SESSION 2B

NEW DEVELOPMENTS IN THE MANAGEMENT AND CONTROL OF CEREAL TAKE-ALL

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Papers	2B - 1 to 2B - 5

to live with the disease in high risk rotational situations. The new fungicides are effective, but they will not eliminate take-all and, if conditions favour its development, it may be expected still to cause yield reductions in spite of their use. They must be seen as parts (all be it important parts) of a package of control measures which will still include husbandry practices, though they may give us more flexibility in our application of these practices. They may, for example, be used to augment the benefits of delaying the sowing of second wheats, or to offset the disbenefits of sowing earlier.

In 1998, almost all second and third wheats would probably have benefited from the chemical control of take-all. In recent drier years, however, many well managed second and third wheats escaped serious depredations by the disease. If 1998 proves to have been a 'one-off' interruption in the trend towards drier autumn and spring conditions then we may question whether the *routine* use of take-all fungicides on all second and third wheats could be justified. We are unlikely ever to be able, at sowing time, accurately to assess the risks of adverse weather occurring during the growing season. Any fungicide applied as a seed treatment will, therefore, have to be regarded as an insurance against an eventuality which may not occur. We may, however, be able to provide an actuarial assessment of the risks which a 'normal' season will bring to a crop in a particular field by applying our knowledge of conditions within that field: previous cropping, soil conditions, nutrient status, proposed sowing date, sensitivity of the variety to moisture stress (the effects of which take-all will exacerbate) and so on. When advising on fungicide use we will also need to know whether the materials will affect the development of take-all decline, and whether we will need to use them in the first year of a cereal sequence (to prevent the build up of inoculum) or merely in the subsequent 'high risk' years.

The advent of agrochemicals effective against take-all is a breakthrough we have long awaited, but their arrival serves to highlight the need (if they are to be used effectively) for a greater understanding of the factors affecting disease development.

REFERENCES

Beale R E; Phillion D P; Headrick J M; O'Reilly P; Cox J (1998). MON65500: A unique fungicide for the control of take-all in wheat. *Proceedings of Brighton Crop Protection Conference - Pests and Diseases* **2**, pp. 343-350

Garrett, S D (1946). Reduction of take-all by artificial fertilisers. *Journal of the Ministry of Agriculture*, **LIII**, 223-225.

Glynne, M D; Cox, J (1959) Fungi and fungus diseases. *Report of Rothamsted Experimental Station 1958*, Part 1, 107.

Hornby, D (1998). Interactions between cereal husbandry and take-all: the background for newer methods of controlling take-all. *Proceedings of Brighton Crop Protection Conference - Pests and Diseases* **1**, pp. 67-76

Loechel A M; Wenz M; Russell P E ; Buschaus H; Evans P H; Cross S; Puhl T; Bardsley E (1998). Root protection using fluquinconazole: a new approach to controlling cereal take-all. *Proceedings of Brighton Crop Protection Conference - Pests and Diseases* **1**, pp. 89-96

Interactions between cereal husbandry and take-all: background for newer methods of controlling the disease

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ABSTRACT

Further information about cereal sequences and their effects on take-all is presented. Results from a large, 9-year field experiment at IACR-Rothamsted are discussed in terms of disease management and the apparent inability of cereals less susceptible than wheat to achieve a natural biological control (take-all decline) that will protect a subsequent wheat crop from severe take-all. Such findings are relevant to the introduction and optimum use of new (chemical) methods of take-all control and to ideas about future cereal cropping.

INTRODUCTION

Currently, the best control for take-all in the UK is not to grow consecutive crops of susceptible cereals (Hornby, 1998). After the late 1980s the cereal production system began to move in this direction and the proportion of wheat fields in England and Wales with first wheat crops, which are usually not at risk from take-all, more than doubled, until by 1995 it was just under three quarters (Polley *et al.*, 1995). However, the changes were dictated by economics, environmental concerns and politics, rather than pathology. In the next two years the trend reversed, so that in 1997 the proportion of fields with first wheat crops had decreased to about three-fifths (Hardwick *et al.*, 1997). In the absence of fungicides or resistant cultivars, those farmers growing cereals intensively can do no more to protect against take-all than pay attention to good husbandry, assess risks (e.g. of breaking a long run of cereals, or taking a third crop) and consider options such as shortening rotations or exploiting the natural biological control phenomenon of take-all decline (TAD) by staying in continuous cereal cropping.

In the search for other means of controlling take-all, biological control has held centre stage for about a quarter of a century, but whereas it has generated much enthusiasm and optimism, there is as yet no product for farmers. Also, there is relatively little research effort going into breeding resistant or tolerant cultivars and apparently none in the UK. However, as other contributions to this conference indicate, take-all fungicides are now a much brighter prospect. The expectation has already been expressed that if new fungicides are introduced, the importance of take-all may be reduced (HGCA, 1998). Although we may be at the threshold of a new era of effective take-all control by fungicides commercially available to farmers, this is unlikely to nullify all the knowledge about minimising take-all, gained in the absence of such chemicals. At the very least, such knowledge will be helpful in achieving optimum use of new fungicides.

In well-run production systems in Britain, changes in husbandry usually achieve only a modest decrease in disease. Trying to minimise take-all by good husbandry recalls the 'many little hammers' analogy used in considering ecological management of crop-weed interactions (Liebman & Gallandt, 1997). That focuses on many indirect controls and many possible interactions that

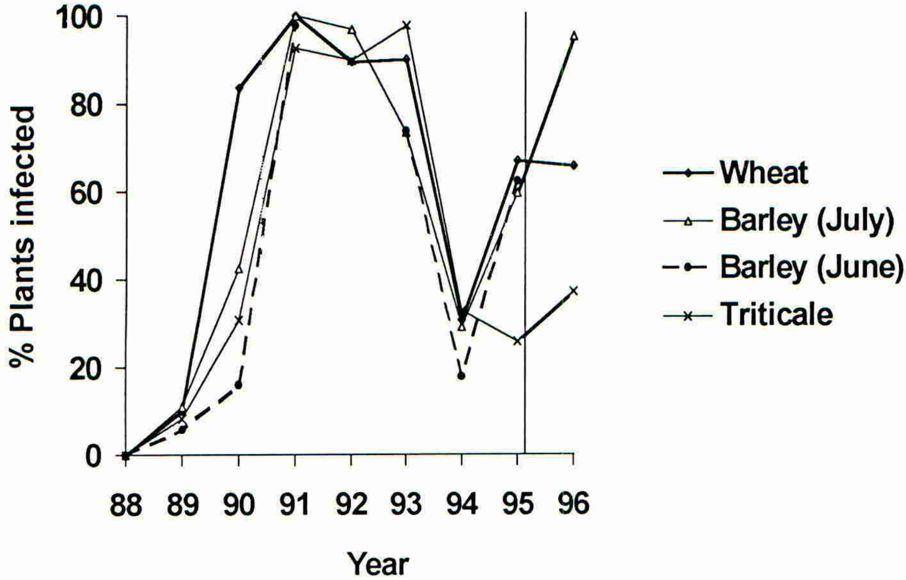

Figure 1. Incidence of take-all in July (at GS 69–71) for winter wheat and winter triticale, and in June (at GS 69–71) and in July (at GS 85–91) for winter barley. *Incidence measured as the percentage of sample plants with any symptom of take-all on attached roots, is shown for eight consecutive crops of each cereal. The vertical line after 1995 indicates that winter wheat was grown in all sequences in the 9th yr. No data are available for June 1992.*

Table 1. Relative susceptibilities (in descending order) of winter cereals to take-all as indicated by disease assessments made in July in each of eight years of a rotation experiments (CS323).

Winter cereal	No. of occurrences in 21* crops at risk of: Moderate + severe take-all (TAR > 100)	Severe take-all (TAR > 200)
Wheat	12	4
Barley	8	2
Triticale	7	2

* Excludes first wheats and winter oat break crops in the rotations.

can lead to successful management. A combination of different methods may have significant advantages, such as additive, synergistic or cumulative action, spreading the burden of protection and giving minimal exposure to any one tactic. It may arise through a lack of an economically viable 'single, large hammer', which in the case of take-all could be a fungicide (most likely), a resistant cultivar, or a biological control agent (perhaps least likely). If new fungicides do not completely control the disease, then their use in combination strategies is likely to be considered. It is worth noting, however, that earlier attempts to combine promising treatments and farming practices for decreasing take-all did not identify any effective package of treatments, because of an absence of strong additive or synergistic effects amongst the factors (Hornby *et al.*, 1990). This conference is an opportunity for the chemical companies to provide information needed to open up this debate.

Table 2. Incidence of take-all in continuous wheat crops and wheat crops in rotation with oats in experiment CS323. *The continuous sequence started in 1998 after two years of oilseed rape; the short runs of wheat were phased in from 1989 onwards, each after a singe year of oats.*

No. of consecutive wheat crops	Plants with take-all symptoms (%)								
	1988	1989	1990	1991	1992	1993	1994	1995	1996
1	0	0	8.8	27.1	49.7	28.6	18.5	31.7	0
2		10.2*	1.5	51.4	90.9	78.8	40.0	22.3	26.5
		36.2							
		56.0							
		38.8							
		37.4							
3			83.6*	25.4	100	99.2	67.7	88.8	32.2
			98.1						
4				100					78.2
5					89.6				
6						90.2			
7							30.9		
8								67.1	
9									65.7

* Values for different sequences with identical cropping up to that year.

Many factors affect take-all, for example, fertilizers, cultivation, sowing date, previous cropping, set-aside, volunteers and inoculum (Becker *et al.*, 1998; Hornby, 1998; Schoeny *et al.*, 1998). In this paper the impact of cereal rotations and their effects on disease and inoculum are explored and discussed.

