6c	75.8a	5016b	108
Untreated		1.1a	6.9a	20.3a	82.4a	4631a	100
Zeals, Wiltshire				14/7	14/7		
Chlorothalonil 1000	GS 37	-	-	5.3b	38.5bc	6877a	106
Chlorothalonil 1000	GS 45	-	-	2.6b	23.9c	7306b	113
Chlorothalonil 1000	GS 59	-	-	3.3b	47.8b	7354b	114
Untreated				23.5a	82.6a	6464a	100

Variety: (Septoria level in untreated GS 45 leaf 3) Pitney-Bounty (20.1%); Farleigh-Bounty (11.0%); Zeals-Maris Huntsman (1.8%)
Figures in same column from same site suffixed with same letter are not significantly different by Duncans Multiple Range Test (p = 0.05)

DISCUSSION

Our results compiled from 25 trials throughout Europe show that chlorothalonil applied at rates of 1000-1500 g a.i./ha provides control of Septoria spp. in winter wheat. This control has been demonstrated under a variety of conditions, including those experienced in Germany and Switzerland where infections of the ears are considered to be the more serious problem. However, in the United Kingdom where severe attacks of Septoria on the ears are not so common, control of leaf Septoria by chlorothalonil has effectively extended the life of the upper leaves of the crop and resulted in considerable yield increases.

The majority of the data presented reports on treatments made during or even after ear emergence. Such treatments are standard practice in many countries with the prime objective of protecting the ear. The more recent data from the United Kingdom indicates that applications of chlorothalonil made before ear emergence will give better control of Septoria on both flag leaf and ear than application made at full ear emergence. This is especially evident on sites where disease attack has occurred early. In a year when conditions were favourable to Septoria spread throughout the season, these results demonstrate the ability of chlorothalonil to control Septoria spp. and reduce spread of the disease within the crop over a considerable period of time. Treatment with chlorothalonil at G.S. 59 is effective when disease attack occurs later. However, if infection pressure is allowed to build up within the crop from an early stage, a considerable proportion of the crop may be infected before a late (G.S. 59) treatment is applied although typical disease symptoms may not be evident. Greenhouse tests have confirmed the more effective control of Septoria by an application of chlorothalonil made prior to infection (V.W.L. Jordan, pers. comm.). In seasons when chlorothalonil is applied to control early attacks of Septoria protection of the flag leaf and ear should also be obtained.

In order to control satisfactorily the complex of diseases which commonly reduce yields of wheat throughout Europe, it is necessary to combine chlorothalonil with compounds with activity against powdery mildew and rusts. A considerable amount of work has been done on this and will be reported at this conference and elsewhere.

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PROCHLORAZ: THE CONTROL OF NET BLOTCH AND SEPTORIA IN WINTER CEREALS

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Summary Trials carried out in the U.K. in Autumn 1980/Spring 1981 showed the benefits of prochloraz against net blotch and *Septoria* spp. on winter barley and winter wheat respectively. Against net blotch, prochloraz was effective as a protectant at 300-400 g a.i./ha giving substantial yield increases when applied in the spring. Work is also reported where autumn applications were made.

Spray timings were examined for optimising protection against *Septoria* in winter wheat. Single and repeat applications were examined. In a severe disease season, applications made at conventional timings for ear disease, gave effective control. Earlier applications normally associated with eyespot timings showed an additional residual effect when applied in combination with sprays made after heading.

Resume Des experiences realisees en Grande-Bretagne en automne 1980 et au printemps 1981 ont demontre les qualites du prochloraz dans la lutte contre l'helminthosporiose et *Septoria* spp. dans l'orge d'hiver et le ble d'hiver respectivement. A raison de 300/400 g de matiere active/hectare, le prochloraz donne une protection efficace contre l'helminthosporiose de l'orge; ceci se traduit par une augmentation substantielle des rendements dans le cas des traitements de printemps. Les resultats des traitements d'automne sont aussi rapportes ici.

On a egalement essaye de determiner la periode ideale a laquelle effectuer les traitements pour obtenir une protection optimale contre *Septoria* dans le ble d'hiver. Les applications uniques commes les applications repetees ont ete considerees. Aux saisons de maladie serieuse, les applications effectuees aux periodes normales ont controle efficacement la maladie des epis. Dans le cas d'application plus precoces, normalement effectuees contre le pietin-verse, une remanence plus prolongee a aussi ete observee lorsque les applications etaient associees a des pulverisations effectuees apres l'epiaison.

INTRODUCTION

Net blotch (*Pyrenophora teres*) and *Septoria* diseases (*S. tritici* and *S. nodorum*) have been widespread in occurrence in UK cereals in 1981 and as with other splash borne diseases, their spread was greatly aided by extended periods of rainfall. Splash borne diseases are defined as those pathogens requiring free moisture or rain drops for optimum dissemination and subsequent infection. This group, which is particularly important on winter sown crops, also includes leaf blotch (*Rhynchosporium secalis*) and the stem diseases, eyespot (*Pseudocercosporella herpotrichoides*) and sharp eyespot (*Rhizoctonia solani*).

Splash borne diseases are diverse in their taxonomy and require the use of a broad spectrum chemical at optimum spray timings for effective control. Prochloraz is effective against a wide range of foliar and ear diseases of cereals, giving consistent yield benefits, reflecting both major and secondary disease control (Harris et al., 1979). Of particular relevance is the high activity found with prochloraz against splash borne diseases including net blotch and Septoria spp.

Net blotch has assumed importance in winter barley in 1980/81 being severe in its spring infection phase. To date few compounds have been reported as giving effective control when sprayed in the spring but early ADAS reports (Technical Newsflash, October 1980) showed prochloraz amongst others to be active against the disease. Consequently a limited number of trials were established in autumn 1980 and extended in spring 1981 to confirm these results and further clarify the effects of spray timing and influence on yield.

In winter wheat, leaf spot (S. tritici) and glume blotch (S. nodorum) can be responsible for significant yield losses due to flag and ear infections. A perennial dilemma in fungicide evaluation against Septoria diseases is the variability of good correlation between efficacy data and yield and in optimising spray timings for maximum disease control. A series of trials were established to look further at this problem using prochloraz.

METHODS AND MATERIALS

The majority of trials reported were located in Suffolk and Norfolk with additional sites also established in Gloucestershire (Table 1). Plot design was randomised block or twin latin square comprising 20 - 50m^2 in plot area and having 4 - 8 replicates. Treatments were applied using a knapsack sprayer with hand held boom fitted with cone nozzles applying a volume of 200l/ha at 2 bar pressure.

Table 1

Site details of winter barley and winter wheat trials

Winter barley		Winter wheat	
Location	Cultivar	Location	Cultivar
Walton on the Naze, Essex	Athene	Forward Green, Suffolk	Mardler
Stoke Holy Cross, Norfolk	Sonja	Stowbridge, Norfolk	Mardler
Iken, Suffolk	Maris Otter	Cockfield, Suffolk	Hobbit
Coln St. Aldwyns, Gloucs	Gerbel/Sonja		
Bourton on the Water, Gloucs	Igri		
Saham Toney, Norfolk	Sonja		

All crop stages were recorded using the Zadoks decimal growth stage key (Zadoks et al. 1974). Sprays were applied on winter barley during the autumn period at GS 15 - 18 but mostly from GS 28 - 50 during the spring. On winter wheat, treatments were made from GS 31 - 65.

Assessments for leaf spot and net blotch were made following the scheme established by the ADAS Assessment Keys.

Additionally, recordings were also made at the initiation of leaf senescence by measuring percentage green leaf area on the flag. Infection by glume blotch was recorded by assessing percentage of glume area infected by Septoria.

Trial sites were yielded using Hege or Claas mini harvesters with an effective cutting area of 11 - 50m^2 per plot.

All treatments of prochloraz were based on the 40% e.c. commercial formulation. Other materials employed were standard commercial products applied at recommended rates.

RESULTS

Infections of net blotch or Septoria developed in most trial sites reaching the flag leaf in the majority of these cases.

Net blotch

This disease remained at fairly low levels during the early spring with infection levels generally at or below 5% on any one leaf at GS 31 - 32. Significantly higher levels were evident particularly after heading with 40 - 50% being recorded on the flag leaf towards senescence.

A series of three trials conducted in East Anglia has shown (Table 2) that 300 - 400g ai/ha prochloraz gave superior disease activity compared with other broad spectrum fungicides such as triadimefon and fenpropimorph when applied protectantly at the relatively early stage of GS 28 - 31. In agreement with ADAS reports, propiconazole also gave good disease control in these trials. Both prochloraz and propiconazole produced similar yield increases of the order of 25% in generally low yielding sites where disease levels remained below 10% throughout the season. Some variability in yield response is seen between the two rates of prochloraz at these low disease levels.

Table 2

Control of net blotch on winter barley at three East Anglian sites

Treatment	Application rate (g a.i./ha)	Net blotch (% area infection on leaf 2) after: T+(2-3) weeks	T+(4-6)weeks	Yield (as % untreated)
Prochloraz	300	0.8	4.7	124.2
Prochloraz	400	0.5	4.2	116.7
Triadimefon	125	2.3	6.1	114.5
Propiconazole	125	1.0	3.6	125.9
Fenpropimorph	750	2.2	6.0	114.5
Untreated	-	2.6	6.7	100
SE $\pm$		0.39	0.85	13.8

Treatments applied at GS 28-31 (5% infection at application)
Spray dates 21.4.81 - 12.5.81
Assessments carried out at GS 37 and 64-75.
Sites at Walton on the Naze, Stoke Holy Cross and Iken.
Untreated yield: 4110kg/ha

In looking further at net blotch control in the spring, Table 2 shows data obtained from two Cotswold sites where infection increased to much higher levels than at the East Anglian sites (21% on leaf 2 at assessment and towards 50% on the flag leaf at senescence). Applications were made at the later stage of GS 32 - 33 and emphasise good protectant activity against increasing infection levels during the 4 - 6 weeks before assessments. Prochloraz gave good yield increases with both 300 and 400 g a.i./ha prochloraz, averaging 30 and 34% respectively. A yield increase of 41% was obtained at the Coln St. Aldwyns site emphasising the high decrease pressure in these trials.

Table 3

The control of net blotch on winter barley at two Cotswold sites

Treatment	Application rate (g a.i./ha)	Net blotch (% infection on leaf 2)	Yield (as % untreated)
Prochloraz	300	9.3	130
Prochloraz	400	9.6	134.5
Propiconazole	125	12.1	119.5
Untreated	-	21.4	100
SE ±		2.7	6.8

Treatments applied at GS 32 - 33 (5% infection at application)
Spray dates 1-5.5.81
Assessments made after 4 - 6 weeks at GS 72
Sites at Coln. St. Aldwyns and Bourton on the Water
Untreated yield: 3107kg/ha

At five sites laid down in Autumn 1980, disease levels remained between 2 - 5% during the winter months and significant re-infection only occurred at one Norfolk site during the spring. Table 3 shows data from this site recorded after autumn, autumn + spring and spring only sprays were applied.

