HGCA

PROJECT REPORT No. 216

DIAGNOSIS, FORECASTING, RISK ASSESSMENT AND CONTROL OF STEM-BASE DISEASES OF WHEAT USING NEW MOLECULAR TECHNOLOGIES

February 2000

Price £9.00

PROJECT REPORT No. 216

DIAGNOSIS, FORECASTING, RISK ASSESSMENT AND CONTROL OF STEM-BASE DISEASES OF WHEAT USING NEW MOLECULAR TECHNOLOGIES

by

G L BATEMAN[1], S G EDWARDS[2], J MARSHALL[3], L W MORGAN[1], P NICHOLSON[4], M NUTTALL[3], D W PARRY[5], A S TURNER[4]

1 IACR-Rothamsted, Harpenden, Hertfordshire AL5 2JQ
2 Harper Adams University College, Newport, Shropshire TF10 8NB
3 Morley Research Centre, Wymondham, Norfolk NR18 9BD
4 John Innes Centre, Colney, Norwich NR4 7UH
5 HRI East Malling,West Malling, Kent ME19 6BJ

This is the final report of a three year project which started in October 1996. The work was funded by a grant of £351,155 from HGCA (project no. 1864).

HGCA Project No. 1864: Final report

Diagnosis, forecasting, risk assessment and control of stem-base diseases of wheat using new molecular technologies

G.L. Bateman, S.G. Edwards, J. Marshall, L.W. Morgan, P. Nicholson, M. Nuttall, D.W. Parry, A.S. Turner

Contents

PART 1: ABSTRACT

Diagnosis, forecasting, risk assessment and control of stem-base diseases of wheat using new molecular technologies

PCR was used to identify and quantify all fungal pathogens of wheat stem bases in nine field experiments at three locations in England. The main aims were to establish relationships between amounts of pathogen DNA determined by PCR, stem-base disease severity and yield loss, to apply quantitative PCR to provide robust data on the efficacy of new fungicides against stem-base diseases and to investigate its use in developing a risk assessment system based on threshold amounts of pathogen. Additionally, an appropriate field-sampling procedure was to be developed.

Quantifiable amounts of fungal DNA and disease were not always present before stem extension, when decisions to apply fungicides are taken. PCR confirmed that symptoms were often identified incorrectly at this time. The early development of pathogens did not often relate to disease severity at grain-filling or to yield losses.

Cyprodinil most effectively controlled eyespot by decreasing both pathogens, *Tapesia yallundae* and *T. acuformis* (the most widespread species), and sometimes contributed to increased yields. Prochloraz controlled eyespot erratically, its effectiveness dependent mainly on the presence of *T. yallundae* and, partly, on rainfall events soon after application. Azoxystrobin contributed to yield increases most consistently. Although it decreased sharp eyespot and its pathogen, *Rhizoctonia cerealis*, these effects were insufficient to account for much of the yield increases. The effects of fungicides on eyespot were sometimes greatest on the most susceptible cultivars. Amounts of *Tapesia* DNA were usually consistent with cultivar susceptibilities.

The only pathogens of brown foot rot present in significant amounts were *Microdochium nivale* vars *nivale* and *majus*. They appeared not to affect yield or to respond greatly to fungicides. The susceptibility of cultivars to these pathogens was often similar to their susceptibility to eyespot, suggesting that they respond to the same host resistance genes or are often secondary colonisers of eyespot-infected plants. The significance of *M. nivale* on shoot bases needs further investigation.

It is suggested that quantitative PCR, more than other methods, can provide accurate evidence of early, extensive disease development that indicates risk. It can be used on a field scale, using appropriate sampling patterns and bulking of samples, as a routine laboratory-based procedure. However, none of the methods currently available can provide precise threshold information on which to base a decision to apply fungicide.

PART 2: SUMMARY

Diagnosis, forecasting, risk assessment and control of stem-base diseases of wheat using new molecular technologies

Objectives

PCR methods have now been developed for quantification of all the pathogens of stem bases of wheat. The objectives of this project were to apply these procedures for:

1. Development of disease forecasting and risk assessments of stem-base diseases in a range of conditions.
2. Provision of robust data relating to the efficacy of new fungicides against stem-base diseases.
3. Development of thresholds for stem-base diseases.
4. Establishment of relationships between stem-base disease severity, PCR-based fungal biomass estimations and yield losses.
5. Development of a sampling system appropriate for PCR-based diagnosis and quantification of pathogens in wheat samples collected in the field.
6. Refinement of molecular techniques to detect and quantify pathogens in crop debris and soil.