FIELD EXPERIMENTATION

A large field experiment, 'Cereal Sequences and Take-all' (code: CS323) was started on West Barnfield II at the IACR-Rothamsted in 1987. Its main purpose was to investigate take-all in winter cereals (wheat, barley and triticale) grown in i) monoculture, ii) rotations with winter oats (a non-susceptible cereal), iii) sequences where one cereal was replaced by another (a 'bridge' crop) when the risk of take-all was great and iv) sequences with alternation of cereals. Hornby & Gutteridge (1995) reported some findings up to and including the 1994 season and demonstrated for the first time take-all decline (TAD) in monocultures of winter barley and winter triticale. (TAD had already been well documented for winter wheat and spring barley monocultures.) These susceptible winter cereals differed in the rates of disease build-up and severity preceding TAD. Disease increase in successive crops was checked when bridge crops were introduced after consecutive wheat crops, but severe take-all occurred on the resumption of wheat. Alternating wheat with barley or triticale resulted in more crops in the sequence with high disease levels compared to a monoculture of wheat. Alternating winter and spring barley delayed the build-up of take-all in successive crops. Variables related to grain quality in pooled sequences were mostly detected in wheat and the patterns of relationship differed amongst cereals; unexpected associations occurred

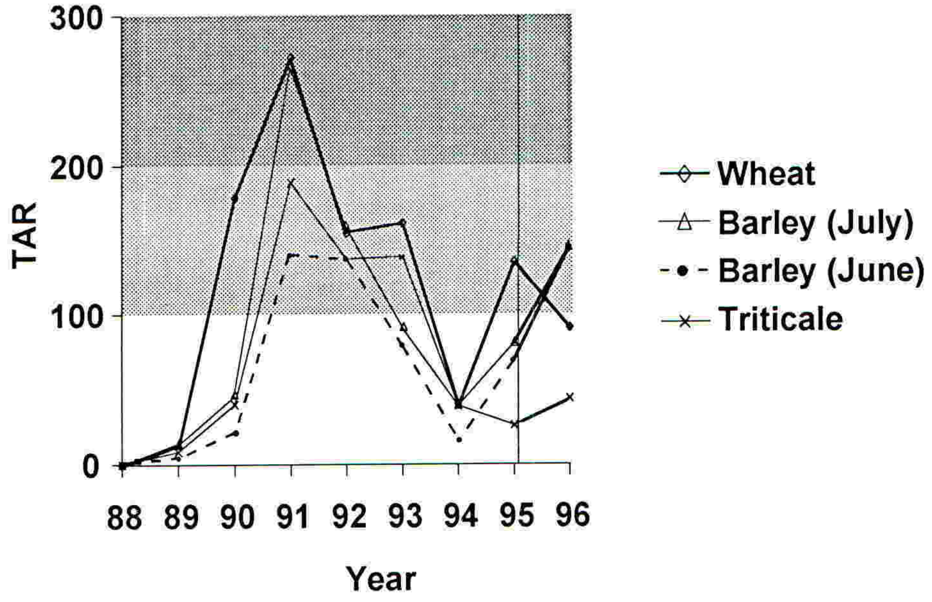

Figure 2. Intensity of take-all, measured as TAR, and the occurrence of TAD during eight consecutive crops of winter wheat, winter barley or winter tricicale. *TAPs are plotted for wheat and triticale as GS 69–71 (July); two sets are plotted for barley (June, GS 69–71 and July, GS 85–91). The horizontal banding (from bottom to top) represents slight, moderate and severe take-all. The vertical line after 1995 indicates that winter wheat was grown in all sequences in the 9th yr.*

Note on standard errors of differences of means (SEDs): *in analyses of variance of TARs in July (all 26 crop sequences, 3 replicates; 50 degrees of freedom) in each of the years 1991–96, SEDs were: 26.53, 28.24, 19.40, 18.53, 29.26 and 26.53, respectively. In analyses of data collected before 1991, the replication was unequal because crop sequences that had not yet deverged were grouped. In 1989 and 1990 the biggest SEDs (i.e. those for comparisons of means with minimum replication) were 19.57 and 26.04, respectively.*

for barley and triticale at low levels of disease (Hornby, 1998). In 1992, the experiment was a source of *Gaeumannomyces graminis* var. *tritici* to study isolates from different hosts and isolates from successive crops during monoculture of wheat, using DNA probes and non-molecular methods (Bateman *et al.*, 1997).

The original cropping plan for CS323 continued into 1995, but then fell victim to large reductions in financial support for take-all research at Rothamsted. Rather than lose this valuable resource completely, it was decided to sow winter wheat on all plots in the autumn of 1995. In the 1995/96 season there were, therefore, 1st-4th and continuous winter wheat crops available for comparison. In a study of the root mycoflora of some of these sequences, four rare microfungi were isolated in June of that year (Kwaśna & Bateman, 1998). After harvest 1996, the site was put into set-aside and sown again with winter wheat in the autumn of 1997 to provide tests of take-all risk and survival of TAD after set-aside. From 1998, it is intended that part of the experiment will be used, as part of a larger project, to study the effects of new take-all fungicide treatments in a TAD situation.

Table 3. Take-all in winter wheat in 1992/93 and 1994/95 (Little Knott, Rothamsted).

	Take-all		TAR
Consecutive crop	% plants infected	Infected roots/plant	
3rd			
4 weeks after early sowing in September 1992	24.7	1.23	
March 1993	64.5	1.23	
July 1993			206
5th			
4 weeks after early sowing in September 1994	47.4	1.25	
March 1995	98.2	5.62	
July 1995			226

Data provided by R J Gutteridge.

It is now possible to summarize disease data for all the 26 cereal sequences in the period 1988-96. Disease incidence and disease intensity (as the take-all rating, TAR, a 0-300 scale explained in Hornby, 1998) are considered here. Most disease assessments are for July, but for winter barley June estimates are also given. All sequences were preceded by two years of oilseed rape and take-all was not detected in the first year of cereals (1988). Growth stages (GS) are given in the decimal code of Zadoks *et al.* (1974).

RESULTS

The shapes of the curves of take-all incidence for cereal monocultures were not conspicuously different up to 1994 (Fig. 1). Within the years 1990, 1991, 1993 and 1995 significant differences amongst the cereals were detected in analyses of variance of incidence data transformed to logits. In 1990 (the third year) incidence in wheat was about twice the 42.5% incidence in barley, but in both wheat and barley incidence peaked at 100% in 1991. Where data for June were available, take-all incidence in barley was often slightly less than in July. Only in barley did incidence decreased much in 1993. Triticale differed from the other monocultures in that peak incidence (97.9%) occurred in 1993 and incidence did not increase following the low level of 1994. The change to wheat in 1996 after barley monoculture was associated with a high incidence (95.3%) of take-all.

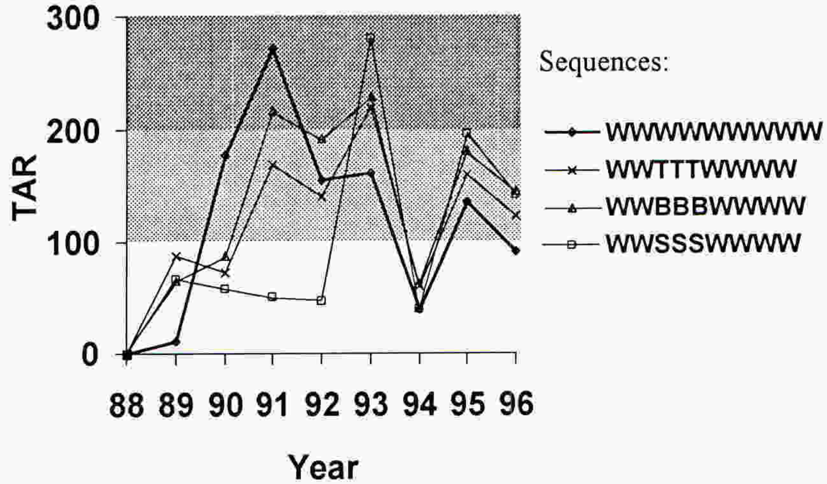

Figure 3. Take-all in July in cereal sequences where there was substitution of winter wheat (W) crops in the 3rd to 5th years (1990–92) by bridge crops: winter barley (B), winter triticale (T) or spring barley (S). *This was the period for which the peak of take-all had been predicted in the wheat monoculture, which is plotted for comparison. Information about SEDs is in the legend to Figure 2.*

Winter wheat, winter barley and winter triticale each had five sequences that comprised monoculture and rotations with winter oats. The TARs during the first 8 years are an indication of the relative susceptibilities of the cereals to take-all (Table 1). The disease categories moderate and severe are those most likely to be associated with decreased yield; slight take-all is less consistently associated with yield depression (Hornby, 1998). The phased sequences of wheat after oats provided comparisons of 1st, 2nd and 3rd wheat crops in each of the years 1990-1996 (Table 2). Disease incidence in these sequences indicates that the 1991/92 season most favoured, and the 1993/94 season least favoured, take-all. The 1993/94 indication accords with Fig. 1, which shows take-all incidence collapsing dramatically in all monocultures in 1994.

TAD first occurred in the monocultures in 1992 (Fig. 2; Hornby & Gutteridge (1995) reported the data up to 1994 as well as data from bioassays of the soil after harvest). The autumn - spring period of 1994/95, which was brighter, warmer and wetter than average, particularly favoured take-all on another field, compared to the same period in 1992/93, which was slightly duller and wetter than average. This may explain the exceptional increase in disease in that field in 1994/95, despite the presumed onset there of TAD in 1993 (Table 3). In the wheat monoculture in CS323, a contemporary upturn in disease was detected (Fig. 2). Despite apparently less favourable conditions in 1996 (judged by the downturn in disease in the wheat monoculture), wheat introduced after barley or triticale monoculture increased disease in those sequences.

Bridge crops substituted for wheat at periods of high risk of take-all failed to prevent severe take-all on resumption of wheat (Fig. 3 and Hornby, 1998). In fact, a winter barley bridge kept disease levels high in more years than in the wheat monoculture and a spring barley bridge preceded the most severe outbreak of take-all. Wheat that had been substituted for barley or triticale maintained high levels of disease for a year longer than did the wheat monoculture (Fig. 4).