It appears that autumn sprays did have an effect on subsequent infection in the spring as disease levels occurring at late flowering were essentially the same from double applications made in autumn + spring and single autumn only sprays. Single spring sprays were slightly less effective than autumn + spring sprays. Applications made in the spring however, were important in maintaining green leaf area and this is well correlated with the yield data.

Table 4

Spray timing and net blotch control in winter barley

Treatment	Application Rate (g ai/ha)	Net blotch (% infection of flag leaf)			Green leaf area (% viable flag)			Yield (as % untreated)		
Growth stage at spraying		GS 15	15+50	50	GS 15	15+50	50	GS 15	15+50	50
Prochloraz	300	9.9	9.4	-	11.0	20.0	-	93.9	106.9	-
Prochloraz	400	7.8	7.9	11.9	7.1	21.3	26.0	94.8	111.7	112.2
Propiconazole	125	7.8	9.6	-	10.4	28.8	-	92.6	112.9	-
Untreated	-		(21.0).			(14.1)			(100)	
SE ±			1.32			1.89			4.71	

Site - Saham Toney, Norfolk.
Treatments applied at GS 15 and/or 50 (3% infection at GS 15, 7.4% infection at GS 50).
Spray dates 29.10.80 and 3.6.81
Assessments made at GS 65 (16 days after spring application)
Untreated yield: 3047 kg/ha

Septoria

Prochloraz generally gave good control of Septoria infections on the upper leaves and glumes, the activity being essentially similar to competitive products when applied at a corresponding frequency and timing. See Table 5.

It is apparent that single applications made at a typical eyespot timing (GS 31) will give little protection to the head and upper leaves later in the season. Some residual effect was however demonstrated when double applications made at GS 31 and GS 60 are compared to single sprays made at the onset of flowering.

Table 5

The control of Septoria in winter wheat at two sites

Treatment	Rate (g ai.ha)	Growth stage at spraying	Septoria (% infection on flag or second leaf)	Septoria (% infection on glume)	Yield (as % untreated)
Prochloraz	400	31	16.4	13.2	106.6
Prochloraz	400	60	9.4	9.3	109.4
Prochloraz	400 + 400	31 + 60	5.9	9.3	110.6
Triadimefon/ captafol	(125/1300)	60	12.1	7.4	109.9
Triadimefon/ carbendazim + Triadimefon/ captafol	(125/250) + (125/1300)	31 + 60	7.5	6.0	114.8
Untreated	-	-	15.7	15.0	100
SE ±			1.9	2.1	3.31

At GS 31 there was 12% infection on leaf 4. At GS 60, 3% infection on flag leaf.
Spray dates 21-23.4.81 and 12-18.6.81
Assessments made at GS 80 5-6 weeks after last application.
Sites at Forward Green and Stowbridge.
Untreated yield: 5720 kg/ha.

The importance of spray timing in reducing Septoria is well illustrated with data obtained from a single Suffolk site (Table 6). In considering single applications, a spray made at GS 37 gave optimum disease control and this is well correlated with the maintenance of green flag leaf area when assessed at GS 79.

An additional application at flowering did not produce any corresponding benefit in disease control but had a significant effect in maintaining green leaf area. This effect was seen with both prochloraz and competitive products.

Table 6

The effect of spray timing on Septoria development in winter wheat

Treatment	Application rate (g a.i./ha)	Growth stage at spraying	Septoria (% infection on leaf 2)	Green leaf area (% viable flag leaf)	Yield (as % untreated)
Prochloraz	400	GS 31	10.5	13.5	105.9
Prochloraz	400	37	3.9	32.3	125.2
Prochloraz	400	65	13.9	27.3	114.4
Prochloraz	400 + 400	31 + 65	6.1	29.3	125.5
Prochloraz	400 + 400	37 + 65	4.1	43.7	129.9
Triadimefon/captafol	125 + 1300	65	15.1	24.3	103.9
Triadimefon/carbendazim + triadimefon/captafol	(125/250) + (125/1300)	31 + 65	4.7	44.3	136.7
Untreated	-		22.1	8.9	100
SE ±			2.2	6.4	5.41

Site - Cockfield, Suffolk
Treatments applied at GS 31 & 37 and/or 65 (5% infection on leaf 4 at GS 31, 22% on leaf 4 at GS 37).
Spray dates - 14.4.81, 15.5.81, 23.6.81.
Assessment of Septoria made 14 days after GS 65.
Green leaf area assessed at GS 85.
Untreated yield: 5520 kg/ha.

DISCUSSION

Prochloraz has confirmed its high potential for the control of net blotch in winter barley producing substantial yield benefits. These findings have been corroborated in 1981 ADAS regional trials (Locke *et al* 1981).

There is strong evidence that prochloraz gives good protectant control of the disease from single spray applications, but conditions clearly exist in practice where more than one application would be expected to give optimum control of the disease without sacrificing good cost/benefit ratios. Work with prochloraz will be extended in further trials to examine multiple applications in the spring. Curative ability will also be examined.

It is clear that further work is required to clarify the benefits of autumn application. There is evidence of a residual effect in the spring following autumn application but this requires closer correlation with yield figures before recommendations can be made.

In controlling Septoria with prochloraz, timing of application was shown to be important if disease control was to be maximised. As expected, conventionally timed applications made at GS 60-65 gave the most effective control of glume blotch and delayed the senescence of the flag leaf. Earlier applications, particularly at GS 37, gave good protection of the flag and upper leaves and this effect was still evident towards crop maturity after a single spray or in combination with a further spray at GS 60 - 65.

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THE COST EFFECTIVE USE OF FUNGICIDES IN WINTER WHEAT IN AN AREA OF HIGH DISEASE RISK

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Summary The response to a full fungicide programme ranged from - 2 per cent on the wheat cultivar Maris Huntsman in 1976 to 57 per cent on Bounty in 1981. The recently introduced semi-dwarf cultivars gave larger yield responses than the longer strawed traditional types. There was no indication that disease control influenced the optimum nitrogen level but the efficiency of nitrogen use was increased.

In a further series of experiments from 1979 - 1981 the cost effectiveness of disease control was assessed by comparing various fungicides and fungicide programmes. Consistently economic yield responses were obtained. The greatest increase in gross margin was £109/ha following the use of a fungicide to control eyespot (*Pseudocercosporella herpotrichoides*) at GS31 together with a broad spectrum fungicide at ear emergence to control *Septoria* spp and mildew (*Erysiphe graminis*).

INTRODUCTION

Farmers' interest in the use of fungicide sprays on winter wheat increased rapidly during the 1970's. The carbendazim-generating (MBC) fungicides are widely used for control of eyespot (*Pseudocercosporella herpotrichoides*). These fungicides were also shown to be effective against glume blotch (*Septoria nodorum*) by Melville and Jemmett (1971). Similarly Jenkins and Morgan (1969) demonstrated the importance of controlling infections of leaf spot (*Septoria tritici*). The introduction of broad spectrum fungicides of the morpholine and triazole groups which offered good control of powdery mildew (*Erysiphe graminis*), brown rust (*Puccinia recondita*) and yellow rust (*Puccinia striiformis*) further encouraged fungicide use.

There is still much discussion concerning the merits of routine, prophylactic applications of fungicides compared to applications based on either a disease forecast or the level of disease already present. Cost inflation may lead to a re-appraisal by some currently using routine applications. However, there are circumstances of regular high disease incidence where the use of fungicides is very cost effective and both approaches can lead to a similar high fungicide input.

ADAS guidelines on the use of fungicides are given in 'The use of fungicides and insecticides on cereals 1981' (MAFF 1981). Threshold values are described where the use of fungicides for disease control is likely to be profitable. NIAB variety testing procedures, described by Fiddian (1979) now includes a fungicide programme designed to restrict diseases to below 10 per cent of leaf area infection. Such data provides valuable information to aid decision making regarding fungicide use.

METHODS AND MATERIALS

The experiments reported were sited at Rosemaund EHF in Herefordshire situated on silty loam to silty clay loam soils of the Bromyard and Middleton soil series. The soil although structurally unstable is water retentive and predominantly of 1 - 2 m depth. Altitude is 84 m with an average rainfall of 664 mm.

Multifactor experiment on winter wheat (1976-79) This experiment contained a comparison of no fungicides with a full fungicide programme, the objective of which was to keep disease levels to a minimum. A range of cultivars representative of high yielding feed wheats, semi-dwarf types and quality wheats were tested at six levels of nitrogen fertilizer with three timings.

Full fungicide programme	Growth stage (Zadoks et al, 1974)
Carbendazim 0.25 kg ai/ha + fluotrimazole 187.5 mls ai/ha	30-31
Captafol 1.4 kg ai/ha + fluotrimazole 187.5 mls ai/ha	39
*Captafol 1.4 kg ai/ha + fluotrimazole 187.5 mls ai/ha	62-65

* In 1976 carbendazim 0.25 kg ai/ha + dithiocarbamate 1.8 kg ai/ha

Fluotrimazole was used in this series of experiments to avoid problems which may have resulted on small plots from triadimefon activity in the vapour phase.

Winter wheat - nitrogen level and timing, chlormequat and disease control 1980-81) A similar experiment continued the principle of testing the response to a full fungicide programme over a range of nitrogen levels and timings with and without the growth regulator chlormequat.

Further details of the treatments are given below:-

1. Nitrogen level (kg/ha)
   six increments of 30 kg/ha giving levels from 0 to 150 kg/ha
2. Growth regulator
   i Nil (control)
   ii Chlormequat at 460 g ai/ha
3. Fungicide
   i Nil (control)
   ii Full fungicide programme consisting of:-
   triadimefon 0.125 kg ai/ha +)
   carbendazim 0.25 kg ai/ha +) at GS 30-31, 39-45 and 70-75
   captafol 1.4 kg ai/ha)

   In addition in 1981 propiconazole at 0.125 kg ai/ha was applied at GS22 to control early mildew infection.