Objective 6 was not achievable in the time scale of the project. The findings relating to the other objectives are summarised under the headings in the Results section below.

Methods

Similar experiments were done in each of three years, 1996/7, 1997/8 and 1998/9, on three sites in England. These were in the west midlands at Harper Adams Agricultural College, in east anglia at Morley Research Centre and in the south-east midlands at Rothamsted Experimental Station. In each experiment, four cultivars of winter wheat with different susceptibilities to eyespot were compared: Lynx (most resistant), Brigadier (not used in the final year because of yellow rust susceptibility), Abbot (final year only), Mercia and Soissons (most susceptible). Four fungicides, applied at recommended rates at GS31, and an untreated control, were compared: prochloraz (as Sportak), cyprodinil (as Unix), azoxystrobin (as Amistar), flusilazole (as Sanction; 1997 only) and experimental formulation HGCA1 (1998 and 1999). There were four blocks, each of 20 plots of a size suitable for combine harvesting for yield measurements. Plant samples were taken from each experiment on four or five occasions, the first two at about GS22 and GS30, before decisions to apply stem-base fungicides are taken in commercial crops. Shoot bases were assessed for eyespot, sharp eyespot and brown foot rot and analysed by diagnostic and quantitative PCR for DNA of nine pathogenic fungi known to contribute to stem-base diseases.

Results and Discussion

Evaluation of diagnostic and quantitative PCR for the identification and severity assessment of eyespot, sharp eyespot and brown foot rot

Disease assessments made before GS31 often did not agree with the pathogen diagnoses using PCR. Some of these discrepancies were site-dependent. This was apparently because symptoms had different appearance and occurred in different combinations at the different sites and, presumably, because different personnel were involved. For these reasons, early visual diagnoses must be considered unreliable.

Visual diagnoses made on stems in summer were generally more successful but there were often discrepancies in relating these to amounts of pathogen present (determined by regressions of incidence or severity of symptoms on amount of pathogen DNA). Eyespot symptoms may sometimes have been confounded with brown foot rot and relationships with DNA of their pathogens (*Tapesia* spp. and *Microdochium nivale*, respectively) were less clear on some cultivars, usually those with least disease. Sharp eyespot symptoms usually had the strongest relationship to DNA of its pathogen, *Rhizoctonia cerealis*. Significant regressions often accounted for a small percentage of the variance, suggesting that other factors contributed to the effects, possibly other pathogens or the same pathogens that decreased after symptoms developed.

The causes of brown foot rot symptoms were difficult to verify. It seemed that the varieties of *M. nivale* were principally involved. *Fusarium* spp. were rarely present in amounts sufficient to quantify. Conditions during summer were insufficiently warm and dry to favour development of *Fusarium culmorum*, often the principal brown foot rot pathogen, during the years of these experiments. A particular problem was that the amount of *M. nivale* in the tissues tended to decline as the tissue aged. This is supported by the generally stronger relationships between brown foot rot symptoms and pathogen DNA in May than in the summer. *M. nivale* apparently disappeared partially from necrotic lesions to which it contributed. *M. nivale* is thought also to be a secondary coloniser of eyespot-infected tissue although this appeared not to be consistent either between years or with the presence of clear eyespot. However, some cultivar differences in incidence of DNA of *M. nivale* reflected their susceptibility to eyespot. This may be because the *M. nivale* was colonising eyespot-infected plants in proportion to the amount of eyespot present or because eyespot-resistance genes also confer resistance to *M. nivale*.

In the regressions of brown foot rot (which may include symptoms of other diseases, especially in early samples) on *M. nivale* DNA, there was no evidence that the different cultivars produced regression lines with different slopes but there was evidence of different susceptibilities of the cultivars, especially in the early samples. *M. nivale* var. *nivale* DNA

tended to correlate better with symptoms than did *M. nivale* var. *majus* DNA. This may be evidence that the former variety is the more effective pathogen. Sometimes, but not always, var. *majus* infected the plants earlier than did var. *nivale*, perhaps developing from infected seed.

The regressions gave evidence of interactions among the pathogens in the development or suppression of disease symptoms, as well as between pathogens and cultivars. This is not explored further in this report.