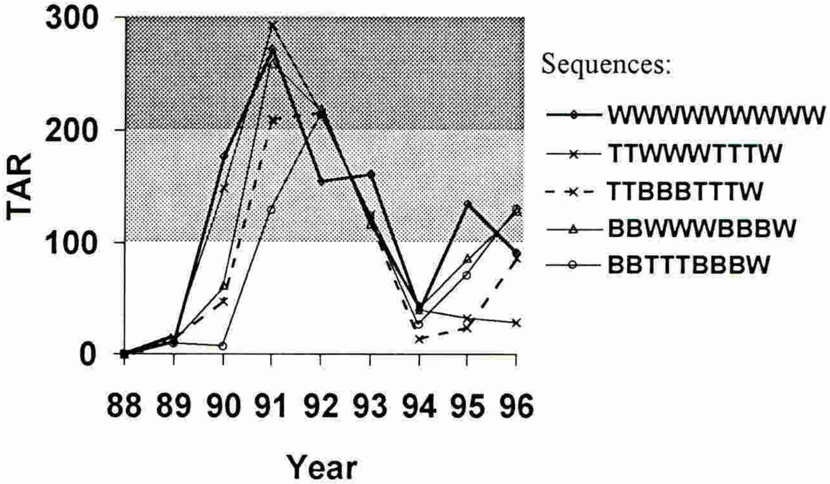

Figure 4. Take-all in July in cereal sequences where there was substitution of winter cereals other than wheat in the 3rd to 5th years (1990–92) by bridge crops: winter wheat, winter barley or winter triticale. *All sequences had wheat in 1996. Information about SED is in the legend to Figure 2; key and other details are in the legend to Figure 3.*

Where cereals were alternated, the wheat-triticale system was worst because it maintained severe take-all levels (TAR >200) in three consecutive years (Fig. 5); wheat-barley also maintained high levels of disease for a year longer than did the wheat monoculture. Disease in the triticale-barley alternation was generally less than in wheat monoculture and alternation of spring barley and winter barley kept disease levels relatively low (a maximum TAR of 159 in 8 years). Despite the suggestion from the wheat monoculture that 1996 was less favourable for take-all than 1995, all other alternating sequences put into wheat in 1996 showed increases in TAR.

DISCUSSION

The Agenda 2000 represents the political and financial framework to adapt the common agricultural policy (CAP) in Europe to the necessities of the 21st century. The proposed move towards a free market place and no set-aside (*Crops* 9 May 1998, pp. 26-27; *Farmers Weekly* 3

July 1998, p. 14) may favour more intensive cereals. A market for new chemicals to control take-all and the need to develop conventional strategies for managing take-all both depend largely on the extent to which cereals will be grown intensively in the future. However, prediction is made difficult because of frequent changes; for instance the compulsory rate of set-aside has been set somewhat higher than expected at 10% for 1999 and dropping to 0% in 2000 may present rotation problems (*Farming News* 3 July 1998, p.1).

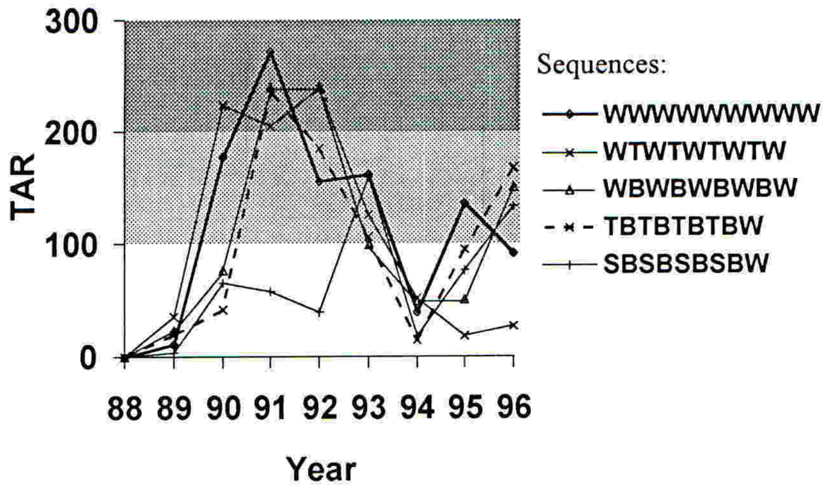

Figure 5. Take-all in July in sequences of alternating cereals compared with take-all in wheat monoculture. *Information about SEDs is in the legend to Figure 2 and the sequences key is as in the legend to Figure 3.*

As originally conceived, CS323 was one of a very few, long-running sequence experiments specifically for the study of take-all in the UK. Most have now ceased due to budget cuts, but a few medium-term (3-4-year) experiments are being funded as a direct result of the appearance of take-all fungicides. Without long-term or medium-term experiments, we are reliant on field observations (often limited) and on the sort of short-term experimentation that has been notoriously misleading in take-all research. CS323, on the contrary, has provided considerable insight into take-all in cereal sequences. Here, data have been selected to illustrate five important points: i) how season interacts with take-all and disrupts expected trends, ii) the significance of different measures of disease (incidence was not very discriminatory; intensity revealed more), iii) relative susceptibility amongst the cereals, iv) relative maturity amongst the cereals and v) the timing of disease assessment.

Previous findings that wheat is the most susceptible cereal and that the susceptibilities of barley and triticale are similar (Hornby & Gutteridge, 1995) are confirmed. On balance, barley is also likely to suffer less yield reduction because it reaches GS 69-71 when wheat is still at GS 45-53, and it goes through these stages at a time when TARs are usually lower than they will be at the equivalent growth stages in wheat (Fig. 2). The difference between the ripening times of the two winter cereals is in the order of 2-4 weeks. Disease increase in later growth stages of barley increases inoculum and may play a role in the induction of TAD. Differences in earliness of ripening amongst wheat cultivars has recently featured in the farming press in the UK, where it was suggested that earliness of flowering could be one characteristic for selecting cultivars most capable of coping with take-all (*Crops*, 18 July 1998, p. 10). However, in the current recommended list of winter wheat cultivars (NIAB, 1998) there is a difference of 6 days only between the earliest ripening cultivar (Soissons) and the latest (Consort). Relevant data on cultivar differences are scarce, although in naturally infested sites in Australia fewer whiteheads (a symptom of take-all) and other correlations indicative of resistance have been observed most frequently in wheats with early maturity (Penrose, 1991, 1995). The predominant view, however, is that differences in susceptibility to the take-all fungus in wheat are very small, environmentally labile and difficult to substantiate, or are non-existent (Penrose, 1995). Although the Australian data question this, strong data from repeatable studies remain limited, particularly for wheat cultivars grown in Britain.

There are several characteristics of wheat cultivars besides earliness of ripening that may affect take-all or its impact on yield, e.g. rapidity of root production, tillering type, level of soluble stem carbohydrate (NIAB, 1998). However, the practical significance of these and any additive or interactive effects remain to be demonstrated. In experiments in Suffolk (Widdowson *et al.*, 1985), the cultivar Avalon grown after Avalon had more severe take-all than cultivar Norman grown after Norman. The findings of soil bioassays lead to the concept that varieties may be equally susceptible to take-all but differ in their ability to increase small populations of the take-all fungus. Avalon ripens about 2 days earlier than Norman, but this hardly seems adequate to explain these results.

Reports of more take-all this year than in recent years, expectations of a boost in cereal production because of EU reforms and the excitement over new fungicides soon to be available commercially for take-all, have brought the disease increased press coverage. This contrasts with four-to-five years ago, when upheavals in organizations traditionally involved in take-all research resulted in much government-funded research being closed down through lack of funds. There has not been a plethora of good, published data in the interim to substantially aid our understanding of the disease. Consequently, the basis for many of the resurrected views on managing take-all expressed currently in the farming press seems no better founded than previously. Indeed, the results reported here urge healthy scepticism in some cases. For instance, triticale has been proposed as a useful alternative to third or fourth wheats (*Arable Farming* 11 July 1998, p. 44) and even as a break in a profitable cereal rotation (*Crops* 9 May 1998, pp. 26-27). Whereas triticale is likely to suffer less than wheat from take-all, it is unlikely to prevent severe take-all in a subsequent wheat crop (Fig. 3) and therefore would not act as a break-crop for the disease. Also, despite earlier advisory statements (Attwood, 1985; Yarham, 1998), the value of barley as a bridge crop is highly suspect. A barley bridge failed to prevent severe take-all in subsequent wheat in the CS323 experiment and the introduction of barley into cereal sequences often resulted in severe disease in more years than occurred in wheat monoculture.

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REFERENCES

Attwood P J (ed.) (1985). *Crop protection handbook - cereals*. BCPC Publications: Croydon.

Bateman G L; Ward E; Hornby D; Gutteridge R J (1997). Comparisons of isolates of the take-all fungus, *Gaeumannomyces graminis* var. *tritici*, from different cereal sequences using DNA probes and non-molecular methods. *Soil Biology and Biochemistry* **29**, 1225-1232.

Becker J; Lavier B; Leaper D J (1998). Take-all (*Gaeumannomyces graminis* var. *tritici*) infestation survey for Germany, France and the UK, 1996-97. *Proceedings of Brighton Crop Protection Conference - Pests and Diseases* Vol. 1, pp. 77-82

Hardwick N V; Slough J E; Jones D R (1997). Winter wheat: a survey of diseases - 1997. 64pp. ADAS/CSL Research and Development: Preston Wynne, Hereford/Sand Hutton, York.

HGCA (1998). Crop management options at low cereal prices. Summer '98 issue. R&D Advisory Committee for Cereals, HGCA: London.

Hornby D (1998). *Take-all disease of cereals. A regional perspective*. CAB International: Wallingford, Oxon.

Hornby D; Bateman G L; Gutteridge R J; Lucas P; Monfort F; Cavelier, A. (1990). Experiments in England and France on fertilisers, fungicides and agronomic practices to decrease take-all. *Proceedings of Brighton Crop Protection Conference - Pests and Diseases*, Vol. 2, pp. 771-776. The British Crop Protection Council: Farnham, Surrey.

Hornby D; Gutteridge R J (1995). The natural biological control phenomenon of take-all decline in different sequences of cereals. In: *Environmental biotic factors in integrated plant disease control*, ed. M. Mańka, pp. 53-60. European Foundation for Plant Pathology and The Polish Phytopathological Society, Poznań.

Kwaśna H; Bateman, G L (1998). Four rare microfungi from the rhizosphere of wheat in the United Kingdom. *Mycological Research* (in press).

Liebman M; Gallandt E R (1997). Many little hammers: ecological management of crop-weed interactions. In: *Ecology in agriculture*, ed. L E Jackson, pp. 291-343. Academic Press: San Diego.

