SESSION 4
FUNGICIDAL SEED TREATMENTS

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The response of winter wheat varieties to rotational position and silthiofam seed treatment

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ABSTRACT

Trials were carried out in second and third wheat situations during the growing season 1999/2000 to compare the performance of 25 winter wheat varieties with and without silthiofam seed treatment. Yield data for the same varieties grown in UK Recommended List trials in first or second wheat situations were analysed for the period 1996-2000. Silthiofam produced a mean yield recovery of 1.06 t/ha, ranging from 0.6 t/ha to 1.59 t/ha depending on variety. A number of varieties were identified that performed distinctly better or worse as second wheats than would have been predicted from their performance as first wheats. With silthiofam, the relative yields of varieties in second wheat situations were still more closely related to their relative yields in second wheat variety trials than in first wheat variety trials.

INTRODUCTION

Take-all of wheat, caused by the soil-borne fungus *Gaeumannomyces graminis* var. *tritici*, is a highly damaging disease affecting the roots and is a major factor limiting the yield of crops grown as second or subsequent wheats in the rotation. Until recently, chemical control was not an option, but seed treatments providing significant activity against take-all, together with a high degree of persistence, have now become available (Beale *et al.*, 1998; Löchel *et al*, 1998).

Evidence is accumulating from UK Recommended List variety trials carried out in different rotational positions that some varieties may be more tolerant than others of the non-first wheat situation (Anon., 2001).

This paper presents trials' results comparing the performance of wheat varieties in first and non-first wheat situations and their response to the control of take-all using silthiofam (previously MON 65500) seed treatment.

METHODS

Four trials were carried out in second or third wheat situations during the growing season 1999/2000 to compare the performance of 25 winter wheat varieties with and without silthiofam seed treatment (Table 1).

Table 1. Trials sites

Location		Soil type	Previous cropping*	Take-all severity
Cockle Park	Northumberland	Sandy loam	WW/WOSR/WB	Moderate
Kingsbridge	Devon	Silty Loam	WW/WOSR/WB	Severe
Newton	Lincolnshire	Silty Clay	WW/P/WW	Slight
Peckforton	Cheshire	Peaty Loam	WW/WW/WOSR	Moderate /Severe

* WW – winter wheat; WOSR – winter oilseed rape; WB – winter barley; P– potatoes

Seed was treated with 'Sibutol Secur' (bitertanol + fuberidazole + imidacloprid), at a rate of 400 ml/100kg seed (56+3.4+35g a.i./100kg seed), either alone, or co-applied with silthiofam at a rate of 200ml/100kg seed (25g a.i./100kg seed). All trials received a standard foliar fungicide programme, aimed at maximising control of foliar diseases and eyespot. Guard plots of the variety Equinox were sampled regularly throughout the season to monitor take-all severity. Percentage green leaf area was assessed in all trials at GS75. In the Kingsbridge trial, where take-all was most severe, plots were assessed for above-ground symptoms of the disease and plants sampled for examination of root infection. Plots were harvested for determination of grain yield.

Yield data for the same 25 varieties grown in first or second and subsequent (predominantly second) wheat situations were provided from UK Recommended List (RL) trials. The RL data set comprised a total of 202 first wheat trials and 48 second wheat trials during the five-year period 1996-2000. As not all varieties were present in all trials, a fitted constants analysis was used to adjust the mean yields for missing data. In what follows, all second and subsequent wheats will be referred to as 'second' wheats.

Yields from seed treatment trials were analysed by analysis of variance for each trial separately and in an over-trials analysis of variance. Mean yields of the 25 varieties in seed treatment trials and in RL second wheat trials were regressed on their mean yields in RL first wheat trials using linear regression analysis.

RESULTS

Mean site yields and the effect of silthiofam seed treatment are shown in Table 2. The mean yield without silthiofam was 7.88 t/ha, ranging from 5.54 t/ha at Kingsbridge, to 10.32 t/ha at Cockle Park. With silthiofam, the mean yield increased to 8.94 t/ha, a mean yield recovery of 1.06 t/ha. Yield recovery was greatest at Kingsbridge (+2.35 t/ha), where take-all was early and severe, and least at Newton (+0.36 t/ha) where take-all was slight.

Table 2. Yield of grain @ 85% dry matter (t/ha). (Over-trials analysis)

Trial site	– silthiofam	+ silthiofam	Yield recovery
Cockle Park	10.32	11.26	0.94
Kingsbridge	5.54	7.89	2.35
Newton	9.77	10.13	0.34
Peckforton	5.90	6.48	0.58
Mean	7.88	8.94	1.06

LSD (P=0.05) treatment means = 0.116
LSD (P=0.05) treatment means within site = 0.231
LSD (P=0.05) site means = 0.164
LSD (P=0.05) yield recovery means = 0.327

Although the mean yield recovery of individual varieties ranged from 0.6 t/ha to 1.59 t/ha, these differences were not statistically significant in the over-trials analysis of variance. This may be partly due to the inherently high level of variability in trials on land infected with take-all.

Table 3 shows the effect of silthiofam on percentage leaf area remaining green at GS75. Overall, silthiofam increased percentage green leaf, with the effect being most pronounced in the Kingsbridge and Peckforton trials where take-all was most severe.

Table 3. Percentage green leaf area at GS 75 (mean of top 4 leaves).

Trial	Date	– silthiofam	+ silthiofam	silthiofam response
Cockle Park	14/07/00	62.2	63.3	1.1
Kingsbridge	25/06/00	63.6	71.1	7.5
Newton	19/07/00	26.7	28.7	2.0
Peckforton	11/07/00	12.7	22.1	9.4
Mean		41.3	46.4	5.1

In the Kingsbridge trial, which was assessed in detail for take-all severity at GS 75, root symptoms were reduced by silthiofam from a mean index of 69.1 to 52.4, a reduction of 16.7. The effect of treatment on above ground take-all related symptoms was more pronounced. A visual assessment of the percentage of each plot suffering from take-all, as recognised by stunting and thinning, revealed that silthiofam reduced the percentage from a mean of 65.8% to 0.7%.

Correlations between the yields of varieties in the seed treatment trials and in RL first and second wheat trials are examined in Table 4. The performance of varieties in seed treatment trials, whether with or without silthiofam, was more closely correlated with their long term performance in second wheat, than first wheat, situations. The highest correlation coefficient was for the mean of silthiofam treated and untreated plots with the RL second wheat trials.

Table 4. Correlation coefficients (r) for yields of 25 varieties in seed treatment trials with their yields in RL trials in second or first wheat situations

	RL trials (5 year mean)	
2000 seed treatment trials	2nd wheat	1st wheat
– silthiofam	0.885	0.676
+ silthiofam	0.835	0.705
mean + / – silthiofam	0.911	0.722

Figure 1a shows the mean yields of varieties in seed treatment trials, both with and without silthiofam, plotted against their 5-year mean yields in RL first wheat trials. The first wheat mean yield was 10.10 t/ha, exceeding that of the second wheat seed treatment trials by 1.69 t/ha (1.16 t/ha and 2.22 t/ha with and without silthiofam respectively). Regression analysis revealed that 53.4% of the variation in variety yields in seed treatment trials could be accounted for by variation in their yields in first wheat trials.

Figure 1b shows the corresponding relationship for RL second wheat trials and RL first wheat trials. Here the first wheat mean yield exceeded that of second wheat by 0.99 t/ha and regression of second wheat on first wheat accounted for 73.6% of the variation.

Taken together, these results indicate a general trend for varieties that were high yielding in first wheat situations to be amongst the higher yielding varieties in second wheat situations and for varieties that were low yielding in first wheat situations to be amongst the lower yielding in second wheat situations. However, within this overall relationship, there were a number of obvious outlying varieties that performed either substantially better or worse as second wheats than would have been predicted from their performance as first wheats. These are identified in figures 1a and 1b, which highlight varieties that showed either large positive or large negative residuals. On this basis, varieties yielding higher than expected in second wheat situations included Aardvark, Charger, Cockpit, Deben and Napier. Varieties yielding lower than expected in second wheat situations included Claire, Equinox, Hereward, Malacca, Oxbow and Shamrock. Other varieties fell closer to the regression line, indicating that their yields as second wheats were nearer to those that would have been predicted from their yields as first wheats. Examples of these were the high yielding variety Tanker, the intermediate yielding variety Consort and the low yielding variety Soissons.

Table 5 examines some of the implications of these results for the choice of high-yielding varieties for first or second wheat situations. The eight (or nine for first wheats) highest yielding varieties are listed for each trials series. Four varieties, Tanker, Savannah, Napier and

Figure 1a. Relationship between yields of varieties in RL first wheat trials and silthiofam seed treatment second wheat trials.