Effects of cultivar and fungicides on stem-base pathogens, determined by PCR, and on diseases and yield of wheat

The aims were to apply quantitative PCR to the assessment of cultivars and fungicides on stem-base diseases and yields of wheat and to compare the performance of this technique with conventional disease assessment methods.

PCR showed that the benefits of cyprodinil, the most active fungicide against eyespot, resulted from its effectiveness against both eyespot pathogens, *Tapesia yallundae* and *T. acuformis*. Its effects were most significant on the cultivars most susceptible to eyespot but, even on these, significant yield increases were not usually achieved.

Prochloraz was erratically effective against eyespot. This variability can not be explained by differences in application times; optimum timings can be variable but the best is reported to be about GS30-31, the growth stages used in these experiments. The performance of prochloraz against eyespot has been reported to depend on its redistribution from foliage to the stem base in rainfall. Significant amounts of rainfall were sometimes associated with eyespot control, as at Harper Adams and Rothamsted in 1998 and at Morley in 1999. It may also sometimes be less effective where eyespot pathogen populations consist almost entirely of *Tapesia acuformis*, because these can include strains with less sensitivity than strains of *T. yallundae*. In the experiments described here, prochloraz was effective on more occasions at Rothamsted than elsewhere, Rothamsted being the only site at which *T. yallundae* was common. In these experiments, pathogen species and rainfall events may both have influenced the performance of prochloraz.

Increases in grain yield resulting from azoxystrobin application were not explained by its effects on particular pathogens as determined by PCR, although control of *R. cerealis* may have contributed. Take-all was severe in some of the second wheat crops used in these experiments and was the main cause of small yields at Harper Adams in 1999. Decreases in take-all severity resulting from azoxystrobin treatments are known to occur and, in some cases, may have contributed to yield increases.

PCR established that brown foot rot was not clearly associated with any pathogen. It has been suggested that *M. nivale* often behaves as an opportunistic coloniser of tissue that is

already diseased, for example with eyespot. It might, therefore, be expected that amounts of DNA of *M. nivale* would be associated with the amount of eyespot. Such an association was suggested on only a few occasions when cv. Lynx had least eyespot and least *M. nivale*, but never convincingly. Further research is needed to establish the contribution, if any, of *M. nivale* to stem-base disease and yield losses.

There was some evidence of interactions between site/year and cultivar on the performance of fungicides and further research, as well as more detailed, in-depth analysis of the present data, are needed to elucidate these.

Rates of development of stem-base pathogens on different wheat cultivars determined by quantitative PCR

Rates of development of the different pathogens on shoot and stem bases were determined by plotting amounts of DNA against time. This was expected to provide information that would help to assess the need for, and optimise the timing of, fungicide applications.

Where *T. yallundae* was present in quantifiable amounts, it usually developed earlier than *T. acuformis*, the PCR results confirming earlier evidence using other methods.

Cultivar differences in amounts of *M. nivale* were most clear in stems during internode extension and when relatively large amounts of DNA were present. In these circumstances, the cultivar differences approximated to the NIAB ratings for eyespot susceptibility, Soissons containing most and Lynx least DNA. This suggests a relationship between genetic resistance to eyespot and *M. nivale*, which may result from a facility for the latter to invade tissues already damaged or weakened by eyespot pathogens. This relationship seems not to have been reported before and, subject to further research to understand the role of *M. nivale* in yield losses, may have relevance to cereal breeding programmes. The late-season decreases in *M. nivale* suggest that brown foot rot symptoms attributable to this fungus will have fully developed earlier; this was supported by regressions of the extent of disease symptoms on amounts of DNA at successive sampling times.

The development of a pathogen may have been suppressed by the presence of other pathogens. Such suppression has already been demonstrated on wheat shoots and may be influenced by the sequence of infection by the different fungi. More frequent sampling would have been necessary to demonstrate clearly the sequence of infections in the experiments described.

Eyespot is recognised as the most important stem-base disease of wheat and the principal target for fungicides applied at the beginning of stem extension. *T. acuformis* was the only eyespot pathogen that occurred in quantifiable amounts in all nine field experiments. This fungus tends to develop late, as it did in most of the experiments described here, and so was not detectable in many of the samples taken before GS31. Other experiments have shown that its

late development also results in smaller yield losses than those caused by the earlier developing *T. yallundae*. Consequently, early infection by the pathogens that would indicate risk and a need to apply fungicides was not often encountered.