NIAB (1998). *1998 Cereal variety handbook*. National Institute of Agricultural Botany: Cambridge.

Penrose L D J (1991). Disease in wheat genotypes naturally infested with *Gaeumannomyces graminis* var. *tritici*. *Annals of Applied Biology* **118**, 513-526.

Penrose L D J (1995). Two wheat genotypes differ in root disease due to *Gaeumannomyces graminis* without interaction with site. *Soil Biology and Biochemistry* **27**, 133-138.

Polley R W; Slough J E; Jones D R (1995). Survey of winter wheat diseases in England and Wales 1995. 44pp. CSL/ADAS: Harpenden.

Schoeny A; Lucas P; Jeuffroy M-H (1998). Influence of the incidence and severity of take-all of winter wheat on yield losses and responses to different nitrogen fertilisations. *Proceedings of Brighton Crop Protection Conference - Pests and Diseases* Vol. 1, pp. 83-88

Widdowson F V; Penny A; Gutteridge R J; Darby R J; Hewitt; M V (1985). Tests of amounts and times of application of nitrogen and of sequential sprays of aphicide and fungicides on winter wheat, following either beans or wheat, and the effects of take-all (*Gaeumannomyces graminis* var. *tritici*), on two varieties at Saxmundham, Suffolk 1980-3. *Journal of Agricultural Science, Cambridge* **105**, 97-122.

Yarham D J (1998). Take-all - the past and the future. *Proceedings of Brighton Crop Protection Conference - Pests and Diseases* Vol. 1, pp. 65-66

Zadoks J C; Chang T T; Konzak C F (1974). A decimal code for the growth stages of cereals. *Weed Research* **14**, 415-421.

Take-all (*Gaeumannomyces graminis* var. *tritici*) infestation survey for Germany, France and the UK, 1996-1997

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ABSTRACT

The intended introduction of a novel fungicide, active against *Gaeumannomyces graminis* var. *tritici*, has prompted extensive monitoring of take-all in Germany, France and the UK. The disease was found in all surveyed areas and the occurrence and severity of the disease was mapped. High disease areas were identified even though the weather conditions during both years were generally not favourable to take-all development. Agronomic factors that influence take-all development, including rotation and sowing date, were examined and both were shown to have a dramatic effect on disease expression.

INTRODUCTION

Take-all is one of the most damaging soil-borne diseases and is one of the key reasons that second and subsequent wheat crops yield less than first wheat crops. The disease is likely to become more important in northern Europe if future agricultural policy changes reduce the profitability of break crops. The causal pathogen, *Gaeumannomyces graminis* var. *tritici*, is known to be widespread across western and central Europe especially in areas of intensive wheat production. Attempts have been made to estimate the regional distribution of the disease in the United Kingdom (Polley & Thomas, 1991; Polley *et al.*, 1994-1996) and other European countries (Mielke, 1995; Zadoks & Rijsdijk, 1984). These estimates were based on visual above-ground symptoms or on yield loss or damage.

Take-all can cause stunting, reduced tiller production, whiteheads and premature crop senescence. However, these symptoms are normally only evident following severe take-all epidemics where yields can be reduced by as much as 50% (Heim *et al.*, 1986). Take-all may have a significant suppressing effect on yield under less severe conditions where above-ground symptoms are seldom seen. As a result, examining roots for disease is the most accurate way of estimating disease attack.

There is renewed interest in monitoring the distribution and severity of take-all in the major wheat growing areas of Europe following the discovery and development of novel chemistry that is active against the disease. As a result, monitoring of commercial wheat crops was carried out in Germany and France during 1996 and 1997 and in the United Kingdom during 1997 using detailed root assessments to determine the disease severity.

METHODS AND MATERIALS

Sampling criteria

In Germany and France, 475 wheat fields were sampled in each country over a 2-year period. Samples were taken at random from the major wheat growing regions.

In the United Kingdom, sampling was carried out on 100 crops during 1997 only. The crops were selected in proportion to the area of wheat grown in regions of England and then in proportion to the potential take-all risk, both estimated using commercially available market research information (Produce Studies Limited). The take-all risk was defined using three categories, namely zero, low, medium and high risk shown in Table 1.

Table 1. Rotational risk based on two previous crops.

Risk to wheat	*Previous crop*	2^{nd} *Previous crop*
Zero	Group C	Group C
	Group C	Group B
Low	Group C	Group A
	Group B	Group C
Medium	Group B	Group B
	Group B	Group A
	Group A	Group C
High	Group A	Group A
	Group A	Group B

Group A: wheat, barley; Group B: rye, maize, grass, set aside, triticale;
Group C: rape, beet, potatoes, peas, beans, oats, others

The market research information showed that 9% of UK wheat was in the zero risk category, 34% in low risk, 33% in medium risk and 24% in high-risk categories. The 100 crops were then selected in this proportion from knowledge of their cropping history.

In all countries, between 50 and 100 plants with roots were systematically sampled from each crop between anthesis and harvest. Excess soil was carefully shaken from the roots.

Assessment method

The root samples were washed thoroughly to remove any remaining soil and the percentage of root area affected with take-all root rot was assessed visually. Each root was classified in to one of the following categories:

Category 0 = healthy roots
Category 1 = 1–10% of root area infected
Category 2 = 11–30% of root area infected
Category 3 = 31–60% of root area infected
Category 4 = 61–100% of root area infected

A severity score, hereafter referred to as the Take-all Index, was derived for each crop using the following formula:

$$\text{Take-all Index} = \frac{(0a+10b+30c+60d+100e)}{t}$$

where a,b,c,d,e represent the number of plants in each of the five categories and t is the total number of plants assessed. Take-all incidence was also determined from the percentage of sampled plants infected with take-all in each crop sample.

RESULTS

Table 2 summarizes the take-all situation in 1996/7

Table 2. Mean take-all index and incidence (in parentheses).

Year	Germany	France	UK
1996	14 (38)	7 (19)	–
1997	20 (51)	3 (17)	26 (86)

Germany: Take-all was found to occur in all parts of Germany in 1996 and 1997. There was a significant difference in the severity and distribution of take-all between the two years. Disease was generally more severe in northern and north-western Germany. The north-eastern and eastern part had less take-all in 1997 compared with 1996 due to drought in the spring. In contrast, the south experienced more take-all during 1997 compared with 1996 (see Figure 1).

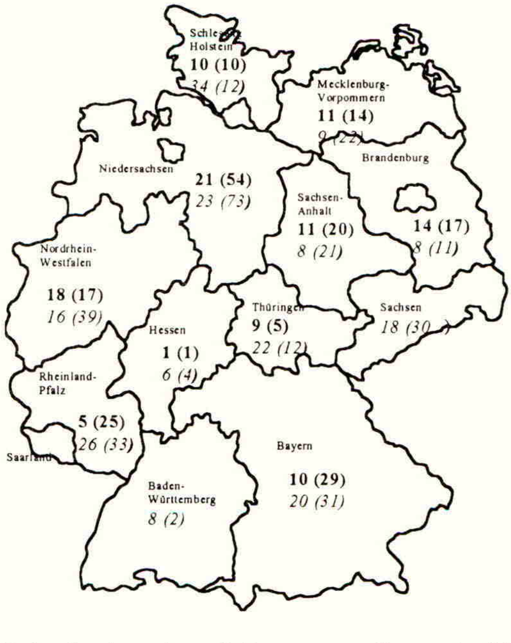

Figure 1. Take-all Index (and number of sites per sampling region) for Germany, 1996-97 (presented here and in Fig. 2 in bold for 1996 and in italics for 1997).

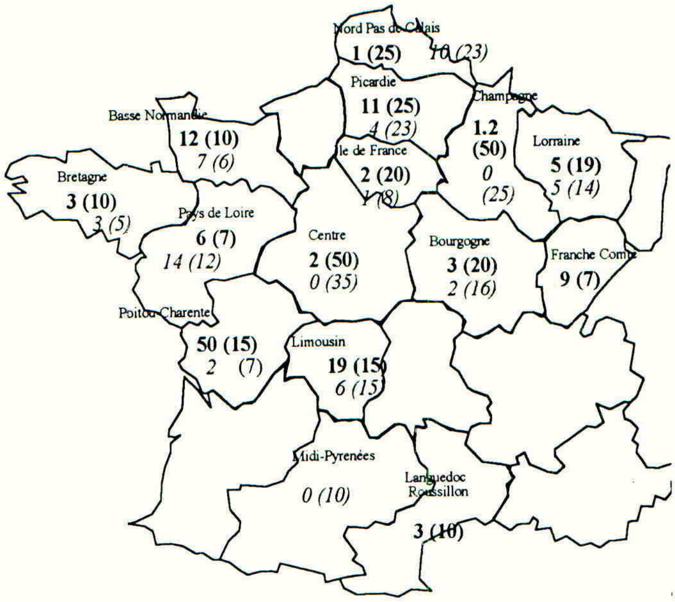

Figure 2. Take-all Index (and number of sites per sampling region) for France, 1996-97.

Figure 3. Take-all Index (and percentage plants affected) for the UK, 1997.

France: Take-all occurred in all of the major wheat growing areas of France. However, the take-all severity was generally less than in Germany and UK. Take-all appeared to be more prevalent in the north-western and western regions and more severe in 1996 compared with 1997 (see Figure 2).

United Kingdom: The severity of take-all was generally similar across much of the country but tended to be least in the southwest. The average incidence was high but the mean severity of attack was only moderate during 1997 (see Figure 3).

Take all and agronomic factors

Rotation: The rotational history of each field was used to assess the effect of the preceding crops on the severity of take-all. Data are summarised in Figures 4 and 5. The results show the dominating influence of wheat and barley in the rotation and that disease severity is closely linked with rotational risk, as defined above.