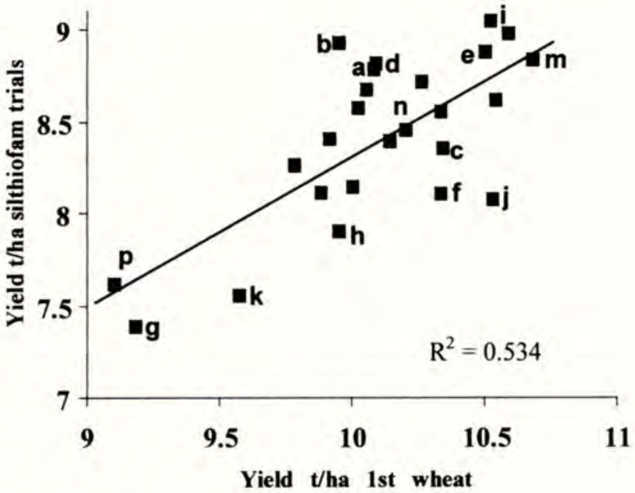
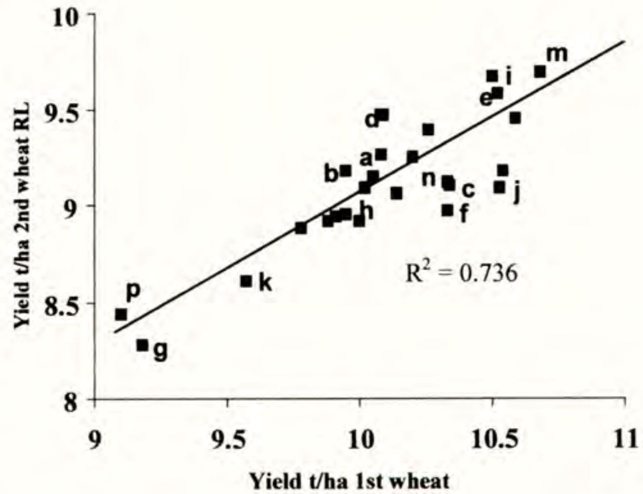


Figure 1b. Relationship between yields of varieties in RL first wheat trials and RL second wheat trials.



a = Aardvark: b = Charger: c = Claire; d = Cockpit; e = Deben; f = Equinox; g =Hereward; h = Malacca; i = Napier; j = Oxbow; k = Shamrock; m = Tanker;; n = Consort; p = Soissons

Deben were common to the lists for RL first wheats, RL second wheats and the seed treatment trials, indicating that these would be a good choice as first or second wheats. Five other varieties appeared only in the first wheat list, indicating that while these would be a good choice as first wheats they may be a less good choice as second wheats. Three varieties, Cockpit, Option and Aardvark appeared only in the second wheat lists (both RL second wheats and seed treatment trials), indicating that these varieties may be a better choice for second wheat situations than for first wheat situations.

Table 5. Mean yield of highest yielding varieties in each series of trials (t/ha)

1st wheat		2nd wheat			
RL trials 5 yrs		RL trials 5 yrs		Seed treatment trials 2000	
Tanker	10.68	Tanker	9.69	Napier	9.05
Savannah	10.59	Deben	9.67	Savannah	8.98
Biscay	10.54	Napier	9.58	Charger	8.93
Oxbow	10.53	Cockpit	9.47	Deben	8.88
Napier	10.52	Savannah	9.45	Tanker	8.84
Deben	10.50	Option	9.39	Cockpit	8.82
Claire	10.34	Aardvark	9.26	Aardvark	8.79
Madrigal =	10.33	Consort	9.25	Option	8.72
Equinox =	10.33				

DISCUSSION

It is well established that rotational position has a major influence on the yield of a wheat crop, with the yields of second or subsequent wheats being lower than those of comparable first wheats. RL variety trials' data revealed an average yield depression of 0.99 t/ha in second wheat, compared with first wheat, trials over the five-year period from1996 to 2000. Two of the seed treatment trials carried out in second wheats in 2000 had only slight or moderate levels of take-all infection and yielded above the five year average for second wheat trials. The other two trials suffered moderate to severe take-all and yielded substantially below the five year average, indicating the potential for greater losses in severe take-all situations.

Although take-all is acknowledged as a major factor limiting yield in non-first wheat crops, others, such as increased severity of eyespot, and reduced fertility may also be important. In all the trials reported here, the effects of diseases other than take-all can be largely discounted due to the use of comprehensive fungicide programmes designed to control foliar diseases and eyespot. In the four seed treatment trials, silthiofam seed treatment produced an average yield recovery of 1.16 t/ha. in second wheats. With no direct means of measuring the potential yields of first wheats in the same trials, it is difficult to estimate the recovery that would have been required to restore yields to the first wheat level. If the 5-year RL first wheat yield of 10.10 t/ha is taken as a realistic average for first wheats, it can be estimated that a total yield recovery of 2.22 t/ha would have been required. Silthiofam delivered 52% of this. Given that silthiofam does not give complete control of take-all root rot, with an efficacy of around 40% quoted by Beale *et al.* 1998, this result indicates that take-all was responsible for the majority of the yield depression in untreated second wheats in these trials.

Although varieties showed a range of responses to seed treatment, the interaction effect did not reach statistical significance, probably due to the relatively high level of error variation associated with patchy distribution of take-all in trials. A similar result was reported from trials carried out by Monsanto in 1996-97 (Spink *et al.* 1998). However, in another series of trials, the authors did detect a significant interaction between variety and seed treatment, with some varieties, notably Rialto and Riband, giving lower responses than others. These two varieties also gave lower than average yield responses when compared with 23 other varieties in these trials reported here, suggesting that consistent varietal effects may exist, but their detection may require trial designs capable of giving greater statistical precision.

There is considerable evidence here and elsewhere that wheat varieties differ in their suitability for growing as second wheats (Anon. 2001). To what extent this is due to differences in their resistance to, or tolerance of, take-all, is unclear. Hollins *et al.* (1986) found little difference in susceptibility to take-all amongst UK wheat varieties available at the time. However, efforts continue in many countries to identify and exploit sources of resistance or tolerance. The seed treatment trials and the RL variety trials identified a number of varieties that appeared to be either well, or poorly, suited to the second wheat position and may therefore be more or less tolerant of take-all. Varieties performing better than expected in second wheat situations included Aardvark, Charger, Cockpit, Deben and Napier. Varieties performing less well than expected in second wheat situations included Claire, Equinox, Hereward, Malacca, Oxbow and Shamrock. Foulkes et al. (1997) suggested that varietal traits conferring tolerance to drought stress were also likely to confer tolerance to take-all. These included high production of above-ground biomass and the ability to partition relatively large amounts of this growth into stem soluble carbohydrate reserves. Early anthesis and efficient rooting were also suggested as characteristics likely to favour tolerance. However, there was no apparent relationship in these trials between the ability of varieties to perform well as second wheats and their stem soluble carbohydrate production or date of anthesis.

Silthiofam seed treatment reduced the yield depressing effect of the second wheat situation by reducing, but not eliminating, the influence of take-all. The relative yields of varieties with seed treatment were still more typical of their long term performance in second wheat trials than in first wheat trials. It is concluded that the choice of varieties for second wheat situations should be based on their performance in second wheat trials, irrespective of whether the use silthiofam seed treatment is intended. Until more evidence is available on variety x seed treatment interactions, the decision to apply the seed treatment should be made irrespective of variety, according to take-all risk parameters.

ACKNOWLEDGMENTS

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Effects of fluquinconazole seed treatment on take-all and yield of winter wheat, and its exploitation in cropping systems

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ABSTRACT

Yield responses to fluquinconazole, applied to the seed of winter wheat in experiments on take-all risk sites in 1996-98, were better related to the yields of untreated plots in the different experiments than to take-all, apparently reflecting, in part, inconsistent effects of the disease on yield. Effects of treatment were not altered by changes in seed rate. In a four-year sequence of winter wheat crops, responses to fluquinconazole in the year of application increased progressively as take-all became more severe. However, applying fluquinconazole to the third wheat, in which take-all was moderate to severe, decreased yield in the fourth wheat compared to plots that followed untreated third wheats, probably because treatment in that year delayed peak disease and the onset of take-all decline. Until more information is available farmers should be cautious about applying fungicides to control take-all to more than two or three consecutive crops of winter wheat, especially if early-sown.

INTRODUCTION

Fluquinconazole is a triazole fungicide which, as a result of an unusual combination of biological and physico-chemical properties, provides partial but useful control of take-all (a disease caused by the root-infecting fungus *Gaeumannomyces graminis* var. *tritici*) when applied to the seed of winter wheat (Lőchel *et al.*, 1998; Wenz *et al.*, 1998). However, to optimise the commercial benefits of any fungicide it is necessary to understand when to use it and how its effects, and the consequent yield responses, are affected by changes in husbandry and interactions with other inputs. For a seed treatment, one of the more fundamental questions is whether or not its effects are altered by changes in seed rate.

Experience obtained using established fungicides against the same or other diseases will often be useful in deciding how best to exploit a new product. However, while a number of fungicides have been shown to have activity against take-all (Bateman, 1989), fluquinconazole is the first to be registered for commercial use against the disease in the UK, where it is marketed as Jockey. The biology of the take-all fungus is also very different from the biology of the leaf pathogens that are the target of most fungicides currently applied to cereal crops. In particular, take-all epidemics develop over a period of years when susceptible crops (especially winter wheat) are grown consecutively. It is, therefore, important to understand how fungicides applied to control take-all affect the subsequent progress of epidemics, including the development and expression of the natural biological control phenomenon known as take-all decline (Slope & Cox, 1964).

In this paper we present a summary of results from a number of, mostly one-year, experiments from 1996 to 1998 that tested the effects of different rates and formulations of fluquinconazole applied to the seed of winter wheat. Also described are results from an experiment testing the effects of sowing treated wheat seed at different rates, and from another one that started in 1997, which is one of a number testing the effects of applying fluquinconazole in different combinations of years.