Evaluation of quantitative PCR as an aid to decision-making in applying fungicides to control stem-base diseases

Stem-base diseases were associated with decreased yields in very few instances. Where a regression of yield on disease incidence or severity was significant, the regression accounted for only a small percentage of the variance, suggesting that other factors were contributing.

Cyprodinil, effective in every experiment, often contributed to yield increases determined in analyses of variance, largely as a result of its effects in decreasing eyespot. However, this was not always related to the presence of quantifiable amounts of DNA of the eyespot pathogens (or symptoms) before the fungicide was applied.

Azoxystrobin was the most effective fungicide in increasing yields. It is unlikely to have contributed to yield increases through its effects on stem-base diseases except, to a small extent, by controlling sharp eyespot. Its effects on sharp eyespot and yield were not related to amounts of DNA of the sharp eyespot pathogen present before the fungicide was applied. There is evidence that some of the effects of azoxystrobin on yield resulted from its effects on decreasing take-all.

We conclude that, where eyespot develops relatively late in winter wheat, as in these experiments, determining amounts of pathogen DNA in the shoot bases does not provide a precise means of assessing risk. It is not possible, therefore, to determine threshold amounts of fungal DNA on which to base a decision to spray. DNA quantification will be useful, when available as a routine test, as a means of determining the extent of early infection in those situations in which symptoms are obscure, as they commonly are. Unlike visual assessments, it can be used on bulked samples rather than on individual plants, provided an adequate sampling procedure is used on the crop. The presence of DNA in amounts that are sufficient to quantify indicate that the infection is extensive.

Assessment of the sampling procedure

Field experiments were sampled by taking three plants from five positions along each of two parallel zig-zag transects in each plot. REML analysis compared the variability of differently sized sampling units (groups of three plants *v.* plots *v.* blocks) at the two pre-treatment sampling times (i.e. before GS31) in 1998 at Rothamsted. The estimated variance increased with increasing size of sampling unit, suggesting that the sampling procedure was adequate. This is consistent with earlier comparisons of sampling patterns and indicates that routine analysis of variance based on plot means is appropriate. A similar procedure should be adopted for field-

scale sampling, ensuring adequate coverage by adjusting the number of sampling points in proportion to the area of the field.

Conclusions

1. PCR procedures identified the fungal pathogens associated with symptoms on shoot bases of wheat plants before stem extension and at a time when decisions on fungicide applications need to be made. The symptoms at this time were in many cases difficult to identify and were often identified incorrectly.

PCR on stems of mature wheat plants usually confirmed the visual identification of eyespot and sharp eyespot symptoms and some instances of mis-identification of symptoms were resolved.

Fusarium spp. were scarce and brown foot rot symptoms were associated only with *Microdochium nivale*. However, relationships between symptoms and the pathogen, and their significance, are obscure and need further investigation.

A potential for using quantitative PCR in understanding interactions among pathogens and variations in behaviour among different wheat cultivars was identified but not explored.

2. Quantitative PCR clarified the effects of fungicides on stem-base diseases by identifying which pathogens contributed to symptoms and which were controlled. The eyespot pathogens *Tapesia yallundae* (where present) and *T. acuformis* were both controlled by cyprodinil, the most effective eyespot fungicide. Consequently, cyprodinil sometimes contributed to yield increases, especially in cultivars most susceptible to eyespot. Prochloraz was only sometimes effective against eyespot and this was usually associated with the presence of *T. yallundae* and, to some extent, with rainfall events soon after its application. The good performance of azoxystrobin against sharp eyespot and its pathogen, *Rhizoctonia cerealis*, were confirmed but large yield increases suggested that the fungicide had other effects; these were not identified but may have included decreased take-all.

No fungicide effectively or consistently decreased brown foot rot or the pathogen *Microdochium nivale*, whose development may have been associated with that of eyespot in some cases.

3. Quantitative PCR confirmed the earlier development of *T. yallundae* than of *T. acuformis*. Late development of *T. acuformis*, the predominant pathogen in most experiments, may have contributed to the scarcity of effects of fungicides on grain yields. A relationship between cultivar susceptibility to eyespot and to infection by *M. nivale* was indicated. The value of, and potential for, quantitative PCR in etiological and epidemiological studies was further emphasised.