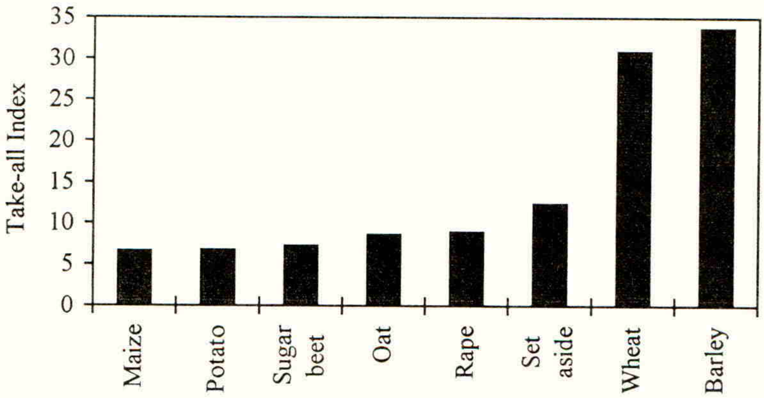

Figure 4. Effect of the preceding crop on the take-all severity in winter wheat.

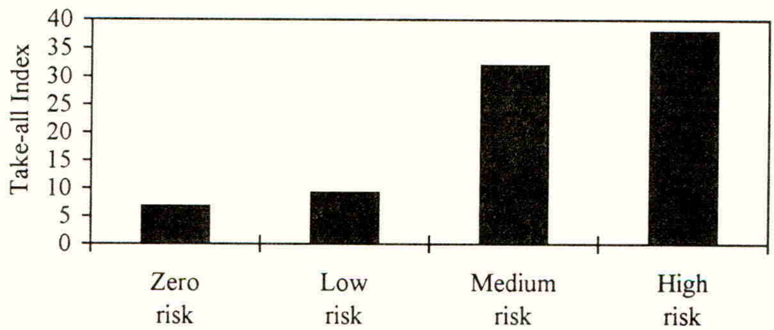

Figure 5. Effect of rotation on take-all severity.

Sowing date: The results from infestation surveys were used to study the effect of sowing date on take-all. Early drilling, up to the end of September, significantly increased the severity of attack compared with later sowings (Figure 6). The data were analysed independently of preceding crop.

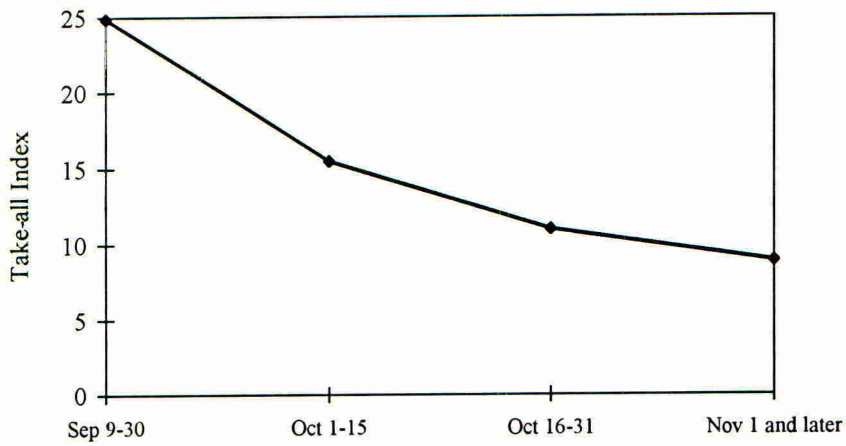

Figure 6. Effect of the drilling date on the take-all severity, 1996-7.

ACKNOWLEDGEMENTS

We thank the University of Göttingen, Germany, Service de Protection des Végétaux, France and Agrisearch (UK) Ltd, United Kingdom for their cooperation in this project.

REFERENCES

Heim M; Folwell R J; Cook R J; Kirpes D J (1986). Economic benefits and costs of biological control of take-all to the Pacific Northwest Industry. *Research Bulletin 0988*, Agriculture Research Center, Washington State University, Pullman.

Mielke, H (1995). Schwarzbeinigkeit im Weizenbau. *Nachrichtenblatt des Deutschen Pflanzenschutzdienstes* **47**, 177-180.

Polley R W; Thomas M R (1991). Surveys of diseases of winter wheat in England and Wales 1976-1988. *Annals of Applied Biology* **199**, 1-20.

Polley R W; Slough J E; Jones D R (1994). *Winter wheat disease survey report 1993.* Central Science Laboratory, MAFF and ADAS, 44pp

Polley R W; Slough J E; Jones D R (1995). *Winter wheat disease survey report 1994.* Central Science Laboratory, MAFF and ADAS, 44pp

Polley R W; Slough J E; Jones D R (1996). *Winter wheat disease survey report 1995.* Central Science Laboratory, MAFF and ADAS, 44pp

Zadoks J C; Rijsdijk F H (1984). *Agro-ecological atlas of cereal growing in Europe. Vol III. Atlas of cereals diseases and pests in Europe.* Centre for Agricultural Publishing and Documentation (Pudoc): Wageningen.

Influence of the incidence and severity of take-all of winter wheat on yield losses and responses to different nitrogen fertilisations

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ABSTRACT

Take-all of wheat remains a damaging disease in all cereal producing areas. This study aimed at measuring the impact of the disease on yield components and its relationship with nitrogen fertilisation. Field experiments were conducted on naturally infested second winter wheat crops in Brittany in 1995, 1996 and 1997. Treatments combined an experimental fungicide applied on the seeds at different rates and two levels of nitrogen fertilisation. Disease incidence and severity were assessed at 3-week intervals from tillering until grain filling. Yield components were measured at harvest. Plant nitrogen concentration was measured at the sampling dates and nitrogen in soil was measured at tillering and harvest. The experimental fungicide allowed different take-all progress curves based either on incidence or severity to be observed. The relationship between the disease progress curves observed along the wheat growth cycle and the yield components affected is discussed. Also discussed is the effect of the different nitrogen treatments applied in terms of yield improvement and nitrogen losses dependent on the disease level.

INTRODUCTION

Take-all is a damaging disease of wheat which remains difficult to control. Yield losses vary considerably among years and locations and are quite unpredictable. Without surveys on disease progress by assessment on the root system of plants, farmers and advisers are often not aware of the occurrence of the disease until the late stages of the crop when patches of short plants or, even later on, patches of whiteheads are noticeable. In addition to the yield losses caused by the disease, a major cause for concern is the absence of return from high input of nitrogen fertilisation and pesticides on the basis of expected high yield. Beyond the immediate economic impact some ecological side-effects have probably to be taken into account, such as possible leaching of nitrogen non-exported by the crop and left in the soil profile at harvest (Lucas *et al.*, 1997). Management of a diseased crop in order to reduce the impact of take-all is hindered by the lack of knowledge of the relationship between disease progress and crop growth and development due to difficulties in setting up comparable experiments where only take-all epidemics vary (Hornby & Bateman, 1991). The present work aims at showing the effect on yield components of winter wheat crops of different take-all incidence and severity progress curves obtained, in the same agronomic conditions, by the application of an experimental seed treatment fungicide. It also attempts to identify some basis for managing nitrogen fertilisation with the intention of reducing yield losses and limiting nitrogen leaching.

MATERIALS AND METHODS

Experiments were conducted on naturally infested second winter wheat crops at Le Rheu (Brittany, western France) in 1995, 1996 and 1997. Trials were designed to assess the effects and interactions of a fungicide applied as a seed treatment (MON65500, Monsanto Europe S.A.) and the total spring nitrogen supply on take-all development and plant recovery. Design differed among years: randomised complete six-block design in 1995, randomised complete block split-plot design consisting of three blocks with fungicide in main plot in 1996 and randomised complete block split-plot design consisting of four blocks with nitrogen in main plot in 1997. Plot size varied among years: 14.5 m^2 in 1995, 180 m^2 in 1996 and 58.5 m^2 in 1997. Treatments combined three fungicide rates (0, 25 and 50 g a.i./100 kg of seed) and two nitrogen doses (110-135 and 180-195 kg ammonium-nitrate ha^{-1}). The low nitrogen dose consisted of two applications, the first one at tillering (GS22-23) and the second one at beginning of stem elongation (GS30-31); the high nitrogen dose included a third application 21-28 days after the second one (GS34-37).

Plants were sampled and assessed at 3-week intervals from tillering (GS22-23) until flowering (GS65) for 1995 or grain filling (GS83) for 1996 and 1997. Except for 1995, four 25 cm x 2 rows subplots were sampled per plot. During the 1995 growing season, plants were collected from a single 50 cm x 2 rows subplot per plot. Root systems were washed free of adhering soil and take-all was visually assessed on ten plants per subplot. For each nodal root system the presence or absence of characteristic symptoms (black stelar discolouration) was recorded in order to calculate take-all incidence. The proportion of root system with symptoms was scored with a five-class severity scale (corresponding respectively to: no symptoms, 1 to 10%, 11 to 30%, 31 to 60% and 61 to 100% of the root system infected). A weighted take-all index (TAI) was calculated according to the formula:

$$TAI = \sum_{i=0}^{4} mi \times ni/n$$

where: mi= mean of i class
ni= number of plants in i class
n= total number of plants scored.

At harvest, samples were examined for yield components: ear and grain numbers were counted and grain weight was assessed. At each sampling time and for each treatment, aerial dry matter and total nitrogen concentration were determined. Data were compared with the critical nitrogen dilution curve established by Justes *et al.* (1994) on a diagram representing nitrogen concentration versus accumulated shoot dry matter. A nitrogen nutrition index (NNI) was calculated with the formula:

$$NNI = N_t/N_{ct}$$

where: N_t= total nitrogen concentration measured
N_{ct}= critical nitrogen concentration corresponding to the shoot dry matter produced.

The nitrogen nutrition is considered optimal when NNI is 1, limiting when it is less than 1 and in excess when it is more than 1. Nitrogen available from soil at the end of winter was determined just before the first nitrogen supply and nitrogen residual was determined after harvest. A nitrogen balance was calculated between inputs (fertilisation + nitrogen available at the end of winter + estimation of mineralisation) and outputs (nitrogen exported by plants in grains and straws + nitrogen residual after harvest).

Analyses of variance were performed using the General Linear Model (GLM) procedure of the SAS software (Statistical Analysis System, SAS Institute Inc., 1989) consistent with experimental designs. Least difference analysis followed significant *F* tests.

RESULTS

Take-all development differed among years (Figure 1).