MATERIALS AND METHODS

Yield responses in 1996-1998

Sixteen data sets were assembled from field experiments in 1996 to 1998 that tested the effects of fluquinconazole applied to the seed of winter wheat grown as a second or, more commonly, third cereal susceptible to take-all. Most of the data sets came from experiments done at Rothamsted Experimental Station but about a third of them came from other sites. Most of the experiments lasted only one year but two of the data sets measured the effects of fluquinconazole in 1998, in plots where it had also been applied in 1997. Another three data sets were from a single experiment that tested the effects of sowing in September, October or November.

Attention was restricted to a sub-set of treatments that was tested most commonly *viz* fluquinconazole (167 g a.i./litre) and fluquinconazole + prochloraz-Cu complex (167 + 34 g a.i./litre), both applied at 450 ml/100kg seed, and triadimenol + fuberidazole (187.5 + 22.5 g a.i./litre) (as Baytan at 200 ml/100 kg seed). In most of the experiments, a programme of broad-spectrum fungicide sprays was applied to all plots, and the effects of seed treatments were then estimated by comparison with the appropriate sprayed controls. Take-all was assessed, by the same two people, on plants that were usually sampled between the end of anthesis and the milky ripe growth stage. Take-all on individual root systems was assessed using a 6-point scale: nil, slight 1 (1-10% roots infected), slight 2 (11-25%), moderate 1 (26-50%), moderate 2 (51-75%), severe (>75%). The data were used to calculate a take-all index for each plot [(% plants with infection in the slight 1 category + 2 x % slight 2 + 3 x % moderate 1 + 4 x % moderate 2 + 5 x % severe) ÷ 5; maximum = 100].

Effects of seed rate

Interactions between fluquinconazole and seed rate were studied in an experiment at Rothamsted in harvest year 1999 on a flinty silty clay loam soil. Seed of winter wheat cv. Riband was treated, as above, with fluquinconazole + prochloraz or triadimenol + fuberidazole or with bitertanol + fuberidazole (375 + 23 g a.i./litre) (as Sibutol at 150 ml/100 kg seed) and sown at 90, 130 or 170 kg/ha. Each of the nine treatment combinations was replicated four times but, because of a slightly irregular layout of the plots, the experiment was arranged as two blocks of 3 x 3 duplicated. Individual plots were 3 m wide x 10 m long from which an area 2.3 m wide was harvested to measure grain yield. Applications to all plots included herbicides, nitrogen (50 kg/ha on 16 March plus 150 kg/ha on 14 April) and foliar fungicides (tebuconazole + fenpropimorph on 29 May). Plant samples to measure diseases affecting the roots and stem bases were taken from all plots on 13 April (GS 30-31; 5 x 15 cm of row/plot) and 5 July (GS 75; 10 x 20 cm of row/plot). Take-all was assessed in the spring as numbers of roots and plants with take-all, and in the summer as described above.

Yield responses in a four-year sequence of crops

Results are presented from an experiment on winter wheat that started in 1997 following linseed in 1996. The experiment, which was on a flinty silty clay loam soil, originally consisted of four randomised blocks, each comprising eight plots that tested, in all possible combinations, the effects of applying or not applying fluquinconazole to the seed in each of three years (1997-1999) (i.e. 2^3). A further test of fluquinconazole was superimposed on this design in 2000 when it became two blocks of 2^4.

Individual plots were 3 m wide x 10 m long, from which an area 2.3 m wide was harvested to measure yield. Before sowing each crop, the whole site was ploughed, with the direction of ploughing (i.e. furrow-throw) alternated in successive years. The 1997 crop was of cv. Brigadier (sown at 380 seeds/m^2 on 17 October 1996) but subsequent crops were of cv. Hereward (sown at 400 seeds/m^2 on 1 October 1997, 380 seeds/m^2 on 12 October 1998 and 380 seeds/m^2 on 22 September 1999). Applications to all plots included nitrogen (applied as split dressings), herbicides and, when considered necessary, foliar fungicides. Plant samples to measure diseases affecting the roots and stem bases were taken from all plots in spring (*c.* GS 30-31; 5 x 15 cm of row/plot) and summer (*c.* GS 75; 10 x 20 cm of row/plot). Take-all was assessed as described above.

RESULTS

Yield responses in 1996-1998

Averaging over all of the available data sets and using t-tests, both formulations of fluquinconazole significantly decreased the take-all index (TAI) by just over 30% ($P <$ 0.001) and significantly increased yield, by 6-7% ($P < 0.05$). Triadimenol had no significant effects on either take-all or yield. Analyses excluding four sites that had less take-all than expected (mean indices in untreated plots ≤ 15) showed very similar effects except that yield responses to fluquinconazole were larger (8-9%).

Significant relationships between grain yield and severity of take-all can often be demonstrated in data from individual experiments. However, single and multiple regression analyses of yield responses (% of untreated), measured on different sites and in different seasons, on take-all indices in untreated plots and on percentage decreases in take-all indices in treated plots, showed no significant relationships for either of the two formulations of fluquinconazole or triadimenol. This was apparently explained, in part, by differing effects of take-all in different experiments. For example, the most severe take-all was seen in the September-sown plots in the experiment testing different sowing dates (mean TAI in untreated plots = 77). Despite this, untreated plots gave reasonably good yields (8.29 t/ha) and there was no apparent yield benefit from the decreases in take-all that resulted from applying fluquinconazole to the seed (mean TAI for both formulations = 54).

Another experiment, on a different site in the same year, had broadly similar amounts of take-all and similar decreases in disease where fluquinconazole was applied to the seed (mean TAI of 49 *vs* 71) but untreated yields were smaller (7.59 t/ha) and there were good responses to the fungicide (22% more than the untreated). Untreated October-sown plots in the experiment testing sowing dates had less take-all (TAI = 42) than the untreated September-sown plots and gave smaller yields (7.98 t/ha). Fluquinconazole also had a proportionately smaller effect on the disease (mean TAI = 36) but despite this there was a positive yield response, which averaged 7%. Regression analyses tended to support these specific comparisons, showing that percentage yield responses to the two formulations of fluquinconazole were significantly, and inversely, related to the untreated yields obtained in each experiment. The relationship for fluquinconazole alone, based on all 16 data sets, accounted for 35.9% of the variance.

Effects of seed rate

In this experiment, almost 60% of plants and an average of almost 1.2 roots/plant were affected by take-all in April. Main effects of seed rate and seed treatment were not significant. In the number of infected roots/plant there was evidence of a significant interaction between seed rate and seed treatment but it was complex and probably spurious. By July, the average number of plants affected by take-all had increased to 86%. Severity of the disease was decreased significantly by fluquinconazole, compared to bitertanol + fuberidazole, but not by triadimenol + fuberidazole (Table 1). A significantly smaller percentage of plants was affected by take-all in plots sown at 170 kg/ha than at smaller seed rates but the total number of plants with the disease was larger. The percentage of plants with severe disease was, similarly, smallest at the largest seed rate but not significantly so. There was no evidence of an interaction between seed treatment and seed rate.

Table 1. Effects of seed treatments and seed rates on take-all in July and on grain yield

	% plants with take-all[1]		Take-all	Grain yield	Thousand
	Total	Severe	index	(t/ha)	grain wt (g)
Seed treatment[2]					
Bit. + fub.	+0.89 (85.5)	-0.98 (12.5)	40	7.78	42.9
Triad. + fub.	+1.11 (90.2)	-0.79 (17.2)	47	8.09	45.0
Fluquinconazole	+0.72 (80.9)	-1.83 (2.5)	29	8.53	44.9
SED	0.216	0.207	5.6	0.256	0.77
P	NS	<0.001	0.012	0.024	0.018
Seed rate (kg/ha)					
90	+1.12 (90.4)	-1.05 (10.8)	43	7.94	44.9
130	+1.05 (89.1)	-1.11 (9.9)	40	7.92	44.2
170	+0.55 (74.9)	-1.43 (5.4)	32	8.55	43.8
SED	0.216	0.207	5.6	0.256	0.77
P	0.026	NS	NS	0.031	NS

[1]Logit transformed values with percentages, obtained by back-transformation, in parentheses.
[2]Bit. + fub. = bitertanol + fuberidazole. Triad. + fub. = triadimenol + fuberidazole.

Effects of triadimenol + fuberidazole on grain yield (compared to bitertanol + fuberidazole) were relatively small and not significant whereas fluquinconazole significantly increased grain yield by *c.* 10%. These differences are only partly explained by effects on thousand-grain weight which was increased similarly, and significantly, by triadimenol + fuberidazole and fluquinconazole. Sowing at 170 kg/ha significantly increased grain yield by *c.* 8% compared to smaller seed rates but seed rate had no significant effect on thousand-grain weight. Neither grain yield nor thousand-grain weight provided any evidence for interactions between seed treatment and seed rate. The yield response to fluquinconazole cannot be attributed unequivocally to control of take-all but this fungicide and triadimenol + fuberidazole had similar effects on other diseases that were recorded in the experiment and that might have been expected to affect yield.