In these experiments the objective was to measure both main effects and interactions in the presence and absence of disease. Consequently the fungicide programme was comprehensive and regardless of cost. The efficacy of fungicides, aspects of timing and cost effectiveness were assessed in a further series of experiments

Economics of disease control (1979-81)

Treatment number	Fungicide treatment	Growth stage
0	Nil (control)	
1	carbendazim 0.25 kg ai/ha	31
2	triadimefon 0.125 kg ai/ha	31
3	carbendazim 0.25 kg ai/ha + triadimefon 0.125 kg ai/ha	31
4	triadimefon 0.125 kg ai/ha	55-59
5	captafol 1.4 kg ai/ha	55-59
6	triadimefon 0.125 kg ai/ha + captafol 1.4 kg ai/ha	55-59
7	carbendazim 0.25 kg ai/ha + triadimefon 0.125 kg ai/ha + captafol 1.4 kg ai/ha	31) 55-59)
8	carbendazim 0.25 kg ai/ha + triadimefon 0.125 kg ai/ha + triadimefon 0.125 kg ai/ha + captafol 1.4 kg ai/ha	31) 55-59)

Assessments

Leaf and ear diseases were assessed at intervals using the 'Guide for assessments of cereal diseases' prepared by Plant Pathology Laboratory, Harpenden. Disease observations and assessments of per cent green leaf tissue were made on 10 tillers taken at random from each plot.

An area of approximately 45 m^2 was harvested from each plot using a small plot combine harvester, fresh weight of grain recorded and a sample oven-dried for an estimate of moisture content and 1000-grain weight.

All experiments were made on second wheat crops after ley with the exception of the multifactor experiment on winter wheat in 1976 and 1977 which were first wheats after ley.

Spray application

In these experiments the plot size was 50.1 m^2. Fungicides were applied by knapsack sprayer (e.g. Oxford Precision Sprayer) in water volumes ranging from 250 to 330 l/ha at 2.7 bar.

Experiment design

The multifactor experiment on winter wheat used a factorial design of a single replicate with the residual variance estimated from the 4-factor interaction.

The winter wheat - nitrogen level and timing, chlormequat and disease control experiment consisted of two randomised blocks with split plots. The 'economics of disease control' experiment was a randomised block with three replications.

RESULTS

Yield responses obtained from a full fungicide programme

The yield responses obtained from the full fungicide programme applied in the two series of experiments 'multifactor experiment on winter wheat' and 'winter wheat - nitrogen level and timing, chlormequat and disease control are given in Table 1. The disease incidence is summarised in Table 2.

Table 1

Yield response to a full fungicide programme (t/ha at 85% d.m.)

Year	Cultivar		Nil	Treatment	Fungicide	Yield response
1976	Maris Huntsman		4.63		5.07	0.44
	Hobbit		4.59		5.31	0.72
	Flanders		4.10		4.49	0.39
		SED		$\pm$0.330		
1977	Maris Huntsman		7.55		7.38	-0.17
	Hobbit		7.11		7.75	0.64
	Flanders		7.58		7.95	0.37
		SED		$\pm$0.292		
1978	Maris Huntsman		7.85		8.22	0.37
	Mardler		7.89		8.29	0.40
	Armada		7.81		8.80	0.99
		SED		$\pm$0.104		
1979	Maris Huntsman		6.67		7.46	0.79
	Mardler		6.22		6.96	0.74
	Armada		6.24		7.84	1.60
		SE		$\pm$0.116		
1980	Bounty		7.75		8.93	1.18
		SED		$\pm$0.298		
1981	Bounty		4.98		7.82	2.84

Table 2

Per cent leaf area infected with mildew or Septoria spp and per cent green leaf area at GS75

Year	Cultivars		Fungicide treatment Nil			Fungicide		
			Mildew	Septoria	Green	Mildew	Septoria	Green
		leaf	3	3	1	3	3	1
1976	Maris Huntsman		3	NA	70	2	NA	67
	Hobbit		9	NA	31	6	NA	33
	Flanders		16	NA	50	5	NA	53
		leaf	1	1	1	1	1	1
1977	Maris Huntsman		4	10	79	tr	8	80
	Hobbit		18	18	56	tr	9	81
	Flanders		2	12	61	tr	11	76
		leaf	1	2	1	1	2	1
1978	Maris Huntsman		4	55	42	0	24	52
	Mardler		1	72	35	0	33	57
	Armada		6	28	43	0	3	68
		leaf	2	2	1	2	2	1
1979	Maris Huntsman		2	32	3	0	16	5
	Mardler		2	44	1	0	22	3
	Armada		11	45	2	0	16	12
		leaf	1	2	2	1	2	2
1980	Bounty		tr	52	26	tr	17	76

NA No assessment, Septoria spp at low level.

Eyespot Number of stems with severe lesions <10 per cent in all years.

There was a marked variation between years in the response to the fungicide programme with 1976 and 1977 generally the least responsive.

Yields were particularly low in 1976 following a dry spring and summer with high temperatures; levels of foliar diseases were low. Yields were high in 1980 following a long cool grain filling period, and the cultivar Bounty gave a large response of 1.18 t/ha to the fungicide programme with Septoria spp as the main foliar disease problem.

Cultivars differed widely in their response to disease control with Maris Huntsman in 1977 apparently showing a negative value; however this was much smaller than the standard error. In contrast Armada gave large yield responses of 0.99 and 1.60 t/ha in 1978 and 1979 respectively. Similar large yield increases of 1.18 and 2.84 t/ha were obtained from Bounty in 1980 and 1981 respectively. 1981 was particularly noteworthy for the high levels of mildew and Septoria spp from early spring to harvest.

Winter wheat - nitrogen level and timing, chlormequat and disease control experiment

Table 3

Yield of grain (t/ha at 85% d.m.)

	Fungicide	Nitrogen level kg/ha						
		0	30	60	90	120	150	Mean
1980	nil	6.35	7.29	7.77	8.25	8.40	8.43	7.75
	programme	7.13	8.39	9.38	9.09	9.75	9.85	8.93
	SED	V.I. = $\pm$ 0.573, H = $\pm$ 0.475						$\pm$0.422
1981	nil	4.60	4.94	5.10	5.26	5.18	5.24	4.98
	programme	6.94	7.42	7.80	8.33	8.18	8.48	7.82

V.I. = for vertical and interaction comparisons

H = for horizontal comparisons only

The mean nitrogen response curve showed an economic response up to 120 and 90 kg/ha in 1980 and 1981 respectively with little indication that the optimum was different following a full disease control programme. The fungicide programme increased yield at all nitrogen levels but the response tended to be greatest at the higher levels of nitrogen. The efficiency of nitrogen utilisation, as described by the slope of the nitrogen response curve, was greater where diseases were controlled by a full disease control programme. No interaction between the growth regulator chlormequat and the fungicide regimes was observed.

Economics of disease control

Table 4

Response in grain yield (t/ha at 85% d.m.)

Treatment number	1979 Hobbit	1980 Bounty	1981 Brigand	Mean increased gross margin £/ha
0	6.84	7.46	6.55	
1	0.20	0.57	0.46	32
2	0.20	0.28	0.34	15
3	0.38	1.14	0.65	53
4	0.34	0.25	0.98	40
5	0.26	0.47	0.61	28
6	0.54	0.77	1.24	60
7	-	1.35	1.51	*109
8	0.47	1.46	2.09	90
SED	$\pm$0.173	$\pm$0.200		

* mean of 1980 and 1981 only.

Statistically significant ($P = 0.05$) yield responses were obtained in 1979 from carbendazim and triadimefon applied at GS 31 and from all fungicides, with the exception of captafol applied at GS 57 - 59.

In 1980 yield increases ($P = 0.05$) were obtained from all fungicide treatments except triadimefon applied at GS 31 or GS 57 - 59. The largest increases in grain yield were given by treatments 9 and 10 where eyespot control at GS 31 was followed by a broad spectrum fungicide mixture at GS 57 - 59.

In 1981 the yield responses followed a similar pattern to that in 1980 but with even higher yield increases from the control of mildew and Septoria spp at GS 55. The highest yields were again given by treatments 9 and 10.

The increased gross margins calculated from the mean yield response and the 1981 recommended chemical cost (assuming a wheat sale price of £100/tonne) are also presented. These illustrate the cost effectiveness of fungicide inputs with the most economic responses being obtained from the most costly fungicide programme tested.

A summary of disease build up on the flag leaf of plants without fungicide and the efficacy of fungicide treatments in reducing the levels of disease is presented in Table 5. In addition a visual assessment of green leaf area is given.

Table 5

Per cent leaf area infected with mildew or Septoria and per cent green leaf area at GS 75

Treatment	1979 Mildew	1979 Septoria	1979 Green leaf	1980 Mildew	1980 Septoria	1980 Green leaf	1981 Mildew	1981 Septoria	1981 Green leaf
leaf	3	2	2	1	1	1	1	1	1
0	3.1	6	22	0.2	19	73	1.6	18	65
1	1.0	8	15	0.2	9	87	1.4	15	63
2	0.1	8	12	0.2	12	77	1.9	11	67
3	0.5	4	31	0.2	7	86	2.8	10	74
4	0.7	3	40	0.0	13	81	0.1	12	78
5	0.4	7	24	0.1	13	79	0.2	7	76
6	0.9	3	40	0.0	8	88	2.2	11	77
7	-	-	-	0.1	4	93	0.1	9	60
8	0.0	4	33	0.1	4	93	0.0	5	81

The late assessments (GS 75) of mildew and Septoria spp showed no clear relationship with fungicide treatment and yield in 1979. However, the effect of fungicide treatment on levels of Septoria spp and the maintenance of green leaf area is more clearly apparent in the 1980 and 1981 data.

DISCUSSION

The main foliar diseases of winter wheat at Rosemaund are mildew and Septoria spp with brown rust and yellow rust rarely of significance. Melville and Jemmett (1971) showed that nine sprays of the fungicide benomyl applied at 10-day intervals from GS 30 to 91 resulted in a yield increase of 43 per cent compared with untreated plots. At Rosemaund in the experiments reported the response to a full fungicide programme ranged from - 2 per cent on the cultivar Maris Huntsman in 1976 to 57 per cent from Bounty in 1981 (Table 1). Other experiments at Rosemaund have given yield responses up to 36 per cent amounting to 2.7 t/ha (Broom and Skyrme, 1981).

The effect of cultivar disease resistance is important and recognised by data given in the NIAB Farmers Leaflet No.8, 1981. Patterson (1980) derived a measure of cultivar sensitivity to changes in site yield and showed that generally short-strawed cultivars were more sensitive than those with longer straw. Similarly Broom and Skyrme (1981) showed that at Rosemaund in 1979 and 1980 a full fungicide programme increased yields more on semi-dwarf cultivars.

In some experiments reported large yield responses were obtained where disease levels were not high. Fungicides may well modify the leaf microflora and increase the duration of green leaf tissue (Table 2 and 5). Grain weight is largely determined by the area and duration of green tissue after ear emergence and in wheat the flag leaf is especially important (Thorne 1966).