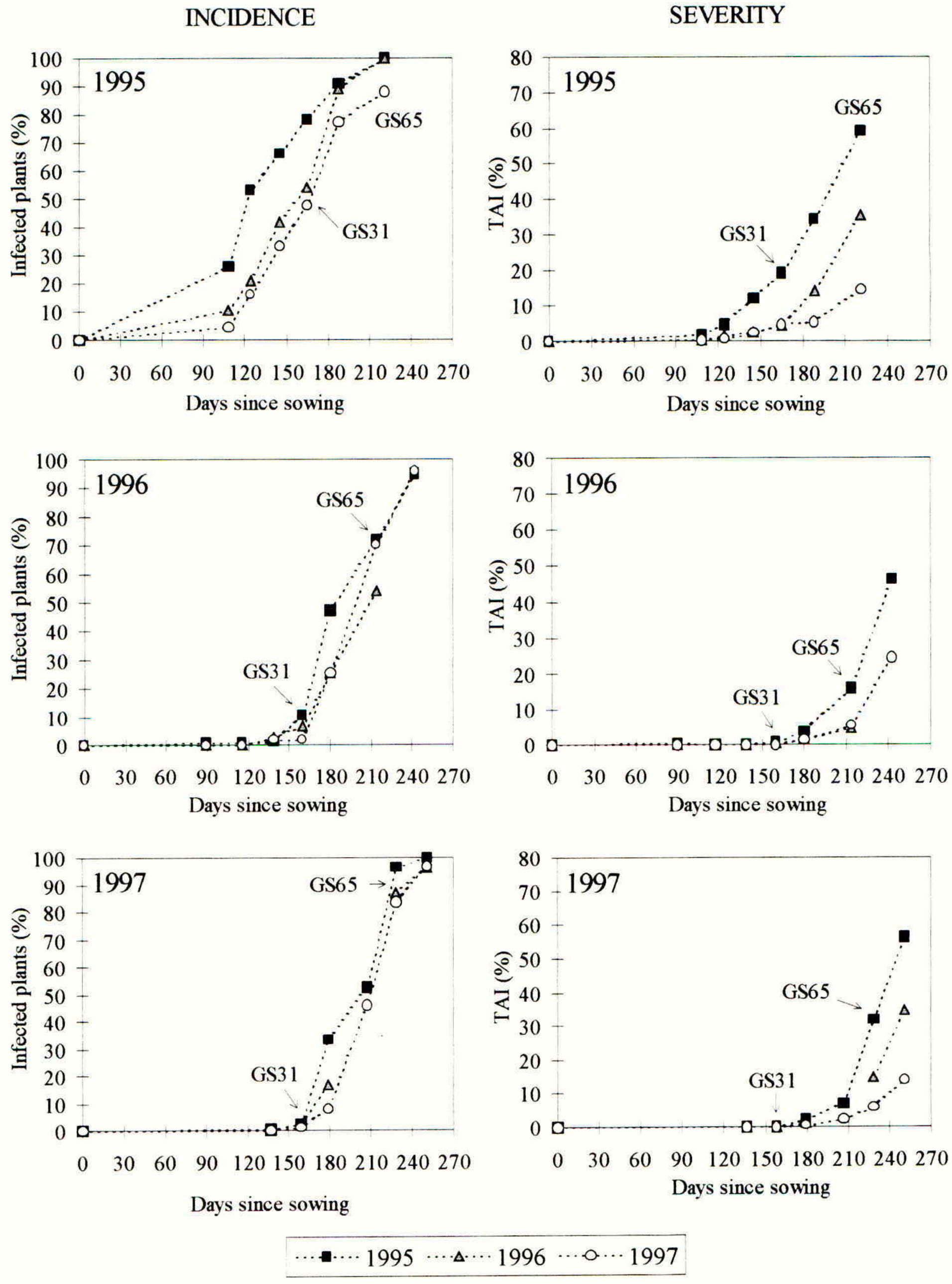

Figure 1. Effect of different rates of seed treatment on take-all incidence and severity in field trials conducted in Brittany.

The epidemic was earlier and more severe in 1995 than in 1996 and 1997. In terms of incidence, the high rate of seed treatment (M50) permitted an efficient protection at least until flowering in the case of the early epidemic (1995) and during part of the stem elongation in the case of late epidemics (1996 and 1997). In terms of severity, TAI was always less in the treated plots than in the untreated plots. The M50 rate significantly reduced TAI until the last sampling date whatever the epidemic. There was no fungicide x nitrogen interaction and nitrogen effects were rare and inconsistent.

Yield responses to seed treatment and nitrogen varied according to epidemics (Table 1). For the late and slight epidemic (1996), factor effects were not significant. Enhanced yield responses were explained for the late and moderate epidemic (1997) and for the early and severe epidemic (1995) respectively by an increased thousand grain weight (late establishing component) and by an increased grain number per m^2 (early establishing component). The latter was essentially a consequence of an increased grain number per ear. No fungicide x nitrogen interaction could be detected.

Table 1. Yield and yield components of winter wheat for different rates of seed treatment and nitrogen doses in field trials conducted in Brittany.

Year	Factor		Yield ($t\ ha^{-1}$@ 85% d.m.)	Thousand grain wt (g)	Grain number per m^2	Ear number per m^2	Grain number per ear
1995	Fungicide	M0	5.99 b	32.4	15618 b	417	36.9 b
		M25	6.69 ab	32.2	17630 ab	427	41.3 a
		M50	7.12 a	32.8	18461 a	440	41.8 a
		P	*0.077*	*> 0.15*	*0.070*	*> 0.15*	*0.019*
	Nitrogen	N-	6.16 b	32.6	15918 b	408 b	38.7 b
		N+	7.04 a	32.3	18554 a	448 a	41.4 a
		P	*0.035*	*> 0.15*	*0.012*	*0.019*	*0.071*
1996	Fungicide	M0	7.80	31.8 b	20660	615	33.6
		M25	8.22	34.1 ab	20412	577	35.9
		M50	8.59	35.0 a	20826	580	35.7
		P	*> 0.15*	*0.117*	*> 0.15*	*> 0.15*	*> 0.15*
	Nitrogen	N-	8.06	33.9	20133	582	34.7
		N+	8.34	33.3	21132	598	35.5
		P	*> 0.15*	*> 0.15*	*> 0.15*	*> 0.15*	*> 0.15*
1997	Fungicide	M0	10.31 b	40.0 b	21840	529	41.4 a
		M25	11.09 a	41.5 ab	22779	555	41.5 a
		M50	11.18 a	42.6 a	22247	562	39.8 b
		P	*0.053*	*0.025*	*> 0.15*	*> 0.15*	*0.111*
	Nitrogen	N-	10.12 b	40.2 b	21359 b	538	40.0 b
		N+	11.60 a	42.5 a	23218 a	559	41.8 a
		P	*0.0001*	*0.006*	*0.035*	*> 0.15*	*0.014*

Values followed by the same letter are not significantly different.

In 1995, nitrogen nutrition was generally limiting of shoot growth from tillering until flowering (Figure 2). NNI values were used to quantify the N stress intensity: they were higher in treated plots than in untreated plots showing a lower stress resulting from seed treatment and were increased after a nitrogen application (e.g. the second nitrogen application increased NNI values from 0.74 to 0.87 for M0 and from 0.78 to 0.97 for M50 between GS30 and GS31). In 1995, nitrogen exportations were significantly greater in M50 treated plots than in untreated plots (Table 2) whereas this effect was less pronounced for late epidemics. Nitrogen residues in soil were equivalent for the low fertilisation whatever the seed treatment rate. For the high fertilisation, they were increased in untreated plots compared to M50 treated plots in the case of the moderate and severe epidemics.

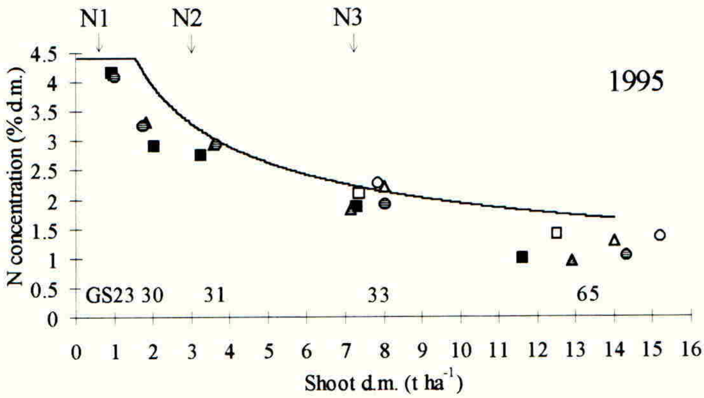

Figure 2. Nitrogen concentration in winter wheat shoots for different rates of seed treatment and nitrogen doses in field trials conducted in Brittany.

Table 2. Nitrogen balance (kg N ha^{-1}) for different rates of seed treatment and nitrogen doses in field trials conducted in Brittany.

Year	Treatment		Inputs	Outputs		Balance
	Fungicide	Nitrogen		Exportation + residue		
1995	M0	N-	228	109.8	75.2	43.0
	M0	N+	298	174.1	108.8	15.1
	M25	N-	228	118.0	74.9	35.1
	M25	N+	298	185.7	88.7	23.6
	M50	N-	228	155.5	70.9	1.6
	M50	N+	298	188.6	90.2	19.2
1996	M0	N-	225	166.4	54.9	3.7
	M0	N+	280	207.3	53.7	19.0
	M50	N-	225	172.4	49.7	2.9
	M50	N+	280	200.9	55.1	24.0
1997	M0	N-	231	155.1	50.2	25.7
	M0	N+	296	234.4	61.2	0.4
	M50	N-	231	167.6	45.3	18.1
	M50	N+	296	245.7	47.5	2.8

DISCUSSION

The application of seed treatment showed a significant effect on take-all and is a useful experimental tool for analysing disease-yield relationships. The results obtained in this study show that it is important to take into account the whole epidemic to judge of the effects of take-all on yield through analysis of all yield components: for similar disease incidence or severity observed at a late stage of plant growth, effects on yield may be very different depending on the earliness of infections. Yields could be increased by the high rate of seed treatment (1.13 t ha^{-1} in 1995, 0.79 t ha^{-1} in 1996, 0.87 t ha^{-1} in 1997) as well as by a third application of nitrogen (0.88 t ha^{-1} in 1995, 0.28 t ha^{-1} in 1996, 1.48 t ha^{-1} in 1997). When effects on yield were significant (in 1995 and 1997), the fungicide seemed to be more efficient in the early epidemic, the late nitrogen application in the late epidemic. The greater NNI observed in the treated plots demonstates a better utilisation of nitrogen supplies as a result of seed treatment. Seed treatment and nitrogen management may have positive effects in terms of delaying take-all epidemics and reducing or correcting yield losses, as shown in other studies (Lucas *et al.*, 1994). More knowledge is needed on the nitrogen requirements of a diseased crop and on its capacity to absorb nitrogen in order to get the best effect on yield response without the risks of nitrogen leaching due to late and inappropriate nitrogen application.