Yield responses in a four-year sequence of crops

There was negligible take-all in this experiment in its first year (1997) but, overall, there was an increase in the disease in each of the following three (Table 2). Fluquinconazole mostly had little effect on the incidence of take-all (% plants affected) but consistently and significantly decreased severity of the disease in 1998-2000. In each of those three years, there was a reasonably good relationship between take-all and grain yield in individual plots which suggested that take-all was probably the main explanation for the progressively smaller mean yields and progressively larger responses to fluquinconazole. Despite this, only in 2000 was the yield response significant, partly reflecting patchiness in the distribution of take-all (except in 1997) and consequently inflated residual mean squares. Therefore, additional analyses were done using as covariates, plot residuals derived from analyses of take-all indices in the same year. These gave significant improvements in precision judged by decreases in residual mean squares which were 48, 32 and 72% smaller in the adjusted analyses in 1998, 1999 and 2000, respectively. In these adjusted analyses, responses were significant in 1998 as well as in 2000 and almost significant in 1999.

Table 2. Average effects on take-all and yield of applying fluquinconazole (F) to the seed of each of four consecutive crops of winter wheat[1].

	Untreated in each year		% plants with severe take-all[2]		Yield response to fluquinconazole	
Year	Mean yield (t/ha)	Take-all index	-F	+F	t/ha(SE)[3]	%
1997	10.02	0	0	0	+0.29 (±0.225)	2.9
1998	7.78	37	23.5	6.0	+0.46 (±0.211)	5.9
1999	5.77	69	52.9	12.8	+0.58 (±0.297)	10.1
2000	4.14	77	55.3	9.9	+0.77 (±0.190)	18.6

[1]Figures are averaged over treatments tested in all preceding years. [2]Back-transformed logits. [3]Standard errors for 1998-2000 are derived from analyses of grain yield in each year in which plot residuals derived from analyses of take-all indices in the same year were used as covariates.

The experiment also provided evidence for effects on yield of fluqinconazole applied in previous years (Table 3). In 1998, yield was apparently increased by applying fluquinconazole in 1997 (significant in the adjusted analysis) but yield in 2000 was decreased by applying fluquinconazole in 1999 (significant in the unadjusted and adjusted analyses) whether or not fluquinconazole was applied in 2000. The yield increase in 1998 was associated with a substantial (50%), but not significant, decrease in the mean severity of take-all (8.6 vs 17.3% plants with severe symptoms). However, the decrease in yield in 2000, as a consequence of applying fluquinconazole in 1999, is not adequately explained by the small differences in take-all measured in summer 2000 (Table 4).

Table 3. Average effects on yield of applying fluquinconazole (F) to the seed of winter wheat in the year preceding the year of measurement[1].

	Grain yield (t/ha)[2]		
Year of measurement	-F	+F	Response (SE)[3]
1998	7.74	8.27	+0.53 (±0.211)
1999	6.01	6.10	+0.09 (±0.297)
2000	4.92	4.14	-0.78 (±0.190)

[1]Figures are averaged over all other treatments tested up to and including the year of measurement.
[2]F indicates fluquinconazole applied in the year preceding the year of measurement.
[3]Standard errors derived from covariate analyses (see footnote to Table 2).

Table 4. Effects of applying fluquinconazole (F) in 1999 and 2000 on take-all and yield in 2000[1].

Year		Take-all		
		No. roots/plant	% plants severe[2]	Grain yield
1999	2000	(spring)	(summer)	(t/ha)
-F	+F	2.83	9.2	5.38
+F	+F	3.09	10.6	4.45
-F	-F	4.13	53.7	4.46
+F	-F	4.55	57.0	3.83

[1]Figures are averaged over treatments tested in 1997 and 1998. [2]Back-transformed logits.

DISCUSSION

The results in this paper illustrate the consistent, and often quite large, effects of fluquinconazole, applied as a seed treatment, on the severity of take-all in winter wheat. Seed rate had no effect in the one experiment testing it, suggesting that the activity of the compound is mostly determined by amounts of active ingredient per seed rather than amounts per unit area.

In individual experiments, including the one testing effects of fluquinconazole in a sequence of winter wheat crops described here, relationships between take-all severity and yield in individual plots can often be demonstrated, suggesting that yield responses to fluquinconazole are likely to be at least partly due to the effects that it has on this disease. However, the relationship between mean yield responses in different experiments, grown on different sites and in different seasons, and mean take-all severities in the same experiments, was not close even though most of them were on take-all risk sites. This may, in part, be because other factors affected grain yield including control of foliar diseases by fluquinconazole (Wenz *et al.*, 1998) although in most of the experiments fungicide sprays were applied to minimise such effects. However, comparing results from different experiments suggested that another reason for the poor correlation was that effects of take-all on yield were inconsistent. In particular, severe disease in one September-sown crop apparently had relatively little effect on yield and so, despite effects of fluquinconazole on take-all, the fungicide also had little effect on yield. The reason for take-all apparently being less damaging in this crop than in some others is uncertain. Conceivably it became severe too late in crop growth to do much damage. As a consequence of these variable effects of take-all, yield responses to fluquinconazole in this set of experiments were more closely related to mean yields than to take-all, i.e. responses were small where yields were relatively large, either because there was little take-all or because it did relatively little damage even if severe, and were large where yields were small as a consequence of take-all that was both severe and damaging.

Using fungicides to manage take-all is potentially much more complicated than using sprays to manage foliar diseases because take-all epidemics develop over a period of years. Actions taken in one year can, therefore, influence disease severity in the next. It is, potentially, even more complicated if there is an intention to exploit take-all decline. This is a form of natural biological control that can provide modest but useful control of the disease where cereals are grown more or less continuously. Although understanding of the phenomenon is imperfect, there is good evidence that it is a consequence of severe take-all and not simply of the number of consecutive crops that has been grown. It is, therefore, important to understand how fungicides used to control take-all affect the development of epidemics, including the development and subsequent stability of take-all decline. The amount of such information that is currently available is, however, very limited. We now have a number of experiments that are testing the application of fluquinconazole to sequences of crops but the one described in this paper is the longest established. This makes it especially valuable but also means that there is little other information to corroborate some of the results, especially those relating to the residual effects of the fungicide.

Mean responses in each of the four years, to fluquinconazole applied in the same year, were consistent with results from the one-year experiments and show a similar inverse linear relationship with mean yield. The response in the first year was relatively small, and not significant, which was consistent with the negligible amounts of take-all in what was a first wheat after a break. There was, however, evidence of a positive yield response in the second year to fluquinconazole applied in the first which, assuming that it was a real effect, was probably a consequence of a smaller increase in inoculum where fluquinconazole had been applied to the first wheat than where it had not. This result was not confirmed by the results from our more recently-started crop sequence experiments but all (three) of these started with a second wheat after a break and so are not strictly comparable. The yield response in 1998, to fluquinconazole in 1997, was also associated with a substantial, although not significant, decrease in take-all which may suggest, but does not prove, that it was a real effect. There may have been similar effects on amounts of inoculum remaining after the 1998 crop but the potential for these to affect amounts of disease in 1999 may have been limited by the generally greater disease pressure.

It is more difficult to explain convincingly the negative yield response in 2000 to fluquinconazole applied in 1999. It is consistent with the hypothesis that applying fungicide during the build-up of take-all may delay the peak of disease and the onset of take-all decline. Consequently, the effects of treatment may then be reversed because of the earlier development of take-all decline in the untreated crops. The associated effects of fluquinconazole in 1999 on take-all in 2000 were, however, small and not significant. They do not, therefore, lend strong support to this hypothesis, but neither do they contradict it in the sense that the rank order for different combinations of treatments in 1999 and 2000 is similar for yields and take-all in summer as well as take-all in spring (Table 4). There is also support for the hypothesis in the disease data from another experiment at Rothamsted, in which fluquinconazole was applied to crops that were close to the peak of disease (Dawson & Bateman, 2001). Nevertheless, the small effect on take-all in 2000 of applying fluquinconazole in 1999 contrasts with the significant effect on take-all of applying the fungicide in 2000. The same samples were used to determine both effects and so, at this stage, the negative effect of fluquinconazole applied in 1999 on yield in 2000 must be treated with some caution. It does, however, emphasise the need for more research on the use of fluquinconazole in sequences of crops. Experiments also need to be done using other fungicides that might be applied to control take-all although, unless such compounds provide more or less complete control of the disease, a similar effect might be expected. Thus, assuming our explanation is correct, it is a consequence of the biological properties of take-all and not a consequence of the specific properties of the fungicide that we have tested. In the meantime, farmers should continue to be cautious about growing more than two or three consecutive crops of, especially early-sown, winter wheat whether or not they use a fungicide.

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Triticonazole based cereal seed treatments for the control of seed- and soil-borne diseases

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ABSTRACT

When used in combination with other active ingredients, triticonazole has given excellent control of the major seed- and soil-borne diseases of wheat and barley. In field trials on winter wheat, the control of artificially infected seed- and soil-borne bunt has exceeded 99%, whilst the reduction of *Microdochium nivale* has resulted in double the number of emerged plants compared with untreated. In winter barley, loose smut and leaf stripe control was 100% and 99% respectively, whilst a reduction in seed- borne net blotch has significantly reduced disease on the upper leaves.

INTRODUCTION

Two triticonazole based products have been developed and launched (2000) in the UK by Aventis CropScience. Triticonazole + guazatine (EXP 80525D), has been developed on wheat for the control of seedling blights (*Fusarium spp., Microdochium nivale, Leptosphaeria* (Septoria) *nodorum*), and seed- and soil-borne bunt (*Tilletia tritici*). Triticonazole + imazalil (EXP 80812A), has been developed on barley for the control of loose smut (*Ustilago nuda*), leaf stripe (*Pyrenophora graminea*), seedling blight (*Fusarium* spp., *Microdochium nivale*), and seed-borne net blotch (*Pyrenophora teres*).