From 118 experiments made between 1970 and 1978 Cooke (1980) reported a mean yield response of 0.185 t/ha (3.31 per cent) from a single spray of broad spectrum fungicide between the start of flag leaf emergence and the milky ripe stage of grain development. Responses quoted at Rosemaund to a mixture of triadimefon and captafol applied at GS 57-59 were much larger being 0.54, 0.77 and 1.24 t/ha for the years 1979, 1980 and 1981 respectively.

The timing of application of fungicides to control Septoria needs to be more precise. Forecasting methods as described by Tyldesley and Thompson (1980) may help improve the yield response obtained. Cooke (1977) obtained yield responses of 0.36 t/ha to a single spray of benomyl or benomyl with maneb, between flag leaf emergence and ear emergence, when the spray followed a postulated infection period but only 0.14 t/ha when no infection period had been recorded.

Fungicide inputs at Rosemaund, for a commercial second wheat crop, consist of a programme for eyespot control at GS 31 and a fungicide to control mildew and Septoria after GS 39 has been reached. A decision has to be taken whether to control mildew at GS 31; over the years 1979-81 this was economic on semi-dwarf cultivars. Further fungicide inputs are then based on ADAS guidelines.

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A REVIEW OF FACTORS INFLUENCING NET BLOTCH OF BARLEY AND CURRENT INFORMATION ON FUNGICIDAL CONTROL

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Summary Experiments were carried out comparing fungicides in their efficacy for controlling net blotch (*Pyrenophora teres*) of winter barley. The results showed that prochloraz and propiconazole gave the best disease control and yield response. Further experiments were done to determine the best time of application of propiconazole and the best yield responses were obtained from sprays applied during the period 12-21 May 1981. Other experiments indicated that the control of net blotch in the autumn was not economic under low disease pressure, that increasing rates of nitrogen resulted in increasing disease levels and that cv. Athene, Hoppel and Sonja are the most severely affected of those cultivars of winter barley grown in England and Wales.

Résumé Certains essais ont été réalisés afin de comparer l'efficacité de plusieurs fongicides en vue de la lutte contre l'helminthosporiose (*Pyrenophora teres*) de l'orge d'hiver. Les résultats ont démontré que le prochloraz et le propiconazole luttaient le plus efficacement contre la maladie et assuraient la meilleure rentabilité eu égard au rendement face au coût des traitements. Des essais ultérieurs ont été effectués afin de déterminer la meilleure période d'application de propiconazole, et les meilleurs rendements au point de vue de la rentabilité ont été obtenus par suite de traitements par pulvérisation effectués entre le 12 et le 21 mai 1981. D'autres essais ont indiqué qu'il n'était pas rentable dans les conditions d'incidence reduite de la maladie de lutter contre l'helminthosporiose en automne, que l'incidence de la maladie augmentait en correspondance avec des apports croissants d'azote, et que cv. Athene Hoppel et Sonja sont ceux atteints le plus gravement parmi les cultivars de l'orge d'hiver cultivés en Angleterre et au pays de Galles.

INTRODUCTION

Net blotch (*Pyrenophora teres* = *Dreschlera teres*) has recently become a major disease problem of barley in southern and western areas of England and Wales. Although low levels of the disease have been recorded for many years it is only since 1978 that widespread and severe infections have occurred on the upper leaves and awns of winter barley in the U.K.

The build-up of net blotch has coincided with major changes in the pattern of barley production in southern England. Since the mid-late 1970's there has been a dramatic increase in the area of winter barley grown, mostly at the expense of the spring barley crop. In some counties, eg Gloucestershire and Oxfordshire, winter barley now accounts for over 60% of the total barley production (Anon, 1981).

The intensification of winter barley has led to an increased autumn workload only met on many farms by earlier drilling, greater reliance on minimal cultivation and in some cases lower standards of stubble hygiene. These changes are likely to have favoured carry-over of the disease on stubble (Evans, 1969). Intensification has also been accompanied by the use of higher levels of nitrogen fertiliser and changes in cultivars and fungicide usage.

Early work on the biology and control of net blotch is reviewed by Shipton (1973). More recently the epidemiology (Jordan, 1981) and control of the seed-borne phase (Locke et al, 1981) have been reported. Little work has yet been reported on fungicidal control in the growing crop.

This paper attempts to relate the severity of net blotch infection to various factors such as cultivar and level of nitrogen fertiliser. It also presents the results of experiments carried out by members of the Agricultural Development and Advisory Service on comparison and timing of fungicide sprays applied to the growing crop.

METHODS AND MATERIALS

Fungicide trials were marked out in crops known to be infected with net blotch. Plots were of 50 m^2 with three or four replicates of each treatment in a randomised block design. Fungicides were applied, at the standard rate according to manufacturers recommendations, by knapsack sprayer at a rate of 200-300 litre water per hectare. Growth stages were described according to the decimal growth stage key (Zadoks et al, 1974) Analyses of variance were used to examine the significance of the data.

RESULTS

(a) Comparison of fungicide trials. Following the widespread occurrence of net blotch in the south of England in the 1979/80 season many trials were carried out with no central co-ordination. Also, in some cases, fungicides were applied at regular intervals in anticipation of a disease build-up late in the season. No useful information was obtained in terms of yield response but these trials did indicate which products should be examined more closely in 1980/81.

In the spring of 1981 trials were laid down at six sites and significant yield data was obtained from five of these sites. Table 1 shows the degree of control of net blotch foliar symptoms obtained from fungicides thought to have some effect against the disease. The results show that the best disease control was obtained with prochloraz and propiconazole, but neither material completely stopped disease progress. A lower degree of control was obtained with iprodione and triforine + mancozeb and in some instances captafol and carbendazim + tridemorph + maneb. Fenpropimorph and imazalil generally had little or no effect on net blotch.

The disease control results are largely reflected in the yield data (Table 2) where prochloraz and propiconazole gave an average yield increase of over 20% compared to the untreated plots. Triforine + mancozeb averaged a 15% increase, captafol 12% and iprodione 10%.

Table 1

Comparison of fungicides for the control of net blotch - percentage control of infection - 1981

Treatment	g a.i./ha	Sites Dorset	 Devon	 Staffs	 Hants	 Dyfed
prochloraz	400	73***	83***	30	52*	85***
propiconazole	125	66***	82***	24	29	75***
iprodione	1000	49***	47**	0	20	-
captafol	1400	6	45**	33	8	-
triforine + mancozeb	280 + 1600	26**	47**	17	19	65***
fenpropimorph	750	0	0	27	38	-
carbendazim + tridemorph + maneb	150 + 380 + 1600	2	42**	0	10	-
imazalil	60	11	27	0	-	-
SE treatment means		±4.85	±0.23	±2.41	±1.73	±3.53
CV%		15.3	14.9	50.7	45.3	15.9
Leaf assessed		1	1	3	2	1
% Leaf area affected on untreated plots (†)		86	41	10	8	93
Date of assessment (and growth stage)		19/6 (75)	10/6 (71)	19/6 (75)	30/6 (72)	12/6 (71)
Days from treatment to assessment		16	20	16	25	32
Cultivar		Athene	Sonja	Igri	Igri	Sonja

Significantly different from untreated control at P = 0.05 (*) P = 0.01 (**) P = 0.001 (***)

(†) Untreated for net blotch; other diseases controlled by sprays of triadimefon and carbendazim.

(b) Timing of propiconazole trials. Severe net blotch (33-100%) infection of the flag leaf, (GS 71-84) was recorded in untreated plots at all sites in this series of trials.

Propiconazole sprays gave a substantial control of infection except at Somerset where infection levels were very high. At the remaining sites single sprays applied at flag leaf emergence (GS 39) to full ear emergence (GS 58) were shown at GS 71-84 (4-5 weeks later) to have given 49-82% control of the disease on the flag leaf. This compared with 70-83% for various two spray combinations and 88-92% for three or four spray programmes.

Table 2

Comparison of fungicides for the control of net blotch - yields as a percentage of untreated control (= 100) - 1981

Treatment	g a.i./ha	Sites: Dorset	Devon	Staffs	Hants	Dyfed
prochloraz	400	123***	150***	110***	106	117
propiconazole	125	117***	145***	109**	111*	126*
iprodione	1000	111*	117*	109**	104	-
captafol	1400	109*	120*	107*	111*	-
triforine + mancozeb	280 + 1600	109*	121**	107*	108*	128*
fenpropimorph	750	104	106	103	106	-
carbendazim + tridemorph + maneb	150 + 380 + 1600	101	114*	107*	111*	-
imazalil	60	102	104	108**	-	-
SE treatment means		±0.13	±0.16	±0.12	±0.25	±0.14
CV%		5.66	7.43	3.20	5.20	10.8
Yield of untreated control t/ha (†)		4.07	3.68	6.02	6.58	2.13

Significantly different from untreated control at P = 0.05 (*), P = 0.01 (**), P = 0.001 (***)

(†) Untreated for net blotch; other diseases controlled by sprays of triadimefon and carbendazim.

The effects of differently timed single, double and multiple sprays of propiconazole on the yield of winter barley in 1981 are presented in Tables 3 and 4. The single spray giving the highest yield at all five sites was applied during the period 12-21 May. This coincided with low levels of disease (less than 3% of the leaf area of leaves 1 and 2) between flag leaf emergence and full ear emergence (growth stages 37-58). Sprays applied at this time increased yields between 12% and 40%. Sprays timed earlier or later increased yield occasionally but less consistently. The addition of a second spray, to supplement that at the optimum timing, further increased yield at three sites. The most effective single spray gave a yield increase equivalent to 48-66% of the yields achieved from a programme of 3 or 4 sprays.