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REFERENCES

Hornby D; Bateman G L (1991). *Take-all disease of cereals*. HGCA Research Review N° 20. 147 pp.

Justes E; Mary B; Meynard J-M; Machet J-M; Thelier-Huche L (1994). Determination of a critical nitrogen dilution curve for winter wheat crops. *Annals of Botany* **74**, 397-407.

Lucas P; Capron G; Guillerm A-Y (1994). Intérêt d'un fongicide expérimental (MON41100) pour l'étude de la nuisibilité du piétin-échaudage en culture de blé d'hiver. Conséquences sur l'utilisation de l'azote du sol par les plantes. *ANPP. Quatrième conférence internationale sur les maladies des plantes*, Bordeaux, 6-8 décembre 1994.

Lucas P; Jeuffroy M H; Schoeny A; Sarniguet A (1997). Basis for nitrogen fertilisation management of winter wheat crops infected with take-all. *Aspects of Applied Biology* **50**, 255-262.

Root protection using fluquinconazole: a new approach to controlling cereal take-all

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ABSTRACT

Fluquinconazole is a unique, highly crop safe triazole fungicide that effectively protects cereal roots against take-all when applied to seed. Results from field trials conducted during 1994–1997 show that the rate of 75 g fluquinconazole/dt is suitable and gives consistent reduction of root infections and whiteheads resulting in significant yield benefits similar to those achievable by foliar sprays against leaf pathogens. Fluquinconazole is a new effective tool for the management and control of cereal take-all.

INTRODUCTION

Take-all, caused by the soil-borne fungus *Gaeumannomyces graminis* (Sacc.) Arx & Olivier var. *tritici* Walker (referred to as Ggt in this paper), is regarded as the most damaging root disease of wheat world wide (Huber & McCay-Buis, 1993). Take-all infection is unpredictable and in the absence of resistant cultivars and effective chemical control the disease decreases both grain yield and quality; it also restricts the options for crop rotation and husbandry. The economic importance of take-all to growers is well established and yield losses of more than 50% have been reported (Manners & Myers, 1981). Primary infections on seedlings is from mycelium in soil and secondary infections from root to root can take place in the crop throughout the season. Hence, a take-all effective fungicide is required to exhibit both a high level of intrinsic activity against Ggt and sufficient persistence to provide effective root protection until close to harvest when the yield potential has been secured. Although triadimenol has been reported to be effective against take-all, fungicidal effects and yield benefits from this treatment tend to be inconsistent (Bateman, 1986).

Fluquinconazole, a triazole fungicide from AgrEvo, has several novel properties including exhibiting distinct take-all efficacy. Russell *et al.* (1992) first described foliar–applied uses which are now commercially established. Mielke (1997) reported on the activity of fluquinconazole against Ggt when applied to seed. This paper reviews the crop tolerance properties and efficacy of fluquinconazole in protecting cereal roots against take-all. Root protection products containing fluquinconazole and coformulations with prochloraz for application to cereal seed will be sold under the trade name Jockey®.

MATERIALS AND METHODS

Several fluquinconazole containing FS (flowable suspension) type formulations have been developed and tested on cereal seed. Prochloraz was applied as copper chloride complex (Cu). Field trials were replicated four times in fully randomised blocks. Take-all trials were conducted in naturally infested soil or in soil artificially inoculated in the previous season, mostly on 2[nd] and 3[rd] year wheat. Assessments were made according to standard and established methods (see results). All dose rates in this paper are given as g a.i./dt (= 100 kg) seed.

RESULTS

Crop tolerance

Field trial results reported in Tables 1 and 2 show that fluquinconazole alone and in mixtures caused no adverse effects on plant stands and crop vigour. Even at the double rate (2N) fluquinconazole-containing treatments showed no adverse effects and performed equally to or better than standard treatments. In most situations there was also no delay in seedling establishment (data not shown) which often is associated with the use of many triazoles.

Table 1. Crop tolerance (% emergence) of fluquinconazole alone and in mixtures on winter wheat (1994-97).

Treatment	g a.i./ dt seed	UK (n = 6)	UK (n = 5)	Germany (n = 7)	France (n = 5)	France (n = 3)	Australia (n = 2)	Australia (n = 5)
Untreated		(345*)	(329*)	(45.4**)	---	(30.5**)	(17.2**)	(107*)
Standard (N)		100.0	78.9	99.7	(222*)	94.1		98.7
Standard (2N)		94.2						
Fluquinconazole (N)	75	98.9	98.0	101.2	93.5	95.5	105.8	99.2
Fluquinconazole (2N)	150	102.0			95.3		109.0	98.0
Fluquinconazole (N)	75	98.7	92.3	98.2				107.9
+ prochloraz Cu	15.3							
Fluquinconazole (2N)	150	95.0						100.1
+ prochloraz Cu	30.6							
Fluquinconazole (N)	75				94.9	99.3		
+ prochloraz Cu	15.3							
+ anthraquinone	50							
Assessment at Zadoks		GS 9-11	GS 9-11	GS 11-12	GS 10-11	GS 10-11	GS 12-21	GS 11-22
Season		1995/96	1995/96	1994-97	1996/97	1996/97	1996	1997

* Plants/m². ** Plants / m row.

Intrinsic efficacy against the take-all fungus (Ggt)

Potency of fluquinconazole against Ggt was evaluated *in vitro* and compared with various triazoles used as cereal seed treatments. Figure 1 shows the results at the lowest concentration at which fluquinconazole provided 100% control of Ggt. The superior intrinsic efficacy is clear.

Table 2. Crop tolerance (% vigour) of fluquinconazole alone and in mixtures on winter wheat (1994-1997).

Treatment	g a.i. / dt seed	UK (n = 6)	UK (n = 5)	Germany (n = 7)	France (n = 8)	Australia (n = 3)
Untreated		(9.1*)	(8.9*)	(101.5**)	--	(0.43***)
Standard (N)		98.7	85.4	98.7	100 (100**)	
Standard (2N)		83.5				
Fluquinconazole (N)	75	97.8	102.2	101.4	99.3	103.4
Fluquinconazole (2N)	150	98.2				
Fluquinconazole (N)	75	91.3	97.8	100.4		110.3
+ prochloraz Cu	15.3					
Fluquinconazole (2N)	150	90.4				
+ prochloraz Cu	30.6					
Fluquinconazole (N)	75				97.8	
+ prochloraz Cu	15.3					
+ anthraquinone	50					
Assessment at Zadoks		GS 10-11	GS 10-11	GS 10-11	GS 10-11	GS 13-22
Season		1995/96	1995/96	1994-97	1996/97	1995/96

* Score 0-10. ** Biomass: vigour assessed visually in untreated versus standard (Germany) and standard (=100) versus other treatments (France). *** Dry weight in g/plant.

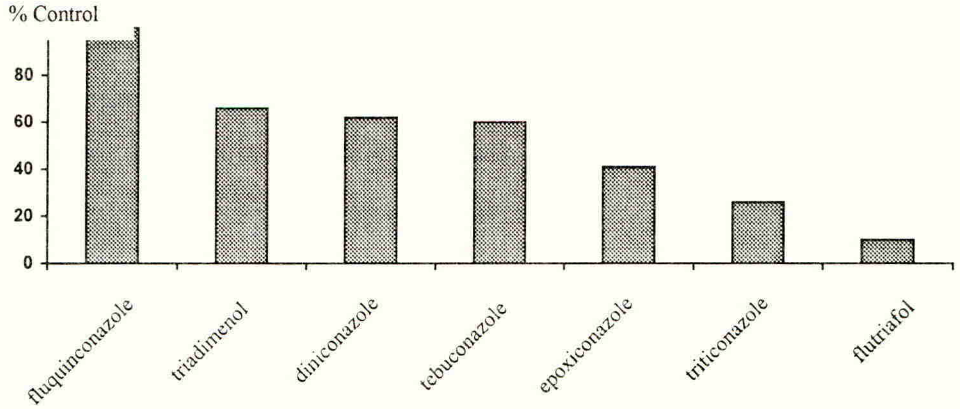

Figure 1. *In- vitro* efficacy of fluquinconazole against Ggt compared with triazoles (all at 0.1 mg/litre.

Take-all control in the field

Data in Table 3 show that fluquinconazole controlled take-all at all crop stages up to GS 71-75 in conditions where the disease occurred in severe patches. Fluquinconazole treatment reduced take-all and gave a subsequent increase in crop yield. Triadimenol had no effect.

Table 3. Effects of fluquinconazole on winter wheat at different crop stages (two UK field trials, 1994/95*).

Treatment	g a.i./ dt seed	GS 12-21 % Ggt root infection	GS 24-31 % Ggt root infection	Ggt root infection at GS 71-75 % plants slightly infected	% plants moderately infected	% plants severly infected	TAR**	Yield dt/ha
Untreated	--	10.3	11.4	33.0	30.5	22.5	162	49.8
Fluquinconazole	75	5.9	7.8	46.5	20.0	10.0	117	57.1 (+ 14.6%)
Triadimenol	42	9.1	11.6	32.0	25.5	27.0	164	51.1

* Trials conducted by Rothamsted Experimental Station, Harpenden, UK. ** TAR: take-all rating = % plants with slight infection + (2 x % plants with moderate infection) + (3 x plants with severe infection); slight infection = (< 25% of the root system infected), moderate infection (25-75%), severe infection (> 75%).

Further results reported in Table 4 provide strong evidence to suggest that the severity of symptoms on roots in fluquinconazole treatments was consistently decreased at each of the four sites, regardless of the intensity of take-all. There was no evidence to indicate that triadimenol had any effect.