4. Quantitative PCR provided clarification of the causes of symptoms and the extent of infection at early growth stages. However, it is suggested that neither this method nor any other is capable of providing *precise* threshold information to enable decisions to be made on the application of fungicides. This is because of varying rates of disease development after the beginning of stem extension and the absence of a relationship between early amounts of pathogen and ultimate disease severity and yield loss.

Quantitative PCR will provide evidence of extensive infection before the time of fungicide applications (the beginning of stem extension), even when symptoms are obscure because of e.g. mixed infections. In such situations, rarely seen in the experiments described, risk of yield loss will have been correctly identified.

5. A sampling procedure for plants before the time of fungicide applications was based on taking small subsamples from a large number of positions along zig-zag transects. This proved to be adequate for small plots and should be scaled-up for whole-field situations.

PART 3: Technical details

Diagnosis, forecasting, risk assessment and control of stem-base diseases of wheat using new molecular technologies

1. Introduction

Many wheat crops are treated routinely with fungicides to control stem-base diseases, especially eyespot (*Tapesia* spp.). Effective use of these fungicides depends on an accurate assessment of disease risk. For eyespot, this is usually done at growth stage (GS) 30-32 (Zadoks *et al.*, 1974) by assessing the extent of leaf sheath penetration (Goulds *et al.*, 1988; Jørgensen *et al.*, 1990). This procedure was established for the first eyespot fungicides, mostly benzimidazoles, but may not be appropriate for other fungicides, for the different eyespot pathogens *T. acuformis* and *T. yallundae* (Goulds & Fitt, 1991) or for different wheat cultivars. Further problems can occur where early symptoms of eyespot are obscured by those of the generally less damaging pathogens that cause brown foot rot (*Fusarium* spp. and *Microdochium nivale*) and sharp eyespot (*Rhizoctonia cerealis*).

Whilst identification of disease symptoms in the early stages of development on shoot bases is difficult, PCR methods are now available for positive diagnosis of the pathogens present. The major pathogens for which PCR procedures have been developed are *Tapesia* spp. (Nicholson *et al.*, 1997), *Fusarium culmorum* (Nicholson *et al.*, 1998), *Microdochium nivale* (Nicholson *et al.*, 1996) and *Rhizoctonia cerealis* (Nicholson & Parry, 1996). There are similar methods for the minor pathogens *F. avenaceum* (Turner *et al.*, 1998) and *F. poae* (Parry & Nicholson, 1996). PCR has already been applied to monitoring stem-base pathogens (Burnett *et al.*, 1992). Quantitative diagnosis of these pathogens was made possible by the development of competitive PCR (Nicholson *et al.*, 1996, 1997).

This report describes results from nine field experiments, over three years and in three localities. The objectives of the project were:

1) Development of disease forecasting and risk assessments for stem base diseases in a range of conditions.

2) Provision of robust data relating to the efficacy of new fungicides against stem base diseases.

3) Development of disease thresholds for stem base diseases.

4) Establishment of the relationship between stem base disease severity, PCR-based fungal biomass estimations and yield losses in wheat.

5) Development of a sampling system appropriate for PCR-based diagnosis and

quantification of pathogens in wheat samples collected in the field.

6) Refinement of molecular techniques to detect and quantify pathogens in crop debris and soil.

Objective 6 proved unachievable in the time scale of the project. The sequence of the other objectives has been changed for presentation in this report to the following:

1) To evaluate diagnostic and quantitative PCR for the identification and severity assessment of eyespot, sharp eyespot and brown foot rot (Section 3).

2) To assess the effects of cultivar and fungicides on stem-base pathogens, diseases and yield of wheat (Section 4).

3) To assess rates of development of stem-base pathogens on different wheat cultivars, using quantitative PCR, as a basis for optimising fungicide applications and their timings (Section 5).

4) To evaluate quantitative PCR as an aid to decision-making in applying fungicides to control stem-base diseases (Section 6).

5) To evaluate a sampling procedure for early diagnosis of stem-base diseases (Section 7).

2. Materials and Methods

2.1. Field experiments

Similar experiments were done in each of three years, 1996/7, 1997/8 and 1998/9, on three sites in England. These were in the west midlands at Harper Adams Agricultural College, in east anglia at Morley Research Centre and in the south-east midlands at Rothamsted Experimental Station.