(c) Effect of autumn net blotch infection on yield. The significance of autumn infection in terms of its effects on eventual yield was investigated at two sites - Oxford and Winchester - using paired plots replicated six times. The treatments compared were a) untreated for net blotch control and b) treated with propiconazole applied at 125 g a.i./ha - this treatment was applied when net blotch was first seen in the crop followed by one (Winchester) or two (Oxford) further applications at three week intervals in an attempt to exclude the disease during the period October to mid December. The entire trial area at both sites was treated in the autumn with

Table 3

Effect of differently timed single sprays of propiconazole at =25 g a.i./ha on yield compared to untreated control (= 100) - 1981

Timing of sprays - week ending:-	Devon	Somerset	Wilts	Berks	Hants
			Sites		
3 April	104				
10		102	124*	113***	
17					
24					112***
1 May		115***	138***		
8					
15	119***			122***	112***
22	137***	119***	140***		
29	119***			120***	
5 June					
12		108***	105		105
19				102	
Yield of untreated control t/ha (†)	4.25	4.90	2.92	4.59	8.32
SE treatment means	±0.15	±0.12	±0.19	±0.12	±0.31
CV%	5.56	4.39	10.23	3.16	5.70
Cultivar	Sonja	Sonja	Sonja	Igri	Igri

Significantly different from untreated control at P = 0.05 (*), P = 0.01 (**), P = 0.001 (***)

(†) Untreated for net blotch; other diseases controlled by sprays of triadimefon and carbendazim.

triadimefon + carbendazim to control other diseases and in spring/summer as per farm practice but using materials having no marked effect on net blotch. Levels of net blotch were low at both sites during the autumn and winter; at Oxford 6% infection was recorded on leaf 2 in the untreated plots (6.1.81, GS 23/24); at Winchester levels were below 1% on the untreated plots throughout the autumn. Propiconazole treated plots showed reduced levels of net blotch through the autumn although these differences did not persist into the spring. There was no significant difference in yields between treatments at either site (Table 5).

(d) Interaction between rate of nitrogen and net blotch. Figure 1 shows the effect of increasing rate of nitrogen application on the level of net blotch infection at three sites. The sites were all at soil index 0 and the nitrogen rates shown were applied at GS 30 (early - mid April). The results from these three sites indicate a relationship between nitrogen application and severity of net blotch attack, higher levels of disease correlating with higher rates of nitrogen application.

Table 4

Effect of two or more sprays of propiconazole at 125 g a.i./ha on yield compared to highest yielding single spray - 1981

Treatments	Sites Devon	 Somerset	 Wilts	 Berks	 Hants
Untreated control (†)	100	100	100	100	100
Highest yielding single spray (= A)	22 May 137	19 May 119	20 May 138	20 May 122	14 May 112
Two sprays:-					
A + 7 weeks earlier	140				
A + 6 weeks earlier		122	161*		
A + 3 weeks earlier		117	176**		
A + 1 week earlier	150*				
A + 1 week later	156***				
A + 3 weeks later		118	145	134***	
A + 5 weeks later				128	107
Three or four spray programme	177***	129*	165*	144***	118**
SE treatment means	±0.12	±0.14	±0.21	±0.12	±0.12
CV%	5.51	5.12	10.07	3.06	2.20

Significantly different from highest yielding single spray at P = 0.05 (*), P = 0.01 (**), P = 0.001 (***)

(†) Untreated for net blotch; other diseases controlled by sprays of triadimefon and carbendazim.

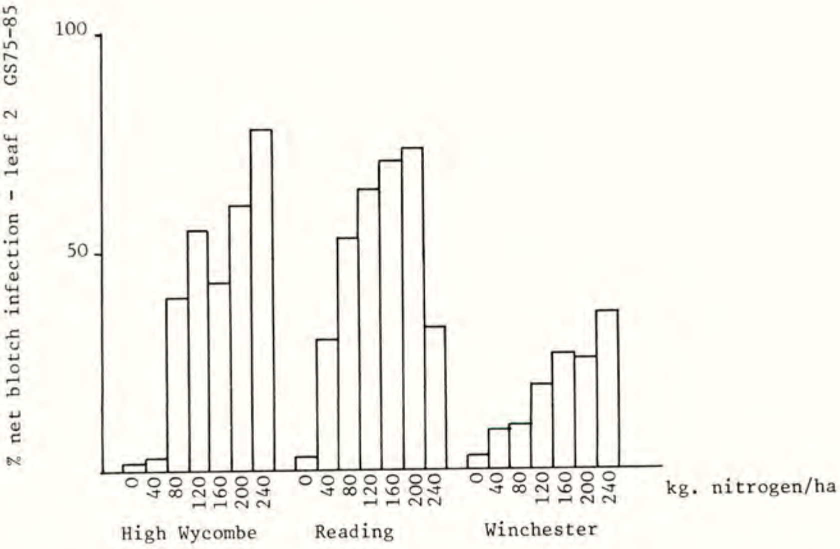
Table 5

Effect of autumn net blotch infection on yield - 1980/81

Site	Treatment	Yield t/ha
Oxford	untreated	5.58
	propiconazole (125 g a.i./ha x 3)	5.47
Winchester	untreated	4.80
	propiconazole (125 g a.i./ha x 2)	4.80

Differences in yield not statistically significant at either site, (P = 0.05).

Figure 1. Interaction between rate of nitrogen and net blotch



(e) Cultivar resistance. Trials carried out at Winchester in 1979/80 and Oxford in 1980/81 have shown that the six-row barley cultivars Hoppel and Athene are very susceptible to net blotch. Of the most widely grown two-row cultivars Igri is more resistant than Sonja. The malting cultivar Maris Otter appears to have good resistance to net blotch. However, there may be races of *Pyrenophora teres* which affect different cultivars as reports from parts of eastern England in 1981 indicated Igri to be more severely affected than adjacent crops of Sonja.

DISCUSSION

In this series of trials we have established that the best fungicide control of net blotch is achieved with the systemic materials propiconazole and prochloraz. The protectant fungicides used in the trials - iprodione, captafol and the dithiocarbamates maneb and mancozeb used in mixtures - have also given worthwhile disease control and yield increases in some cases. However, it is worth noting that the percentage control of disease symptoms with the best fungicides is only 70-85%. This level of control would not be considered satisfactory for some other cereal diseases, such as powdery mildew, but is the most that can be achieved using the presently available range of products at recommended rates.

More work needs to be carried out on spray timing, especially in relation to epidemiology and disease forecasting. Our trials have indicated the best time of application in 1981 but this will possibly vary from season to season depending upon the weather conditions. The trials have also shown that in some cases a two spray programme is economic in a year of high disease pressure.

From the more limited work on the benefits of the control of net blotch in the autumn it would appear that this is generally not worthwhile. However, disease levels in the autumn of 1980 were not very high and it could be that treatment at this time would be cost effective if net blotch were more severe.

With many diseases increasing levels of nitrogen fertiliser may lead to increased levels of infection. This appears to be the case with net blotch where a good correlation was found between nitrogen levels and disease severity.

Most of the widely grown winter barley cultivars have been introduced in the past six or seven seasons and all are more susceptible to net blotch than the oldest cultivar still grown, Maris Otter. It could be that as plant breeders have been taking no account of net blotch in their breeding programme that more susceptible cultivars have been developed. It now seems that breeding for resistance to net blotch should be given a higher priority.

Finally it is worth mentioning that all of the work in this paper refers to winter barley. However in the summer of 1981 many spring barleys in southern England, especially those adjacent to winter drilled crops, became infected with net blotch. It may be that the disease could become a problem on the spring drilled crops as well as those sown in the autumn.

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PROPICONAZOLE; DISEASE CONTROL IN CEREALS IN WESTERN EUROPE

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Summary Trial work in the important cereal growing countries of Western Europe showed propiconazole to be an effective fungicide for control of cereal foliar diseases. A good level of activity against rusts *(Puccinia spp)*, powdery mildew *(Erysiphe graminis)*, glume and leaf blotch *(Septoria spp)*, net blotch *(Drechslera teres)*, leaf blotch *(Rhynchosporium secalis)* and a side effect against eyespot *(Pseudocercosporella herpotrichoides)* was achieved at the rate of 0.125 kg/ha. The spectrum of activity is thus broader than the cereal fungicides now in use. Only in the case of severe eyespot or in certain situations of leaf and heavy glume blotch attack, is the addition of a reduced rate of carbendazim or of captafol respectively, required.

The use of propiconazole is primarily recommended according to disease situation but it may also be applied in fixed spray programmes.

Résumé Les traveaux d'essais dans régions céréalières de l'Europe de l'Ouest ont demontré que propiconazole est un fongicide efficace pour la maîtrise des maladies foliaires des céréales. Une bonne activité a été enregistrée à la dose de 0.125 kg/ha contre les rouilees (*Puccinia spp)*, oidium *(Erysiphe graminis)*, septorioses sur feuilles et glumes, helminthosporiose *(Drechslera teres)*, rhynchosporiose *(Rhynchosporium secalis)* ainsi q'un effet secondaire contre piétin-verse *(Pseudocercosporella herpotrichoides)*. Par conséquent, le spectre d'activité est plus large que celui des fongicides actuels. Uniquement en présence d'une sévère attaque du pietin-verse ou dans certain cas d'une forte attaque de septoriose, il est recommandé d'ajouter une faible dose de carbendazime ou de captafol.

L'utilisation de propiconazole est à priori préconisé selon la situation des maladies, mais, peut être appliqué suivant un calendrier de traitement fixe.

INTRODUCTION

Urech *et al* (1979) described the basic properties of propiconazole* (trade name DESMEL ® in Germany and TILT ® in all other countries) and gave preliminary results to show a comparable activity to current standards against powdery mildew *(Erysiphe graminis)* of wheat and barley, brown rust *(Puccinia hordei)* of barley, yellow rust *(Puccinia striiformis)* of wheat, leaf blotch of barley *(Rhynchosporium secalis)* and Septoria leaf and glume blotch. Against eyespot (*Pseudocercosporella herpotrichoides)* activity was also demonstrated; an unusual property for a triazole fungicide.

* Propiconazole is the proposed BSI common name for CGA 64250, the code number of 1 - (2-(2,4-dichlorophenyl)-4-propyl-1,3-dioxolan-2-yl-methyl)-1H-1,2,4-triazole).

Since then, activity against net blotch of barley (*Drechslera teres*) by the Agricultural Development and Advisory Service has been shown (Newsflash ADAS/PP/154).

The objective of this paper is to give confirmatory evidence of the above and to present new information demonstrating the broad disease control spectrum of propiconazole by citing evidence from trials conducted in Great Britain and continental Europe.

METHODS AND MATERIALS

Trials results from England (7), France (3), Germany (7), Holland (1) and Switzerland (1) are presented. These are selected from the large number conducted in each country on the basis of being typical of the disease control levels generally achieved, having minimal complications from secondary diseases and where possible, a sufficiently low experimental error. The trials were of randomized complete block design with 4 or 5 replications and a plot size of at least $10m^2$.

Propiconazole at the standard rate of 0.125 kg/ha was compared with the appropriate standard (triadimefon, triadimefon + carbendazim, carbendazim or triforine + maneb) at the locally recommended rates. Against eyespot a mixture of propiconazole + carbendazim at 0.125 + 0.1 kg/ha respectively and against mildew and leaf spot, a rate of 0.25 kg/ha propiconazole was used as additional comparisons. Against leaf spot in England, the 0.25 kg/ha rate was applied either as one dose or two doses of 0.125 kg/ha, 27 days apart and in Germany, a mixture of propiconazole + captafol at 0.125 + 0.6 kg/ha was included to conform with the local commercial recommendations for the product. Unless otherwise stated, propiconazole was formulated as a 25% e.c. w/v, propiconazole + carbendazim as a 45% w.p. and propiconazole + captafol as a 72.5% w.p. Standard treatments used as comparisons were the commercial formulations of triadimefon (25% w.p.), triadimefon + carbendazim (36.5% w.p.), triadimefon + captafol (71.25% w.p.), fenpropimorph (75% e.c. w/v), triforine (20% e.c. w/v) and maneb (80% w.p.).