Field trials were conducted by Aventis CropScience and, independent research establishments, during the period 1994-1998, throughout the UK.

MATERIALS AND METHODS.

Chemicals, seed, treatment and sites

Triticonazole + guazatine 12.5 + 150 g a.i./l FS formulation as EXP 80525D (Premis®).
Triticonazole + imazalil 12.5 + 12.5 g a.i./l FS formulation as EXP 80812A (Robust®).
Commercial standard products were used at the label rate.

In trials determining performance against seed-borne diseases, seed was naturally infected with the pathogen under test, except for bunt where spores were mixed with either the seed or the soil. Seed samples were treated using a laboratory seed treater such as the Mini-Rotostat.

Drilling was carried out using a semi-precision cone drill such as a Hege. Seed depth and seed rates were selected as to be representative of commercial practice for each crop. Plot sizes were variable, but were generally 10-20m². Sites were selected to be representative of cereal growing areas in the UK and were widely spread to provide a range of soil types and climatic conditions under which to compare product performance.

Disease Assessments

Loose smut (*U. nuda*) was assessed as the number of smutted heads per plot. Assessments were made at ear emergence once disease expression was complete. Results are expressed as disease incidence and percent disease control compared to the untreated.

Leaf stripe (*P. graminea*) was assessed by counting the number of infected tillers per plot. Assessments were made at ear emergence once disease expression was complete. The results have been expressed as percent disease control compared to the untreated.

Seed-borne net blotch (*P. teres*) was assessed as the percent infection on 20 leaves/plot.

For seedling blight (*M. nivale*) on wheat, the number of plants emerged were assessed in 5 one metre row lengths per plot. The results are expressed as the number of plants per metre row. In barley, stem-base browning was assessed by sampling 50 plants per plot and counting the number with basal lesions.

Seed- and soil-borne bunt (*T. tritici*) was assessed by counting the number of diseased ears in each plot and expressed as a percentage of the untreated or as infected ears/m^2.

RESULTS

In a series of field trials carried out in 1994 and 1995, (Table 1) EXP 80525D achieved almost complete control of seed-borne bunt, despite the high infection levels of between 24% and 68% of ears infected in the untreated.

Table 1. Control of seed-borne bunt with EXP 80525D

	Trial No	UA2	UJ2	UR2	UA2	UJ2	UR2
	Series No	94SA1	94SA1	94SA1	95S78	95S78	95S78
	Harvest Yr	1994	1994	1994	1995	1995	1995
	(g a.i./100kg			% infection			
Untreated	-	64.0 a	24.0 a	68.0 a	42.7 a	26.5 a	53.3 a
EXP 80525D	5 + 60	0.0 d	0.0 b	0.0 b	0.0 c	0.7 b	0.0 b
Triadimenol+fuberidazole	375 + 45	0.0 d	0.0 b	0.0 b	-	-	-
Bitertanol+fuberidazole	56 + 35	-	-	-	0.0 c	1.0 b	1.0 b
LSD (P=0.05)		4.0	8.0	4.0	4.3	4.9	5.6
				% Efficacy			
EXP 80525D	5 + 60	100	100	100	100	98	100
Triadimenol+fuberidazole	375 + 45	100	100	100	-	-	-
Bitertanol+fuberidazole	56 + 35	-	-	-	100	96	98
Variety		Riband	Riband	Riband	Riband	Riband	Riband
Sowing date		21.10.93	19.11.93	21.10.93	10.10.94	17.11.94	03.11.94

In three trials in 1995 and one in 1996, levels of soil-borne bunt infection were relatively low. However, EXP 80525D gave excellent control equal or superior to that given by the standards. Results are presented in Table 2.

Table 2. Control of soil-borne bunt with EXP 80525D

	Trial No	DL4	DL1	DL1	DL1
	Series No	S01	S03	S04	S13
	Harvest Yr	1995	1995	1995	1996
	(g a.i./100kg		% infection		
Untreated	-	15.6	6.2	10.8	16.8
EXP 80525D	5 + 60	0.2	0.1	0.0	0.1
Fludioxonil	5	0.7	0.3	0.5	-
Bitertanol+fuberidazole	56 + 35	-	-	-	0.2
LSD (P=0.05)		1.2	0.9	1.3	-
			% efficacy		
EXP 80525D	5 + 60	99	98	100	99
Fludioxonil	5	96	95	95	-
Bitertanol+fuberidazole	56 + 35	-	-	-	99
Variety		Konsul	Konsul	Konsul	Hussar
Sowing date		27.09.94	24.09.94	05.10.94	03.10.95

The results from five trials carried out in 1996 against *M. nivale* (four on cv. Woodstock and one on cv. Hunter) are presented in Table 3. On the Woodstock, EXP 80525D gave significant increases in emergence of 100-148% over the untreated. The standard treatments gave similar increases. On cv. Hunter, which had a lower level of seed-borne infection, EXP 80525D gave an increase in emergence of 22%.

Table 3. Control of *M nivale* seedling blight EXP 80525D (in terms of plant stand)

	Trial No	UR1	UM1	UR1	UH1	UM1
	Series No	S58	S58	S53	S53	S53
	Harvest Yr	1996	1996	1996	1996	1996
	(g a.i./100kg			Plants/m row		
Untreated	-	17.2 b	16.0 e	21.0 b	54.7 c	21.9 d
EXP 80525D	5 + 60	42.6 a	35.7 c	42.0 a	66.9 ab	44.6 ab
Guazatine	60	41.9 a	41.3 b	-	-	-
Fludioxonil	5	-	-	43.0 a	63.9 b	44.1 ab
LSD (P=0.05)		2.7	5.3	3.0	8.1	6.4
				Plant stand as % of untreated		
EXP 80525D	5 + 60	248	224	200	122	203
Guazatine	60	244	259	-	-	-
Fludioxonil	5	-	-	205	117	201
Variety		Woodstock	Woodstock	Woodstock	Hunter	Woodstock
Sowing date		21.11.95	24.11.95	21.11.95	10.11.95	24.11.95
Seed infection level (%)		40	40	40	30	40

Against three seed stocks in six trials with a range of infection levels from 4 – 50 plants per plot infected with loose smut, both EXP 80812A and tebuconazole + triazoxide gave complete control. See Table 4 for details.

Table 4. Control of loose smut with EXP 80812A

	Trial No	UM1	UM2	UM3	UR1	UR2	UR3
	Series No	97S29	97S29	97S29	97S29	97S29	97S29
	Harvest Yr	1997	1997	1997	1997	1997	1997
Treatment							
	(g a.i./100 kg	Infected ears/plot					
Untreated	-	39.8 a	50.0 a	37.3 b	4.0 a	6.5 a	6.5 a
EXP 80812A	5 + 5	0.0 d	0.0 d	0.0 c	0.0 b	0.0 b	0.0 b
Tebuconazole+triazoxide	3 + 3	0.0 d	0.0 d	0.0 c	0.0 b	0.0 b	0.0 b
LSD (P=0.05)		5.2	7.2	7.7	1.0	4.2	1.0
		% control					
EXP 80812A	5 + 5	100	100	100	100	100	100
Tebuconazole+triazoxide	3 + 3	100	100	100	100	100	100
Variety		Pastoral	Manitou	Pastoral	Pastoral	Manitou	Pastoral
Sowing date		15.10.96	15.10.96	16.10.96	02.12.96	02.12.96	02.12.96
Seed infection level (%)		1.2	1.6	2.6	1.2	1.6	2.6

In this series of six winter barley leaf stripe trials, two different varieties Pastoral and Gaulois, with infection levels of 29% and 61% respectively were sown. Meaned across all sites tebuconazole+triazoxide and EXP 80812A gave 99.9% and 99.5% control of leaf stripe. Results are presented in Table 5.

Table 5. Control of winter barley leaf stripe with EXP 80812A

	Trial No	UM1	UM2	UM3	UR1	UR2	UR3
	Series No	97S35	97S35	97S35	97S35	97S35	97S35
	Harvest Yr	1997	1997	1997	1997	1997	1997
Treatment							
	(g a.i./100 kg	Infected tillers/plot					
Untreated	-	53.5 a	63.0 a	59.8 a	124.3 a	622.8 a	682.3 a
EXP 80812A	5 + 5	0.0 c	2.0 c	0.0 c	0.0 c	0.3 c	0.0 c
Tebuconazole+triazoxide	3 + 3	0.5 c	0.0 c	0.0 c	0.0 c	0.0 c	0.0 c
LSD (P=0.05)		6.3	6.8	6.4	16.0	29.2	20.2
		% control					
EXP 80812A	5 + 5	100	97	100	100	100	100
Tebuconazole+triazoxide	3 + 3	99	100	100	100	100	100
Variety		Pastoral	Gaulois	Pastoral	Pastoral	Gaulois	Gaulois
Sowing date		11.10.96	11.10.96	15.10.96	31.10.96	31.10.96	02.12.96
Seed infection level (%)		29	61	29	29	61	61

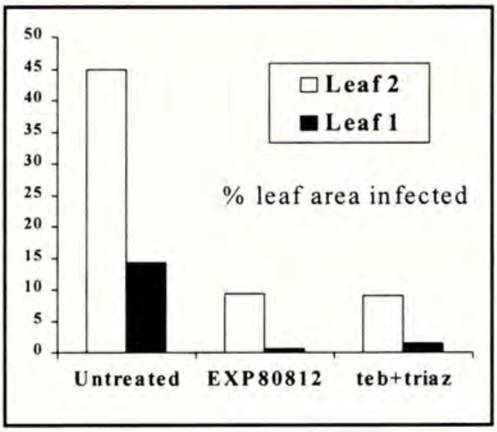
In five trials to investigate activity against stem-base browning on winter barley, EXP80812A gave a 75% reduction in the number of infected plants compared to a 36% reduction with tebuconazole+triazoxide. Results are presented in Table 6.