Each experiment had four randomised blocks of 20 plots (minimum dimensions 10 m x 3 m) in which the effects of five fungicide treatments (including untreated controls) were compared on four cultivars of winter wheat, grown as second wheat crops. The cultivars chosen had different susceptibilities to eyespot according to NIAB ratings. They were Lynx ("good" resistance to eyespot in NIAB trials but it did not appear in Recommended Lists), Brigadier (rating 5), Mercia (rating 5) and Soissons (rating 4). In 1998/9, Brigadier was replaced by cv. Abbot (rating 5) because of the former's susceptibility to yellow rust (*Puccinia striiformis*). The fungicide treatments, applied at approximately GS31, were: none (a no-fungicide control); prochloraz (350 g a.i. ha^{-1} as Sportak); cyprodinil (750 g a.i. ha^{-1} as Unix); azoxystrobin (250 g a.i. ha^{-1} as Amistar); flusilazole (200 g a.i. ha^{-1} as Sanction), 1996/7 only; HGCA1 (an undisclosed formulation), in 1997/8 and 1998/9. Epoxiconazole (86.5 g a.i. ha^{-1} as Opus) was applied during May where development of foliar diseases was observed; later fungicide applications were made as appropriate.

Husbandry was standard for the farms, except for sowing dates (these were moderately early when possible to encourage disease, but were sometimes delayed by adverse weather and soil conditions) and those involving experimental treatments. Dates and growth stages of treatments and the main husbandry operations are shown in Table 2.1.

2.2. Sampling

Plant samples were taken from all plots on four or five occasions (Table 2.1). The first sample was taken at approximately the two-tiller stage (GS22), usually in February. The second was at the beginning of internode elongation (GS30-31), immediately before fungicide treatments were applied. The third was taken 2-3 weeks after fungicide application. In 1997, two further samples were taken, one during May and one in July, during grain ripening. In the other years, these were replaced by a single sample during late anthesis or the early ripening stages (but later at Harper Adams in 1999).

At each sample time, three plants were taken from each of 10 sampling positions in each plot. The sampling positions were located at random positions along two, approximately parallel, zig-zag transects in each plot.

2.3. Disease assessments

Assessments of disease on shoot bases were made immediately after sampling. In samples taken before, and sometimes up to 3 weeks after, fungicide applications, symptoms considered to be eyespot, sharp eyespot or brown foot rot were recorded as present or absent on leaf sheaths of each whole plant. Indeterminate symptoms were sometimes recorded also. In samples taken after fungicide applications, the incidence of symptoms identified as these diseases was usually recorded only on the lower internodes of the main stem of each plant. In the later samples, eyespot was also recorded as slight, moderate or severe on the main stem, according to the amount of girdling and stem softening (Scott & Hollins, 1974). The same severity categories were used for sharp eyespot and brown foot rot in some samples. A disease index (describing disease intensity, being based on measures of incidence and severity) was calculated per plot from these categories using the formula: DI = 100[no. stems in sight category + 2(no. stems in moderate category) + 3(no. stems in severe category)] ÷ 3[total no. plants].

2.4. Molecular diagnosis and quantification of fungal pathogens

2.4.1. Tissue preparation

The plant parts (shoot or main stem bases) used for disease assessments were prepared immediately afterwards for DNA extraction. The basal region (3-5 cm lengths, depending on growth stage) were cut off and roots were removed as close as possible to the shoot. The tissue was chopped coarsely, transferred to pre-weighed flat-ended tubes that were placed, open, in a freeze drier for a minimum of 48 h, depending on sample numbers in each batch and degree of wetness. After freeze-drying, tubes were weighed again to allow the dried weight of plant material to be calculated.

The material was milled to a fine powder in a ball mill (e.g. Glen Creston) for 5-10 min, depending on the age of the tissue. The milled material was transferred to 50 ml disposable centrifuge tubes for DNA extraction.