Table 4. Effects of fluquinconazole on winter wheat under different disease levels (UK field trials, 1996/97).

Treatment	g a.i./ dt seed	% Ggt root infection at GS 71-75 Woburn*	Rothamsted*	Chishill	East Winch	Yield dt/ha Woburn*	Rothamsted*
Untreated	--	41.9	17.0	8.7	25.1	37.6	78.4
Fluquinconazole	75	22.7	7.1	2.8	17.6	48.9 (+ 30.0%)	83.1 (+ 6.0%)
Fluquinconazole + prochloraz Cu	75 15.3	20.2	7.3	4.7	16.0	48.4 (+ 28.7%)	82.8 (+ 5.6%)
Triadimenol	42	43.9	17.4	5.3	26.8	37.0	79.5
LSD (P = 0.05)		15.24	5.61	3.93	12.70	11.80	3.54

* Trials conducted by Rothamsted Experimental Station, Harpenden, UK.

Results from trials conducted in Germany (Table 5) demonstrate that fluquinconazole controls take-all on both wheat and barley. Yield increases in both cereals followed similar trends although differences to untreated are not statistically significant on barley.

The potential of fluquinconazole to significantly reduce take-all whitehead incidence and increase yield is shown by trials conducted in Australia (Table 6).

Table 5. Effects of fluquinconazole on winter wheat and winter barley (Germany, 1995 - 1997).

Treatment	g a.i./ dt seed	Winter wheat (n = 8) Ggt root infection (Scale 1-9)	Winter wheat (n = 8) Yield dt/ha	Winter barley (n = 3) Ggt root infection (Scale 1-9)	Winter barley (n = 3) Yield dt/ha
Untreated	--	5.4	80.6	6.2	61.3
Fluquinconazole	75	2.3	90.1 (+ 11.8%)	2.6	69.1 (+ 12.7%)
Fluquinconazole	75	2.7	89.6 (+ 11.2%)	3.4	67.3 (+ 9.8%)
+ prochloraz Cu	15.3				
LSD (P = 0.05)		0.39	3.50	0.38	8.38

* Scale as described by Mielke (1974).

Table 6. Effects of fluquinconazole on wheat (four field trials Australia, 1996*).

Treatment	g a.i./ dt seed	% whiteheads	Yield dt/ha
Untreated	--	55.5	23.7
Fluquinconazole	75	38.0	28.4 (+ 19.8%)
Fluquinconazole	75	25.6	29.9 (+ 26.2%)
+ prochloraz Cu	15.3		
LSD (P = 0.05)		6.28	2.10

* Trials conducted by CSIRO and NSW Agriculture.

Results summarised in Table 7 are derived from Mielke (1997) who studied the effects of fluquinconazole on various yield components. All fluquinconazole treatments reduced take-all root infections, significantly reducing premature ripening. Crop density, grain, ear yield and thousand grain weight were increased. Treatment had no effect on the number of grains per ear.

Table 7. Effects of fluquinconazole on yield components on winter wheat (three field trials, Germany 1995/96).

Treatment	g a.i./ dt seed	Ggt Infection (Scale 1-9[a])	Premature ripening (%)	% increase crop density	% increase grain yield	% increase ear yield	% increase TGW	No. grains/ ear
Untreated	--	5.1	22.4	(42.2[b])	(51.0[c])	(1.18[d])	(37.9[e])	34.2
Fluquinconazole	37.5	4.3	15.6	4.2	18.4	1.7	11.5	32.5
Fluquinconazole	50.0	4.2	14.3	8.1	26.3	21.4	12.7	33.5
Fluquinconazole	75.0	4.1	13.8	10.3	31.7	24.2	15.6	33.5
Fluquinconazole	100.0	4.2	13.8	8.2	27.8	22.8	13.8	33.7

[a] Scale as described by Mielke (1974). [b] Number of ear-bearing culms per mini plot. [c] Grain weight in g per mini plot. [d] Yield of individual ears in g. [e] Thousand grain weight in g.

Yield benefits from fluquinconazole use are a key feature of take-all control. Table 8 summarises the data collected from a range of field trials conducted between 1994 and 1997 in which fluquinconazole was used at its expected commercial rate, using different cropping systems. These data, and those presented in Figure 2, show that the yield benefit achieved by fluquinconazole applied to seed is equivalent to that given by a foliar fungicide controlling foliar pathogens.

Table 8. Yield benefits (dt/ha) in Ggt field trials on winter cereals (Germany, France, UK).

Treatment	g a.i./ dt seed	Winter wheat 1994/95 (n = 19)	Winter wheat 1995/96 (n = 20)	Winter wheat 1996/97 (n = 18)	Winter barley 1995/96 (n = 8)
Untreated	--	72.6	82.5	72.8	65.7
Fluquinconazole*	75	80.7 (+11.2%)	90.0 (+9.0%)	81.1 (+11.4%)	72.7 (+10.6%)
LSD (P = 0.05)		1.70	1.95	2.31	4.78

* Including mixtures with prochloraz Cu and anthraquinone.

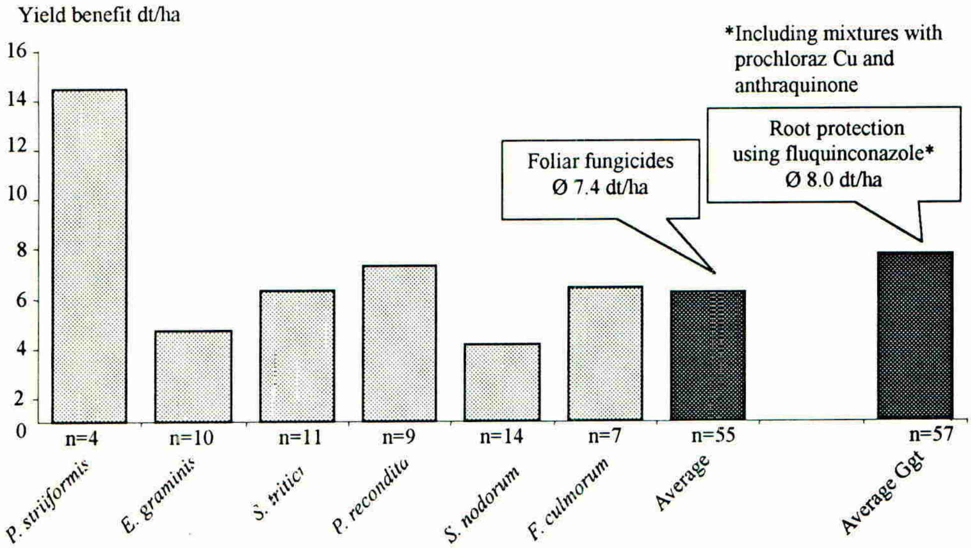

Figure 2. Yield benefits from root protection compared with control of foliar pathogens by fungicide sprays.

DISCUSSION

The aim of cereal take-all management is to avoid economic crop losses. Data have clearly shown that root protection using fluquinconazole can result in yield benefits of up to 20% and more in severe take-all situations. Data from more than 50 take-all trials conducted over three consecutive seasons in different disease pressure situations in Germany, France and the UK show consistent average yield increases of 9-11%. First results investigating the mechanism of root protection against take-all indicate that following application to seed, the fungicide makes available a long-lasting protection zone in the rhizophere.

The presence of fluquinconazole in roots and stems as well as in leaves has been confirmed (H. Buchenauer, pers. comm.). It was further observed that roots of treated plants are thicker, shorter and showed modifications of endodermal tissue. This tissue is known for its capacity to provide resistance against attack of Ggt (Skou, 1981). The cell walls of the endodermal tissue of fluquinconazole treated seedlings were broader and exhibited more intense staining of lignin (B. Wilmsmeier, pers. comm.). Results of these investigations will be reported at a later stage. In most cases it is not a single pathogen but a complex of them which reduce the quantity and quality of yield. In addition to Ggt, fluquinconazole applied to seed also controls *Basidiomycetes* including *Tilletia* and *Ustilago* species and shows distinct effects against some foliar pathogens. The full spectrum of activity of fluquinconazole when applied to cereal seed is reported in these proceedings. Coformulations with prochloraz have been developed also to provide control of *Fusarium* spp.

The Agenda 2000 proposals in Europe will have profound effect on crop rotations in which cereals will be favoured relative to pulses and oilseeds. It is assumed that increased cereal production will involve an expansion of third and longer runs of cereals (Gregory, 1998). The excellent Ggt activity, combined with broad-spectrum disease control and outstanding crop safety, will make fluquinconazole a major new tool for future take-all control and cereal disease management in Europe and around the world.

REFERENCES

Bateman G L (1986). Effects of triadimenol-containing seed treatment on winter wheat infected with take-all. *Zeitschrift* für *Pflanzenkrankheiten und Pflanzenschutz* **93**, 404-414.

Gregory R S (1998). Cereals in a cereal rotation. In: *Arable cropping under Agenda 2000*, pp. 23-30. Conference papers published by Semundo Limited: Cambridge.

Huber D M; McCay-Buis T S (1993). A multiple component analysis of take-all disease of cereals. *Plant Disease* 77, 437-447.

Manners J G; Myers A (1981). Effects of host growth and physiology. In: *Biology and control of take-all,* eds M J C Asher & P J Shipton, pp. 237-248. Academic Press: London.

Mielke H (1974). Untersuchungen über die Anfälligkeit verschiedener Getreidearten gegen den Erreger der Schwarzbeinigkeit *Ophiobolus graminis* Sacc. *Mitteilungen der Biologischen Bundesanstalt für Land- und Forstwirtschaft, Berlin-Dahlem* **160**, 1-61.

Mielke H (1997). Untersuchungen zur Bekämpfung der Schwarzbeinigkeit im Getreide durch Saatgutbehandlung. *Nachrichtenbatt des Deutschen Pflanzenschutzdienst (Braunschweig)* **49**, 300-304.

Russell P E; Percival A; Coltman P M; Green D E (1992). Fluquinconazole, a novel broad spectrum fungicide for foliar application. *Brighton Crop Protection Conference Pests and Diseases - 1992*, pp. 411-418.

Skou J P (1981). Morphology and cytology of the infection process. In: *Biology and control of take-all*, eds M J C Asher & P J Shipton, pp. 175-197. Academic Press: London.