Table 6. Control of Fusarium seedling blight stem-base browning on winter barley with EXP 80812A

	Trial No	UM1	UR1	UR2	UR3	UR4
	Series No	98S11	98S11	98S11	98S11	98S11
	Harvest Yr	1998	1998	1998	1998	1998
Treatment						
	(g a.i./100 kg			% plants infected		
Untreated	-	10.6 a	32.5 a	46.0 a	13.5 a	51.0 a
EXP 80812A	5 + 5	0.0 c	8.0 c	8.5 c	4.5 b	25.0 b
Tebuconazole+ triazoxide	3 + 3	0.0 c	22.5 b	31.5 b	17.0 a	42.5 a
LSD (P=0.05)		3.0	5.2	7.8	5.0	9.2
				% control		
EXP 80812A	5 + 5	100	75	81	66	51
Tebuconazole+ triazoxide	3 + 3	100	31	31	0	16
Variety		Pastoral	Manitou	Pastoral	Manitou	Pastoral
Sowing date		21.10.97	27.10.97	27.10.97	29.10.97	29.10.97
Seed infection level (%)		38	40	38	40	38

A trial on net blotch infected spring barley seed showed that both treatments reduced the level of net-blotch throughout the season, up to final leaves 1 and 2 (figure 1). The yield from the two seed treatments was 0.9 t/ha greater than the untreated.

Figure 1. Control of seed-borne net blotch with EXP 80812A



Assessed 119 days after sowing

DISCUSSION

Triticonazole is the first new active ingredient to be registered in the UK for the control of cereal seed- and soil-borne diseases for a number of years. Triticonazole is highly active on *Tilletia* and *Ustilago* spp. and gives moderate control of *Pyrenophora* spp. By combining triticonazole with other active ingredients, the two products EXP 80525D and EXP 80812A both have broad-spectrum disinfection activity.

Microdochium nivale is arguably the most important seed-borne disease of wheat in the UK. It may cause losses at plant emergence, early seedling growth and later in the life of the plant as seedling blights and foot rots.

For use on wheat, triticonazole has been combined with the well-proven active ingredient guazatine (as EXP 80525D) which gives effective protection against *M. nivale* and *L. nodorum* (Cox and Mussard, 1994). Together, triticonazole and guazatine control all of the major seed- and soil-borne diseases of wheat. The results presented in Tables 1 to 3 shows that EXP 80525D is at least as effective, and often more effective, than the market leading standards.

For use on barley, triticonazole has been combined with one of the most effective active ingredient for control of leaf stripe and seed-borne net blotch, imazalil. The combination of these two active ingredients (EXP 80812A) gives a product that provides outstanding control of all the major seed- and soil-borne diseases of barley as presented in Tables 4 to 6 and in Figure 1.

Because of its extremely high level and consistency of control, EXP 80812A has been approved by the National Institute of Agricultural Botany (NIAB) for retrieval of loose smut.

In conclusion, the data presented in this summary show the two new seed treatments based on triticonazole to give excellent broad-spectrum control of all the major seed- and soil-borne diseases of wheat and barley and both will make a useful contribution to UK agriculture.

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A9873C, a broad spectrum fungicide seed treatment for peas

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ABSTRACT

A9873C is a new seed treatment product with activity against a broad spectrum of pea diseases. This product has been introduced in New Zealand in 2000 and it is currently in the registration process in France and United Kingdom. A9873C contains three active ingredients of which (R-)-metalaxyl and cymoxanil, with different modes of action, are active against *Peronospora viciae*. This provides an anti-resistance strategy to prevent rapid development of insensitive strains as well as a tool to control downy mildew in areas where resistance of *P. viciae* against phenylamides has developed. Field trials in UK and France as well as in New Zealand have demonstrated excellent control of downy mildew and yield trials in New Zealand have shown increases in grain yield. A9873C has also shown excellent control of *Pythium ultimum* in growth chamber trials in France and Switzerland. A9873C contains fludioxonil as a third component. In growth chamber trials in France this phenylpyrrole compound gave very good control of seed-borne *Mycosphaerella pinodes*. A9873C is recommended as part of integrated approaches, incorporating cultural, varietal and chemical control strategies.

INTRODUCTION

Pea plants are susceptible to soil-borne disease organisms. For the production of optimum yields of processing peas continued cool weather until the period of maximum blooming is favourable. Aside from temperature being a specific factor in good pea production, the need for uniform moisture supply is important. For germination, pea seeds require at least 33% soil water over the permanent wilting point, a point significantly higher than for most other vegetable crops. The early sensitivity to moisture remains with the pea plant until it has reached maturity (Nonnecke, 1981). Due to these pathogen friendly agronomic factors, pea seeds will be attacked by pathogens if not protected by fungicide seed treatments.

The spectrum of fungal pea diseases is broad and includes, downy mildew (*Peronospora viciae*), foot rot diseases (*Mycosphaerella pinodes*), root rot diseases (*Fusarium solani* f.sp. *pisi*, *Pythium* spp., *Rhizoctonia solani*, *Aphanomyces euteiches*, *Thielaviopsis basicola*), stem rot, seed rot, seedling blight (*Pythium* spp.) and *Fusarium* wilt (*Fusarium oxysporum* f.sp. *pisi*). (Anon.1993).

A9873C is a fungicide product that has been designed to protect pea seedlings against a broad range of diseases, especially those caused by *Peronospora viciae*, *Pythium* species and *Mycosphaerella pinodes*.

METHODS AND MATERIALS

Field trials to test A9873C for activity against *Peronospora viciae* and *Ascochyta* spp. were carried out at different sites in New Zealand, United Kingdom and France. The trials were prepared using normal cultivation methods with commercial herbicides applied as required. They were based on a randomized complete block design with four replicates. The different seed treatments were applied to seed lots using a batch slurry method.

The experiments evaluating the efficacy of the seed treatments were sown either by hand to give single row plots with a total length of 10 m/plot or using a seven coulter seed drill with plots of 9 m length and 15 cm drill rows. Assessments for disease infection were undertaken in the hand sown plots on the 10 m row length and in the plots drilled with a machine on 3 x 1 m length of row/plot .

The two yield trials were sown using a seven coulter seed drill with 9.45 m^2 plots in the dry seed trial and a 10 coulter seed drill with 9.75 m^2 plot size in the process yield trial. Pea seed yields from each plot were harvested taking 9.45 m^2 or 4 m^2 respectively with the plot yields converted to yield/ha. The process crop yield was corrected to a tenderometer reading of 105.

Growth chamber trials were carried out to test activity against *Pythium ultimum* and against *Mycosphaerella pinodes*. A mixture of sterilised peat and sand was used. In the case of *Pythium ultimum* the soil was artificially inoculated. In the case of *Mycosphaerella pinodes* artificially infected seeds were used. Fifty seeds were planted per tray. The trays were incubated at 10-15°C with alternating 14 hours daylight and 10 hours dark. The number of healthy plants were counted from emergence up to 3 to 8 weeks after planting.

A9873C, Wakil XL®, is a WG formulation containing cymoxanil 10% + (R-)-metalaxyl 17.5% + fludioxonil 5%. In all trials, quoted here, the product was used at 200 g/100kg seed and was compared with standard products at label rates. All rates of use are expressed as g a.i./100kg seed, i.e. cymoxanil (C) + (R-)-metalaxyl (M) + fludioxonil (F) 20+35+10 g a.i./100kg seed.

Statistical tests were performed at a 5% level based on untransformed values.

RESULTS

A field trial carried out in the UK in spring 1998 showed excellent control of *Peronospora viciae* by A9873C. Thiram + thiabendazole + metalaxyl (Apron® Combi) had no effect on downy mildew. This was expected at this site where the standard product was known to be non-effective due to the prevalence of *P. viciae* strains insensitive to phenylamides (table 1).

Table 1. Activity of A9873C, against *P. viciae* at 240 days after sowing (DAS) in UK.

Treatment	g a.i./100kg	No. Infected Plants per Plot
Untreated		9.5
A9873C	20+35+10	0.0
thiram +thiabendazole+metalaxyl	30+36+70	13.8
LSD 0.05		4.7

Three field trials carried out in France in spring 1998 showed that A9873C, controlled *P. viciae* whereas the standard product, containing metalaxyl + oxine copper + carbendazim (Proxima®), without an anti-resistance partner against downy mildew, failed to control the disease or provided only partial control (table 2).

Table 2. Activity of A9873C against *P. viciae* at three sites in France.