All treatments were applied by precision plot sprayers at 2 bars pressure and in a water volume of 200 to 500 l/ha (200 l/ha used in United Kingdom trials only).

Eyespot assessments in United Kingdom trials were by the method described by Scott and Hollins (1974) on 100 tillers per treatment; in France by assessing % stem cross section filled with mycelium at the base (200 tillers per treatment) and in Germany, by assessing lesion severity on a 0-2 scale and calculating the disease index (0-100 scale) in a similar way to the Scott and Hollins formula (Bockmann 1963). These methods are referred to in table 1. Foliar and ear diseases were assessed as % area infected unless otherwise stated. Yields were measured using combine harvesters modified for trials work and all grain yields are corrected to 16% moisture content.

RESULTS

Eyespot (*Pseudocercosporella herpotrichoides*). Table 1 gives results of eyespot control from single trials in England, France and Germany. In the English trial, eyespot infection was moderate with a mean infection of 50%. Carbendazim at 0.25, triadimefon + carbendazim at 0.125 + 0.25 and propiconazole + carbendazim at 0.125 + 0.1 kg/ha all gave similar disease control of between 56 and 70%. Propiconazole alone at 0.125 kg/ha gave partial disease control. The French and German trial results quoted on crops severely infected with eyespot showed that propiconazole + carbendazim (0.125 + 0.1 kg/ha) gave similar disease control to the standards and an equally good yield benefit. Propiconazole alone gave an intermediate result.

Table 1 Control of eyespot *(P. herpotrichoides)* in winter wheat

treatment kg ai/ha	% eyespot infection after flowering			Grain yield as % untreated		
	England[1]	France[2]	Germany[3]	England	France	Germany
untreated	50	81	74	(6510) (kg/ha)	(5586) (kg/ha)	(6515) (kg/ha)
carbendazim 0.25/0.2	22	12	-	106	114	-
triadimefon + carbendazim 0.125 + 0.25/0.18	15	-	25	111	-	112
propiconazole + carbendazim 0.125 + 0.1	21	16	34	110	115	113
propiconazole 0.125	38	41	38	104	112	110
			LSD % P = 0.05	11.8	2.3	5.1

[1]Disease index after Scott and Hollins cv. Armada
[2]% stem base cross section infected cv. Top
[3]Disease index 0-100 cv. Diplomat
All applications made at GS 30-32

Mildew *(Erysiphe graminis)*. Results from two English and one Dutch trial on wheat are presented in table 2. At March, England, all treatments gave only moderate control of mildew which was well established at application; triadimefon gave slightly better control than propiconazole at 0.125 kg/ha, but there was a negligible difference between propiconazole at 0.25 kg/ha and triadimefon. Grain yields at harvest showed that only the 0.25 kg/ha rate of propiconazole gave a significant increase over untreated; the 0.125 kg/ha rate of propiconazole and triadimefon were similar.

At Brandon, England, all treatments applied at the early stages of mildew infection gave good control; triadimefon was slightly better than propiconazole at 0.125 kg/ha but again propiconazole at 0.25 kg/ha was similar to triadimefon. Grain yields at harvest were significantly higher with all treatments compared to untreated plots. The results of the Dutch trial showed similar results. Yield improvements over untreated were good, with propiconazole at either 0.125 or 0.25 kg/ha and with triadimefon.

On winter barley in England and Germany (table 3) both propiconazole and triadimefon gave excellent control of aggressive attacks in the autumn. Appreciable yield response resulted from the single autumn treatment.

Septoria leaf and glume blotch *(Septoria tritici* and *S. nodorum)*. In table 4, results from single trials in England and Germany are presented. A single application of triadimefon + captafol at 0.125 + 1.3, propiconazole + captafol at 0.125 + 0.6 and propiconazole alone at 0.25 kg/ha each applied after ear emergence were compared with a double treatment of propiconazole alone at 0.125 kg/ha applied at flag leaf emergence and again after ear emergence. The level of attack in the German trial was particularly severe and prolonged. In both trials foliar disease control was best by the split application of propiconazole alone and this treatment gave the highest yields. The control of glume blotch was similar with all treatments at between 50 and 60%.

Table 2 Control of mildew *(E. graminis)* in winter wheat

treatment kg ai/ha	% foliar mildew England[1] March Foliar	England[2] Brandon Flag	England[2] Brandon Ear	Holland[3] Flag	Holland[3] Ear	Grain yield as % untreated England March	England Brandon	Holland
untreated	39	33	23	25	15	(4964) (kg/ha)	(2538) (kg/ha)	(5600) (kg/ha)
triadimefon 0.125	15	1	4	6	0	107	154	113
propiconazole 0.125	20	5	6	10	0	109	145	117
propiconazole 0.25	16	2	5	6	0	112	148	124
					LSD % P = 0.05	10.4	21.3	10

[1]17 days after single application at GS 63 cv. Kinsman 10-15% foliar infection at treatment

[2]37 days after single application at GS 39 cv. Sappo 5% foliar infection at treatment

[3]18 days after single application at GS 59 cv. 'experimental' 15% flag infection at treatment

Table 3 Control of mildew *(E. graminis)* in winter barley in the autumn

treatment kg ai/ha	% mildew infection England[1]	Germany[2]	Grain yield as % untreated England	Germany
untreated	56	100	(4225) (kg/ha)	(4054) (kg/ha)
triadimefon 0.125	16	9	108	124
propiconazole 0.125	14	8	113	119
		LSD % P = 0.05	28	15.9

[1]35 days after single application in November at GS 14.23 cv. Maris Otter Soil type: sandy loam

[2]13 days after single application in November at GS 21 cv. Malta Soil type: sandy loam

Table 4 Control of leaf spot and glume blotch *(Septoria spp)* in winter wheat

	kg ai/ha	% Septoria England[1] Flag	% Septoria Germany Flag[2]	% Septoria Germany Ear[3]	Grain yield as % untreated England	Grain yield as % untreated Germany
1	untreated	19	40	70	(5964) (kg/ha)	(3500) (kg/ha)
2b	triadimefon + captafol 0.125 + 1.3	13	33	31	129	127
3b	propiconazole 0.25	9	30	35	129	125
4a +b	propiconazole 0.125 propiconazole 0.125	8	11	29	132	134
5b	propiconazole + captafol 0.125 + 0.6	-	23	33	-	120
				LSD % P = 0.05	11.6	10

[1]27 days after (b) application at GS 71; (a) application at GS 45 cv. Armada
[2]Carbendazim-based product applied to all treatments for control of eyespot
[3]15 days after (b) application at GS 55; (a) application at GS 37 cv. Diplomat
31 days after (b) application

Brown Rust *(Puccinia hordei, Puccinia dispersa)* in barley and rye. The control of brown rust in trials in France and Germany is shown in table 5. Propiconazole gave good control of brown rust in both barley and rye. The activity as demonstrated in the German trial was superior to the standard due to the longer lasting effect. Propiconazole also gives good control of *Puccinia striiformis* and *P. triticina* as reported by Urech *et al* (1979).

Table 5 Control of *(P. hordei, P. dispersa)* in barley and rye

treatment kg ai/ha	% Brown Rust Germany[1]	% Brown Rust Germany[2]	% Brown Rust France[3]	Grain yield as % untreated Germany	Grain yield as % untreated France
untreated	78	70	49	(4050) (kg/ha)	(3092) (kg/ha)
triadimefon 0.125	41	54	4	121	139
propiconazole 0.125	28	35	5	138	144
			LSD % P = 0.05	8.4	10.3

[1]25 days after single application at GS 39 Spring Barley cv. Dura
[2]56 days after single application at GS 31-32 Winter Rye cv. Carsten
[3]18 days after second application at GS 61 Spring Barley cv. Thibault
First application at GS 32

Leaf blotch of barley *(Rhynchosporium secalis)*. Table 6 gives results from single trials in England, Germany and France. In England propiconazole was clearly superior to triadimefon for control of this disease. Disease data in the French and Germany trials refer to flag leaf infections and the good control achieved by propiconazole resulted in yield improvements of above 20% over untreated.

Table 6 Control of leaf blotch *(Rhynchosporiun secalis)* in winter barley

treatment kg ai/ha	% foliar leaf blotch England[1]	Germany[2]	France[3]	Grain yield as % untreated England	Germany	France
untreated	21	70	28	(4641) (kg/ha)	(3886) (kg/ha)	(3850) (kg/ha)
triadimefon 0.125	4	45	9	104	117	114
propiconazole 0.125	1	20	9	108	125	124
			LSD % P = 0.05	12.1	12.8	11.9

[1]64 days after single application at GS 24 cv. Maris Otter
[2]24 days after single application at GS 31 cv. Dura
[3]40 days after single application at GS 32 cv. Sympa

Net blotch *(Drechslera teres)*. Results from single trials in England, Germany and Switzerland are given in table 7. Disease control by propiconazole was much better than the standards. In the Swiss trial a moderate attack of *R. secalis* was also present; in the English trial both *R. secalis* and mildew occurred.

Table 7 Control of Net blotch *(Drechslera teres)* in winter barley

treatment kg ai/ha	% foliar net blotch England[1]	Germany[2]	Switzerland[3]	Grain yield as % untreated England	Switzerland
untreated	22	50	20	(5100) (kg/ha)	(4929) (kg/ha)
triadimefon 0.125	18	41	12	119	108
triforine + maneb 0.266 + 1.6	17	-	-	120	-
propiconazole 0.125	6	3	4	135	117
			LSD % P = 0.05	23	7.2

[1]36 days after last spray at GS 47 All treatments applied at GS 47, GS 26 and GS 14.21. Leaf blotch and some mildew also present. cv. Sonja
[2]17 days after second application at GS 49; first application at GS 32 cv. Mammot
[3]14 days after second application at GS 59; first application at GS 32. Leaf blotch also present. cv. Gerbel

Large yield increases were recorded from the English trial of 35% following propiconazole and 19 or 20% following the triadimefon or triforine-based standards.

DISCUSSION AND CONCLUSION

The results presented in table 1 - 7 are a representative selection of more than 1,000 trials carried out in Western Europe.