2.4.2. DNA extraction

Milled plant sample was added to 30 ml CTAB buffer (Nicholson & Parry, 1996) in 50 ml centrifuge tubes. The tubes were shaken well and incubated at 65°C for 1-2 h with shaking at intervals. Following incubation, 10 ml of 5 M potassium acetate and 5 ml $CHCl_3$ were added to each sample. The tubes were mixed by inversion, placed at -20°C for 30 min and centrifuged at 3,000 rpm for 15 min. A standard volume (600 µl) of supernatant was removed from the upper (aqueous) phase to enable quantification of fungal DNA content on the basis of units mg^{-1} dry

weight of plant tissue. This was added to a fresh tube (2 ml) containing 1.2 ml ethanol. A second sample was removed at this time and treated in the same way to act as a 'backup'. The second tube was stored at 4°C.

The tubes were shaken and left standing at 4°C for 1 h. They were centrifuged in a benchtop microfuge for 10 min and the supernatant carefully decanted off. The pellet was washed in 1 ml ice-cold 70% ethanol and centrifuged at half-speed for 10 min. The 70% ethanol wash was repeated and samples left to air-dry. The DNA pellet was redissolved in TE buffer at 0.1 µl mg^{-1} dry weight of plant material. DNA was quantified by SybrGreen fluorescence (see below) and concentration figures used to prepare sub-samples at fixed concentrations (typically 40 ng μl^{-1}). DNA samples were stored at 4°C until use (or frozen for long-term storage).

2.4.3. SybrGreen DNA quantification

Quantification was carried out according to the method of Hopwood *et al.*, (1997). Standard dilutions of DNA (*Hin*dIII-cut λ DNA) were prepared in a working 1:10000 dilution of stock SybrGreen solution (Flowgen). The dilution series ranged from 0-2.0 ng μl^{-1} in 0.2-ng increments. Aliquots (100 µl) of each dilution were pipetted into a microtitre plate and placed in a Titertec Fluoroscan II fluorescence plate reader. Emission was read at 538 nm after excitation at 485 nm.

A standard curve relating DNA concentrations to excitation/emission figures was prepared (r^2 typically 0.99) and applied to excitation/emission figures from 1 µl of each DNA sample in 100 µl working dilution of SybrGreen. Duplicate readings were taken for each sample and mean concentrations determined. All samples were then diluted to a fixed concentration (typically 40 ng μl^{-1}) on the basis of the above quantification prior to PCR.

2.4.4. PCR amplification

Diagnostic PCR for *T. yallundae*, *T. acuformis*, *M. nivale* var. *nivale*, *M. n.* var. *majus*, *F. avenaceum*, *F. culmorum*, *F. graminearum*, *F. poae* and *R. cerealis* (Doohan *et al.*, 1998; Nicholson & Parry, 1996; Nicholson *et al.*, 1996, 1997; Parry & Nicholson, 1996; Turner *et al.*, 1998) was performed as described by Nicholson & Parry (1996) in volumes of 50 µl containing 200 ng DNA extracted from infected plant material. Samples were applied to a preheated PCR block and denatured at 95°C for 2 min prior to cycling. DNA was amplified using 'touchdown' PCR (Don *et al.*, 1991) to ensure specificity of product amplification. The annealing temperature was 66°C for the first 5 cycles and 64°C for the next 5 cycles, followed by 25 cycles at 62°C. The temperature cycle consisted of denaturation (95°C) for 30 s, annealing (as described above) for 20 s and extension (72°C) for 45 s with maximal ramping rates between temperatures. A final extension step of 5 min was incorporated followed by cooling to 10°C

until recovery of samples.

2.4.5. Quantification of fungal content using competitive PCR

Heterologous competitor fragments were generated for all the target fungi from the sequence of the 23 kDa extrinsic polypeptide of photosystem II (Wales *et al.*, 1989) gene of *Pisum sativum* as described by Nicholson *et al.* (1997). DNA templates, for use as competitor molecules, were developed from a 435-nucleotide fragment using the general method described by Förster (1994) to generate a competitor fragment which had 5' and 3' termini identical to the fungal 'target' primer sites but which had no internal sequence homology to the 'target' sequence. The process was carried out for the target sequences of all nine of the stem-base pathogens to produce competitors for each. The competitor fragments were cloned into pGEM-T (Promega) and transformed into electro-competent *E. coli* (strain JS5) according to the supplier's instructions (Bio-Rad). Plasmids containing the competitor DNA fragment were harvested and purified using 'Wizard miniprep' system (Promega) according to the manufacturer's instructions. Stocks of each competitor DNA were diluted in TE buffer and stored at -20°C until used.