		No. Infected Plants per Plot		
		Trial 1	Trial 2	Trial 3
Treatment	g a.i./100kg	44 DAS	51 DAS	35 DAS
oxine copper . (OC)	60	81.5	25.3	15.3
A9873C	20+35+10	0.0	0.0	0.8
metalaxyl+ OC+ carbendazim	70+30+30	23.8	6.5	1.5
LSD 0.05		16.5	5.1	4.7

A field trial carried out in the Canterbury region of New Zealand in spring 1998 (table 3) showed a high level of control of *P. viciae* by A9873C. At the second assessment, 65 days after sowing, levels of downy mildew infection were lower in the A9873C treatment than in the standard treatments (R-)-metalaxyl (Apron XL®) and fosetyl-Al (F-Al) + thiabendazole (TBZ) + thiram (Aliette Super®). The degree of downy mildew infection in the (R-)-metalaxyl treatment was due to the prevalence of phenylamide insensitive strains of *P. viciae* in this region.

Table 3. Activity of A9873C against *P. viciae* in the Canterbury region of New Zealand.

		% Plants Infected	
Treatment	g a.i./100kg	58 DAS	65 DAS
untreated		94.7	94.7
A9873C	20+35+10	0.0	0.0
M	350	80	59.3
F-Al + TBZ + thiram	153+50+37	0.0	22.6
LSD 0.05		8.9	14.1

Three field trials carried out in in the Wairarapa region of New Zealand, one in the spring of 1997 and two in 1999 showed excellent control of primary systemic infection from *P. viciae* by A9873C (table 4).

Table 4. Activity of A9873C against primary systemic infection from *P. viciae* at 29 DAS in 1997 and in 1999 in the Wairarapa region of New Zealand.

		% Plants Infected		
		Cultivar 1	Cultivar 1	Cultivar 2
Treatment	g a.i./100kg	1997	1999	1999
untreated		62.1	6.6	15.8
A9873C	20+35+10	0.0	0.0	0.0
M	350	0.0	0.0	0.1
F-Al+TBZ+thiram	153+50+37	4.4	0.7	0.0
LSD 0.05		3.7	1.7	3.5

The effect of *P. viciae* on yield was assessed in 1998 and 1999 in two spring field trials in New Zealand. The results showed that all seed treatments increased the grain yield compared with the untreated. The yield increase was higher in the A9873C treatment compared with the (R-)-metalaxyl treatment. The increase in yield in the seed treatments was probably due to increases in plant populations and the reduction in downy mildew infection (table 5).

Table 5. Mean grain yield from A9873C in New Zealand

Treatment	g a.i./100kg	Grain yield kg/ha [a]	Grain yield kg/ha [b]
Untreated		1835	6511
A9873C	20+35+10	5792	7341
M	350	4012	7254
F-Al+TBZ+thiram	153+50+37	5287	6530
LSD 0.05		1147	[c]

[a] dry seed yield ; [b] process fresh yield corrected to TR 105; [c] treatment differences not statistically significant

In three growth chamber trials carried out in France in 1999 and in 2000, A9873C showed excellent activity against *Mycosphaerellea pinodes*. The seed used in these trials was artificially infected with the disease. Activity of A9873C was comparable to the standard Wakil® Elite, cymoxanil + oxadixyl + carbendazim (MBC) + thiram 20+50+40+100g a.i./100 kg seed (table 6).

Table 6. Activity of A9873C against *M. pinodes* in growth chamber trials in France. Number of healthy plants (50 planted), 28, 52 or 21 days after planting respectively.

		Number of healthy plants		
		Trial 1	Trial 2	Trial 3
		1999	1999	2000
Treatment	g a.i./100k	28 DAS	52 DAS	21DAS
Untreated		1.0	0.0	0.3
A9873C	20+35+10	48.0	47.0	47.0
C+oxadixyl+MBC+thiram	20+50+50+100	47.0	47.0	48.3
LSD 0.05		7.1	10.6	2.4

In two growth chamber trials A9873C was tested against *Pythium ultimum*. The first trial was carried out in Switzerland in 1998, the second trial in France in 2000. In both trials sterile soil was artificially inoculated with the pathogen. In trial 1 the activity of A9873C was high and comparable to the standards. In trial 2 A9873C outperformed the standard treatments (table 7).

Table 7. Activity of A9873C against *Pythium ultimum* in growth chamber trials carried out in Switzerland and in France. Number of healthy plants out of 50 sown.

Treatment	g a.i./100kg	No. Healthy Plants Trial 1 20 DAS	Trial 2 29 DAS
Untreated		9.0	8.8
A9873C		46.0	43.8
C+oxadixyl+MBC+thiram	20+50+50+100	46.0	35.8
Metalaxyl+OC+carbendazim	70+30+30	48.0	nt
F-Al+MBC+thiram	150+40+50	nt	26.0
LSD 0.05		4.4	6.1

nt: not tested

DISCUSSION

The data presented in this paper demonstrate that A9873C controls three important pathogens of peas.

The control of *Mycosphaerella pinodes* can be attributed to the active ingredient fludioxonil. Koch & Leadbeater (1992) have also shown activity of fludioxonil against *Ascochyta pisi* and *Mycosphaerella pinodes* in field trials in UK in 1989. Gehmann *et al.* (1990), and Leadbeater *et al.* (1990) have shown the broad spectrum of activity of this phenylpyrrole compound in wheat, barley, rye, maize, rice, pea, potato and oilseed rape against a range of seed-borne pathogens.

Mueller *et al.* (1997) have shown that fludioxonil has limited uptake into wheat seeds during germination and emergence. The compound tends to stay in the region of the seed, forming a protective shield around the seed and coleoptile as it grows through the soil. This enables fludioxonil to give long lasting protection against seed- and soil-borne pathogens.

The control of *Pythium* species can be attributed to the active ingredient (R-)-metalaxyl and the control of *P. viciae* can be attributed to both, (R-)-metalaxyl and to cymoxanil.

The data presented in this paper demonstrate the excellent activity of A9873C and greatly increased grain yields in areas where downy mildew strains with reduced sensitivity to phenylamides have developed. These data confirm earlier findings of Falloon *et al.* (2000).

The combination of the two active ingredients, (R-)-metalaxyl and cymoxanil, with different modes of action for the control of downy mildew, means that A9873C contains an in-built anti-resistance strategy.

However, as *P. viciae* has seed-, soil- and air-borne phases the pathogen by itself bears a high risk to develop resistance to chemicals. To protect the new combination product from rapid sensitivity shifts it is therefore recommended to use it in integrated approaches that incorporate cultural practices. Falloon *et al.* (2000) describe likely components of such IPM approaches including long crop rotations (up to 5 years) between pea crops to prevent build up of soil-borne oospore inoculum of *P. viciae*. Late spring/early summer sowing of pea crops may also help to avoid cool damp weather that is conducive to downy mildew epidemics. Full rates of copper- or non-phenylamide-based fungicides, if available and registered in a country, should also be used as foliar applications to pea crops for control of downy mildew. Another likely future component of integrated downy mildew control is the production of new pea cultivars with durable resistance to the disease.

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Seed treatment according to need in winter wheat

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ABSTRACT

Several significant changes have taken place in the UK cereals industry in the last few years. Lower cereal prices have forced growers to seek input cost savings. Increased consumer concerns for the environment and food safety, and the introduction of more rigorous quality standards imposed by the end use markets all require that pesticide use is according to need. The diversity of new seed treatment products also encourages growers to target seed treatment to the range of pathogens present. Winter wheat is the largest cereal crop in the UK, requiring over 300,000 tonnes of seed each year. Survey evidence shows that in low disease seasons it may be possible to sow over half of the winter wheat for ware untreated. This paper reviews the current status of wheat seed production in the UK, and the research work which is being carried out to support and promote better targeting of seed treatments' through improved seed testing technology, whilst maintaining a high level of seed health.

INTRODUCTION

Changes in the use of seed treatments following the withdrawal of organomercury, the results of a survey of seed-borne diseases on cereals (Cockerell & Rennie, 1995) and research (Paveley & Davies, 1994) which showed no benefit of seed treatment on crop establishment or yield, where seed was sown untreated, provided the stimulus to re-evaluate seed treatment strategies in the UK. The mechanisms for maintenance of cereal seed health and the use of seed treatment in the UK were reviewed by Paveley *et al* (1996). They identified options for changing to a strategy of "treatment according to need" to improve both seed health and the economic efficiency of seed production in the long term.

Since the review, the need for growers to reduce costs has increased. A competitive world cereal market has continued to demand lower production costs. The arrival of new seed treatments, not specifically aimed at controlling seed-borne pathogens but other crop pests and diseases, provides a diversity of products (Table 1), that encourages growers to target seed treatments to the range of pathogens present. Increased consumer concerns for the environment and food safety, and the introduction of more rigorous quality standards imposed by end use markets all require that pesticide use should be according to need.