Mildew, rusts, Septoria leaf spot and glume blotch, leaf blotch and net blotch of barley were well controlled by one treatment of propiconazole at 0.125 kg/ha when first symptoms were visible. Effective protection was for three to five weeks. ADAS work in progress (Locke, personal communication) confirms that after this time a second application is worthwhile if re-infection occurs.

Against Septoria leaf spot and glume blotch, a single treatment after ear emergence with propiconazole alone at 0.25 kg/ha or propiconazole at 0.125 kg/ha plus a reduced rate of captafol of 0.6 kg/ha gave up to *circa* 50% control. However, a double treatment of propiconazole at 0.125 kg/ha with an interval of 3-5 weeks between sprays gave improved disease control of 58 to 73%. It is important that the first treatment is applied at the beginning of disease build-up for best effect and this is in agreement with ADAS trial results which showed that application of foliar fungicides at flag leaf emergence resulted in improved yield response in comparison with later treatments (Cook 1980). Our interpretation of this data is that the two-spray approach with the emphasis on the early treatment and a flexible attitude towards the second treatment according to weather, disease activity etc., is an appropriate practical recommendation.

Eyespot control by propiconazole was confirmed in table 1, but against high infection the control was not sufficient. The addition of a reduced rate of carbendazim at 0.1 kg/ha increased the activity to the level of the standards. Limited experience in France suggests that against eyespot in barley, propiconazole alone may be sufficiently effective. This has not been confirmed in the U.K.

The broad spectrum of activity of propiconazole alone which includes control of net blotch and leaf blotch of barley; and leaf spot and glume blotch of wheat, allows the farmer to solve his disease problems in most situations with one single product. Two exceptions exist; a) crops with severe eyespot infections require propiconazole plus carbendazim at 0.1 kg/ha (in France 0.15 kg/ha) and b) where only a single application is acceptable in high risk situations against *Septoria* on ears, propiconazole plus a reduced rate of captafol at 0.6 kg/ha or the increased rate of 0.25 kg/ha is recommended.

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NOTES

TRIADIMENOL SEED TREATMENT ON SPRING BARLEY; RESULTS OF A 60 SITE EVALUATION IN THE UNITED KINGDOM, 1980

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Summary In 1980 seed grain of five spring barley cultivars was treated with a triadimenol formulation and compared with a standard (ethirimol plus phenyl mercury acetate). At sixty sites in the United Kingdom, seed grain of each treatment was drilled side by side in ca. 2-3 ha plots. No significant differences were found in numbers of plants emerged, tiller numbers, % grain >2.5 mm, and % grain >2.2 mm. Triadimenol treated crops yielded significantly more grain, had more grains per ear, heavier grains as measured by 1000 grain weight and more grains in the largest size category (>2.8 mm). Triadimenol treatment significantly reduced mildew infections and increased green leaf area. In a limited number of trials, brown and yellow rusts and leaf blotch occurred, and infection was reduced by triadimenol. At over 80% of the 54 sites harvested yield differences resulted in a financial gain from the use of triadimenol seed treatment.

Résumé En 1980 des semences de cinq variétés d'orge de printemps furent traitées avec une formule de triadiménol et comparé avec une formule courante (éthirimol plus acétate de phényl de mercure). Dans soixante exploitations en Grande-Bretagne, des semences traitées de différentes facons furent semées côte à côte sur des parcelles d'environ 2 à 3 ha. Aucune différence significative ne fut observée dans les nombres de plantes levées, les nombres de talles, les pourcentages de grains de grosseur supérieure a 2,5 mm et ceux de grosseur supérieure a 2,2 mm. Les cultures traitées au triadiménol donnèrent nettement plus de grains, le nombre de grains par épi et le poids des grains (poids de 1.000 grains) augmenta, et on enregistra plus de grains dans la catégorie de grosseur supérieure (+ de 2,8 mm). Le traitement au triadiménol reduisit très nettement l'oidium et augmenta la surface verte des plantes. La rouille jaune, la rouille brune et la rhynchosporiose, apparues dans un nombre limité d'exploitations, furent réduites par traitement au triadiménol. Pour plus de 80% des 54 exploitations, l'accroissement des rendements apporta un gain financier du fait du traitement des semences au triadiménol.

INTRODUCTION

The successful control of powdery mildew of barley (*Erysiphe graminis* f. sp. *hordei*) by means of a seed treatment was first achieved with the fungicide ethirimol. Benefits from treatment included larger, more vigorous plants, with more roots and more fertile tillers bearing ears with larger grains (Brooks, 1970, 1972; Hall, 1971; Finney and Hall, 1972). This method of protecting barley crops from mildew, and thus increasing grain yields, became popular in the 1970s and there are many examples of yield responses to ethirimol treatment (Jenkyn, 1974;

Jenkyn and Moffat, 1975; Little and Doodson, 1971; Doodson and Saunders, 1969). More recently triforine (Schicke et al. 1971), thiophanate-methyl (Mercer, 1971; Jenkyn and Prew, 1973) and nuarimol (Casanova et al. 1977) have been developed as seed treatments for the control of powdery mildew and certain other diseases of barley.

The effectiveness of a dry formulation containing triadimenol (25% w/w) and fuberidazole (3% w/w) as a seed treatment in the United Kingdom was reported by Wainwright et al. (1979) and by Adam et al. (1981). The most commonly occurring seed-borne fungal diseases of barley were well controlled and at the same time, in the case of the spring crop, season-long protection from mildew and leaf blotch (*Rhynchosporium secalis*) was usually afforded. Yellow and brown rusts (*Puccinia striiformis* and *P. hordei*) which usually occur later in the season were sometimes less well controlled. During this development work the problem inherent in the use of small plots was experienced. Due to interference between plots results may underestimate the treatment effect (Jenkyn et al. 1979). Despite the very good fungicidal effect of the triadimenol seed treatment in the trials reported in 1979 by Wainwright et al. at this Conference, yield responses to treatment and disease infection on untreated plants were not high.

This paper reports the findings from 60 sites in the United Kingdom where triadimenol treated spring barley seed was drilled by farmers in an attempt to avoid the small plot problem and to evaluate the treatment under practical field conditions.

METHODS AND MATERIALS

A dry seed treatment containing 25% w/w triadimenol and 3% w/w fuberidazole was compared with a standard treatment which was a flowable formulation of ethirimol (580 g/l) plus an organo-mercurial fungicide, which was either a dry seed treatment containing 3.36% w/w phenyl mercury acetate or a liquid formulation containing 33.6 g/l of phenyl mercury acetate.

Sixty sites from Newquay, Cornwall in the South to Fochabers, Moray in the North, were located. Certified (C2) seed lots of the spring barley cultivars Aramir, Ark Royal, Georgie, Golden Promise and Keg, were divided and one half of each was treated with the experimental triadimenol formulation whilst the other half received the standard. Depending upon the location of the chemical applicator seed grain was treated using one of the following: Centaur Mk I, Centaur Mk II, Plantector Mk II, Rotostat Mk II. The machinery was calibrated to apply the following dose rates: triadimenol 25% w/w plus fuberidazole 3% w/w (150 g/100 kg seed grain), ethirimol 580 g/l (670 ml/100 kg seed grain), 3.36% phenyl mercury acetate dry seed treatment (120 g/100 kg seed grain), 33.6 g/l phenyl mercury acetate liquid seed treatment (110 ml/100 kg seed grain). Relevant data concerning the seed and treatments are given in Table 1. The treated grain was weighed-off into 50 kg multi-ply paper sacks ready for drilling.

Each farmer received 500 kg of seed grain of each treatment to drill ca. 2-3 ha depending upon the farmer's choice of seed rate. Seed drills (Table 2) were calibrated so that the same seed rate could be used for both treatments and drilling was done by the farm staff in their accustomed manner.

Every site was monitored by recording, for each treatment, the final plant stand; mildew and other air-borne diseases by grading the top 3 leaves of 25 tillers on a 0-9 logarithmic scale, usually more than once; green leaf area using a logarithmic grading system; numbers of fertile tillers by sampling 10 x 5m lengths of row; grain number per ear by sampling 200 ears; the yield of grain by harvesting a strip, usually longer than 100 m (grain weight was corrected to 14%

moisture) and finally a 2 kg grain sample was analysed for clean grain content, hectolitre weight, thousand grain weight and grain sizes >2.8, >2.5 and >2.2 mm.

Table 1

Seed grain and treatment details

Cultivar	Aramir	Ark Royal	Georgie	Golden Promise	Keg
Applicator	Rotostat Mk II	Centaur Mk I	Centaur Mk II	Plantector Mk II	Plantector Mk II
Application date	21/1/80	15/1/80	16/1/80	29/1/80	18/1/80
Thousand grain wt	44.1	31.8	45.0	43.3	41.0
Moisture content %	15.2	14.6	16.2	14.1	15.4
Germination %	98	99	97	98	95
Mercurial formulation	PMA 33.6 g/l LS	PMA 33.6 g/l LS	PMA 33.6 g/l LS	PMA 3.36% w/w DS	PMA 3.36% w/w DS
Seed loading as % of target dose					
Triadimenol	125	114	99	81	86
Ethirimol	98	90	100	95	99
Mercury	88	72	71	94	76

DS = Dry seed treatment   LS = Liquid seed treatment

Table 2

Types of cereal seed drills employed

38 Massey-Ferguson MF 30	1 Alpha-Accord pneumatic
5 Farmhand placement	1 Bettinson 3m (sponge metering rollers)
4 Carier cultivator	1 John Deere 8250
3 Ransomes Nordsten	1 Wartsila Falcon 400
1 International S61	1 AVA Viking type H.S.
1 International 510	1 Western/Fiona D78
1 Massey-Ferguson MF 29	
1 Massey-Ferguson MF 34	

39 sites were combine drilled with fertilizer

RESULTS

Table 3 summarises the results of the whole programme of trials. The means from each treatment were statistically analysed using a test based on Student's t-distribution and calculating the probability of a difference between the two treatment means. The number of results used to calculate each mean varied because in a programme of this size inevitably not all of the planned assessments were carried out at each site. There were no significant differences between triadimenol seed treatment and the standard in numbers of plants emerged, tiller numbers, % grain >2.5 mm and % grain >2.2 mm. However, the triadimenol seed treated crops yielded significantly more grain, more grains per ear, more grains in the largest size category of >2.8 mm and heavier grains as measured by 1000 grain weight.

Table 3

Overall means for emergence, yield and disease parameters

Treatments	g a.i./ 100 kg seed	Emergence		Yield and grain quality								Disease infection levels (%) (top 3 leaves)						
												Mildew						
		Plants/m^2	% of seed sown	No. tillers/m^2	Yield kg/ha	No. grains/ear	Hectolitre wt (kg)	1000 Grain wt (g)	% Grain >2.8 mm	% Grain >2.5 mm	% Grain >2.2 mm	GS 22-39	GS 40-59	GS 60-85	Brown rust	Yellow rust	Leaf blotch	% GLA
Triadimenol + fuberidazole	37.5 4.5	292	73	910	5539	22	67	38	56	82	92	0.1	0.3	1.0	0.8	1.6	0.4	72
PMA + ethirimol	3.7-4.0 388.6	295	74	924	4966	21	66	36	49	79	92	2.4	6.0	14.3	2.6	4.1	3.0	52
Statistical Significance		NS	NS	NS	**	*	NS	*	*	NS	NS	**	**	**	-	-	-	**
No. of values		59	59	51	54	50	55	55	55	55	55	54	42	43	7	5	8	45

GLA = green leaf area   NS = not significant

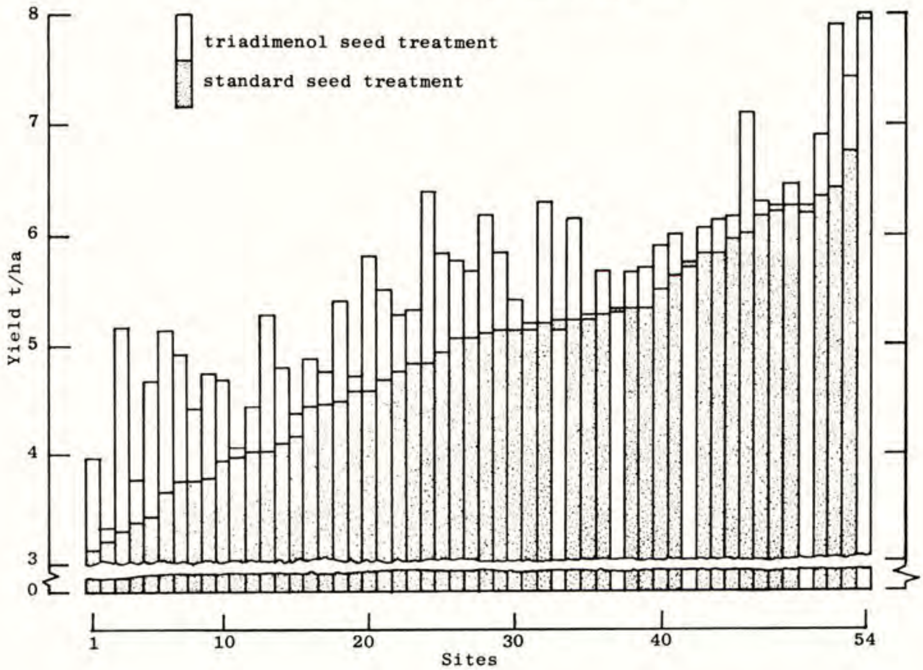
* P = <0.05   ** P = <0.001

Mildew infection levels on the top 3 leaves were meaned into three groups based upon growth stage at assessment time irrespective of trial site. Triadimenol seed treatment significantly reduced the amount of mildew compared with the standard. There was insufficient information on the other diseases to warrant statistical comparison, but there was less brown and yellow rust and leaf blotch on plants from seeds treated with triadimenol and green leaf area was significantly improved.

The yield results from all sites harvested are shown in Figure 1. The yields obtained from the standard are illustrated in order of increasing magnitude together with the corresponding yields from the triadimenol seed treated crops. To illustrate the development of mildew infection (Figure 2) assessments were meaned according to the time after drilling. The resulting curves were smoothed by the technique of running means and each point represents the average of three adjacent values.

Fig. 1

Yield results from 54 spring barley sites



The results were analysed in economic terms (Figure 3; Table 4) by assuming that the cost of treatment with the triadimenol formulation and the standard was £90 and £70 per tonne of seed grain respectively and the gross income from spring barley was £90 per tonne. Results for each site were corrected for differences in cost of treatment and seed grain due to small variations in seed rate between the two drilled areas. As expected there were considerable differences between cultivars in the intensity of mildew attack and the response from seed treatment with triadimenol (Table 4). Golden Promise was the most susceptible to mildew and gave the highest yield response to treatment.

Fig. 2

Mildew infection progress with time from 57 spring barley sites

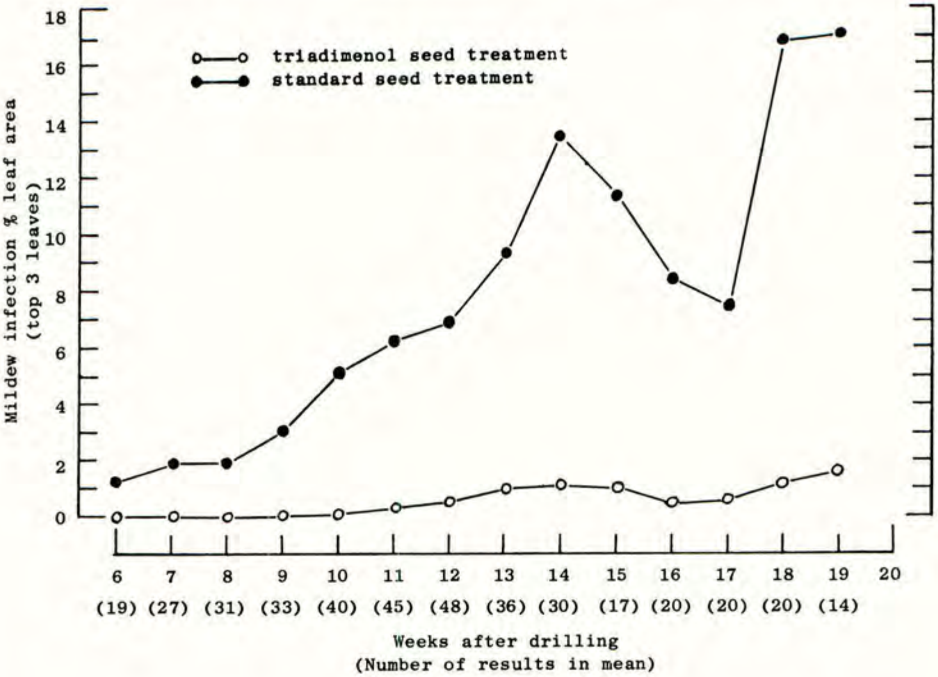


Table 4

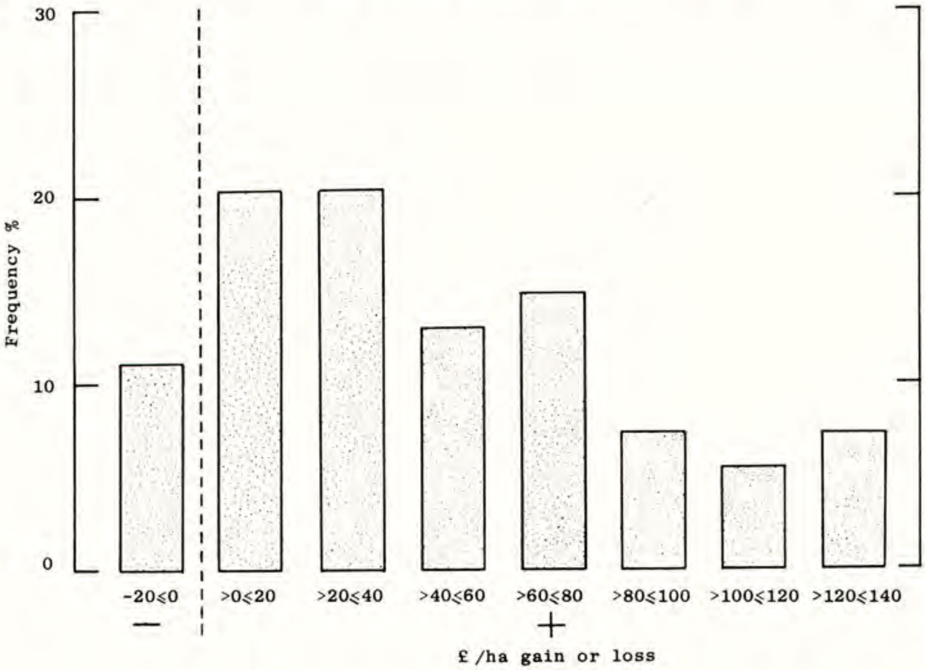
Yield increase, mildew infection levels and economic response measured for different cultivars

Cultivar	Number of sites in mean	Mean % mildew infection* (top 3 leaves)		Number of sites in mean	Mean yield increase from triadimenol over standard kg/ha	Mean net gain from triadimenol over standard £/ha
		triadimenol	Standard			
Golden Promise	14	2.00	21.54	12	971	83·61
Georgie	17	0.83	11.82	16	630	53.93
Ark Royal	13	0.52	8.24	13	411	34.07
Keg	12	0.66	8.17	11	304	23.15
Aramir	1	0.05	3.41	2	253	21.26

* Mean mildew infection values calculated from highest mildew records from each site regardless of cereal growth stage

Fig. 3

Percent frequency distribution in arbitrarily chosen class intervals of £ gain or loss per hectare from triadimenol over the standard from 54 spring barley sites



DISCUSSION

The objective of this reported sixty site project was to try to overcome the small plot problems and to test the triadimenol treatment in a wide range of conditions on a farm scale. The yield responses over the standard (Table 3; Figure 1), many of which were substantial, and the more severe mildew infections compared with previous small plot trials, suggest that the final testing of a fungicidal seed treatment on a farm scale provides a more realistic measure of the treatment effect. The fungicidal superiority of triadimenol over the standard, particularly against powdery mildew, was clearly evident (Table 3; Figure 2). Triadimenol treatment also reduced infection of brown and yellow rust and leaf blotch, augmenting the results of earlier reported field work (Trägner-Born and Van den Boom, 1978; Wainwright et al. 1979; Adam et al. 1981). Cultivar choice influenced the mildew infection in these trials (Figure 2) and large differences in susceptibility are evident from the figures in Table 4, with Golden Promise, which dominates in Scotland, sustaining the highest infection.

The use of a seed treatment to control diseases is essentially prophylactic. It is important, therefore, for potential users to be able to judge whether or not the investment is likely to be worthwhile. The results expressed in Figure 3 and in Table 4 are based upon assumptions of treatment costs and income from spring barley. They are, therefore, not actual examples of financial gain but they serve to illustrate the probable outcome of the trials in economic terms. At over 80% of the sites a financial gain resulted from the use of triadimenol seed treatment but clearly the magnitude of gain was greatly influenced by cultivar choice.

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