Table 1. Winter wheat seed treatments for disease control (Anon., 2000a)

Active ingredient	Diseases controlled							
	Bunt	Loose smut	Fusarium	Septoria	Yellow rust	Take-all	BYDV	Approx. cost (£/tonne of seed treated)
Guazatine	+		+	+				39
Carboxin + thiram	+	+	+	+				42
Triticonazole + guazatine	+		+	+				43
Bitertanol + fuberidazole	+	+	+	+				43
Fludioxonil	+		+	+				44
Triadimenol + fuberidazole	+	+	+	+	+			87
Bitertanol, fuberidazole + imidacloprid	+	+	+	+			+	106
Triadimenol, fuberidazole + imidacloprid	+	+	+	+	+		+	134
Fluquinconazole + prochloraz	+		+	+		+		170
Silthiofam						+		TBA

Winter wheat is the largest cereal crop in the UK, with approximately 2 million ha sown in 1999 requiring 354,000 tonnes of seed, (Anon., 2000b). For treatment according to need to be a viable option, the rapid availability of information from seed tests is needed. This will allow seed producers to identify seed stocks with high levels of contamination and remove them from the multiplication chain or make informed decisions on the most effective treatment for the diseases present. Rapid testing is required due to the very short period between harvesting and sowing. The development of an effective disease management strategy for wheat also depends on a thorough knowledge of the biology and epidemiology of the two main seed-borne diseases, *Microdochium nivale* and *Tilletia tritici*. Since December 1998, research work funded by the Home-Grown Cereals Authority has been on-going to develop rapid seed health tests and to set treatment and rejection thresholds for *M. nivale* and *T. tritici* through field work and mathematical analysis.

Seed health testing

Highly sensitive, rapid and specific PCR protocols for the detection of *M. nivale* and *T. tritici* have been established, enabling information on seed quality to be provided rapidly (test results within 48 hours) to seed producers. Quantification experiments using competitive PCR show a good correlation between the PCR test and the traditional agar plate test for *M. nivale*, (Figure 1). and the PCR test for *T.tritici* and the current wash test, (Figure 2). The resultant calibration curves permit estimation of infection levels from PCR data (each data point represents a PCR assay from one seed sample).

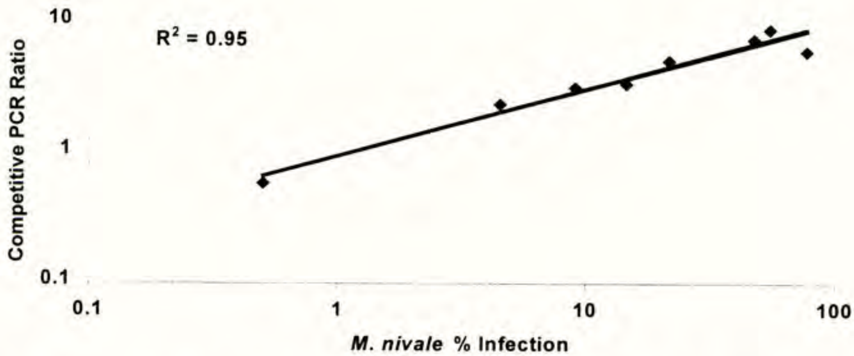

Figure 1. Calibration curve of PCR assays for *M. nivale* against agar plate results

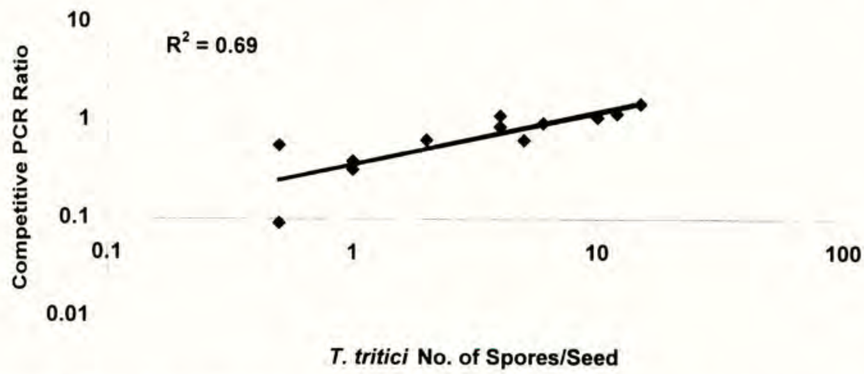

Figure 2. The relationship between the PCR test for *Tilletia tritici* and the current wash/filter method.

Health tests are carried out on small samples of seed. To ensure robust interpretation of seed test results, confidence limits for seed test results must be established to take account of sample variation. Data on the distribution of infection within seed crops and seed lots, and the effects of sampling on the relationship between the test result and actual level of infection are being assessed (Thomas *et al*, 2001). From this information, recommendations on sampling procedures (either on farm or before processing), maximum seed lot size and sample size will be made.

Relationship between the seed test results and disease expression in the field.
Current advice suggests that winter wheat should not be sown untreated unless seed-borne *M. nivale* is below 5%. It is likely that this may be over cautious in certain situations. The results of seed health tests cannot be converted into reliable decisions without understanding the relationship between test results and disease expression in the field. For any given test result, the interactions with agronomic and environmental conditions which lead to different outcomes must be properly quantified if thresholds are to be robust but not over cautious. Although the relationship between test results and disease expression, and the extent of its variation, for *M nivale* has been established (Hare *et al*, 1995, Cockerell, 1995) the data require critical analysis to determine treatment thresholds. Field experiments are underway to test whether "worst case" outcomes are adequately represented in existent data.

During 1995/6, trials were established at three UK sites to establish the relationship between *T. tritici* spore contamination recorded in the seed test and disease expression in the field. A healthy seed stock was artificially inoculated with spore loadings of 0, 10, 100, 1000 and 10,000 spores per seed. Statistical analysis showed that 100 spores per seed appeared to be the critical contamination level to cause field infection (Cockerell, unpublished data). However, this information is limited and current advice is to treat seed if 1 or more spores per seed are recorded in a seed test. Field trials were sown in autumn 2000 to look more critically at the effect of low levels of spore contamination between 1 and 10 spores per seed. The trials will be destructively sampled and high sampling intensity will be used to approximate to proof of absence. These trials will also be used to better quantify the multiplication potential of *T. tritici* by relating seed infection to the spore loading of the harvested seed.

Multiplication and risk of spread to neighbouring crops.
There are significant gaps in understanding the risks posed to neighbouring and following crops by *T. tritici*. There is evidence of drift of *T. tritici* spores from adjacent infected crops (Yarham & McKeown, 1989). In this case, drift occurred to bare soil which was being drilled with healthy wheat seed and the emerging seedlings picking up infection from the soil-borne spores. There was little evidence of any gradient of infection from the adjacent infected crop, suggesting that spread of spores might occur over substantial distances. Clearly the spread of spores will be related to the wind speed and turbulence at the time of spore release during harvest. Trials have been established to quantify the risks of such spread during the harvest operation. First year results have shown that spores of *T. tritici* are capable of long distance spread during the harvesting of infected crops. Spores and crop debris carrying spores of the fungus were trapped up to 64 metres downwind of a combine harvester during harvesting. These spores can survive in dry soil for many weeks and are capable of infecting newly sown or emerged crops. Experiments are underway to relate the density of spores arriving at ground level to the level of infection in the emerging crop.

Setting treatment and rejection thresholds through mathematical analysis.
Given the quantitative data being collected and the epidemiological understanding from the current literature, a mathematical analysis will be used to describe the effects of changing thresholds and the use of seed treatments on the long term health status of UK wheat stocks. The analysis of the long term effects of changes in treatment and rejection thresholds should provide a rational, quantitative basis for seed health decisions.

DISCUSSION

Many thousands of tonnes of seed are treated each year with a fungicidal seed treatment, when the level of seed-borne disease does not justify treatment (Cockerel & Rennie, 1995). With the current economic state of UK farming and the pressures on environmental protection, this situation is difficult to justify. However, many of the potential risks to changing the current policy are not fully qualified. Any strategy for change from the current strategy of routine prophylactic treatment must (a) ensure long term security of wheat production against deleterious effects of seed-borne disease on yield and grain quality; (b) minimise input costs; (c) maximise any potential benefits of seed treatment against foliar diseases (d) ensure adequate returns to agrochemical companies and plant breeders to stimulate better seed treatments and varieties; and (e) minimise risks to operators, consumers and the environment. The first of these aims cannot be compromised, and the high multiplication potential of *T. tritici* does not allow the current level of suppression to be relaxed. However, treating seed which does not carry infection, does not improve the health status of the UK seed supply. The current environment under which seed production takes place makes it reasonable to suggest that seed treatments should be targeted more effectively, while achieving a balance between the other needs.

The value of seed health testing lies in its ability to support decisions about suitability for seed, the need for treatment and the type of treatment required. Survey evidence (Cockerell & Rennie, 1995) suggests that in low disease seasons it may be possible to sow over half of winter wheat for ware untreated, giving savings of approximately £8 million per annum. In high disease seasons this figure would reduce to approximately £2 million. The exact level of cost reduction would depend on the extent to which the health of the seed supply improved through better information for management decisions and the level at which treatment thresholds are set.

With the introduction of new take-all seed treatments growers now have a wider choice of wheat seed treatments. The significant variation in cost (from £40/t to £170/t) and the different spectrum of disease control offered by each product makes knowing the health status of the seed essential if informed decisions on product choice are to be made. This may allow savings by using lower cost products or sowing untreated seed when disease levels allow. If better information is made available to growers then the practice of farm saving seed can be based on sound knowledge.

The key to treating seed according to need will be robust protocols for sampling and testing of seed. This, together with a thorough understanding of the epidemiology of *M. nivale* and *T. tritici*, should allow treatment thresholds to be set at levels which, on average, maximise profit, and avoid the risk of occasional severe loss in an individual crop. This strategy should also place pathogen populations under constant downward pressure in order to maintain a reliable supply of high health status seed.

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