Initial tests were carried out to determine the concentration of competitor DNA template for each primer-pair that would result in approximately equal amplification of both fungal and competitor fragments when 0.1 ng of fungal DNA was used in the PCR reaction. Fungal total genomic DNA, in the range 1 pg to 10 ng, of the respective fungal species was then added to reagent mixtures containing the selected quantities of the relevant competitor DNA molecule prior to PCR. The reaction components and amplification conditions were the same as those for conventional specific PCR detailed above. Following amplification, the PCR products of each reaction were separated by electrophoresis through 2% agarose gel. Gels were stained with ethidium bromide, viewed under UV light on a 'Gel Doc 1000' system (Bio-Rad) and analysed using Molecular Analyst software (Bio-Rad) to estimate the relative degree of amplification of the fungal and competitor PCR product in each sample. The relationship was then determined, for each dilution series, between the PCR product ratios and the amount of fungal DNA added to the reaction. This generated a standard curve, by reference to which the amount of fungal DNA, of the relevant species, in plant samples was estimated.

2.5. Statistical analyses

Data were analysed using Genstat. Effects of treatments on disease variates and DNA quantity were determined by factorial analysis of variance. Percentage data were transformed to logits ($0.5\log(p/100\text{-}p)$) for analysis. DNA quantities were analysed as pg fungal DNA ng^{-1} total DNA and also after transforming these values to $\log_{10}$; the latter are not presented as they provide no additional information. Variance components of differently sized sampling units (three-plant

sampling points, plots and blocks) were determined by restricted maximum likelihood (REML) analysis. Relationships between variates were determined by regression analyses. Effects are considered to be significant where $P \leq 0.05$.

3. Evaluation of diagnostic and quantitative PCR for the identification and severity assessment of stem-base diseases

3.1. Results

These results compare visual assessments of disease with the presence of pathogens determined by PCR. In samples taken early in the season, when decisions to apply fungicides need to be made, diseases are often difficult to identify on the shoot bases. In these samples, the validity of the visual diagnoses was principally under test. Pathogen DNA was often present at this time in amounts that were insufficient to quantify. Therefore the comparisons between disease incidence and the pathogens present are made using DNA incidence expressed as the number of plots of each cultivar in which DNA of each fungus was present.

Pathogen DNA was usually quantifiable in the samples taken in summer. Therefore the relationships between visible disease symptoms and DNA of the suspected pathogens were investigated by regression analyses of the amount of symptoms (the dependent variable) on the amount of pathogen DNA (the independent variable). The amount of symptoms is represented by the disease index (i.e. a measure of severity or, better, intensity, being calculated from incidence and severity values), except for sharp eyespot and brown foot rot at Harper Adams (1997) and Morley (all years), where disease severity categories were not recorded. These analyses were done on the final sample in each experiment, taken at a time when symptoms on stems are often relatively easy to identify visually. It was therefore considered that these regressions were likely to provide the best indication of the accuracy and consistency of the DNA quantification results. Regressions were subsequently done on other, earlier samples for brown foot rot, for which the relationships between symptoms and pathogens were unclear in the final samples. The analyses include tests of whether the regression lines for the different cultivars are different, parallel or coincident (indicated in the tables).

The effects of fungicide, applied after the second sample (GS30-31), are not considered here.

3.1.1. Eyespot

In 1997, DNA of *Tapesia* spp. was not found at Harper Adams or Morley but *T. yallundae* was recorded in most plots at Rothamsted at GS30-31 (Table 3.1). Eyespot was usually recorded on fewer than 10% of plants but this frequency was exceeded on cvs Brigadier and Soissons at GS30-31 at Rothamsted.

In 1998, DNA of *Tapesia yallundae* was not recorded at GS22-26, and was recorded at GS30-31 at a low frequency at Rothamsted and Morley (Table 3.2). *T. acuformis* was recorded

at GS22-26 only at Morley and at GS30-31 at high frequencies at Harper Adams and Morley and at low frequency at Rothamsted. No eyespot symptoms were recorded at Harper Adams up to GS30-31, suggesting that the pathogen was not causing symptoms or, more likely, indistinct symptoms were mis-identified as other diseases. Eyespot was present in both samples at Morley and cultivar differences were clearer at GS30-31 from the disease data than from the DNA incidence data. At Rothamsted, eyespot (described as "possible eyespot" because of indistinct symptoms) was recorded at GS22-26 when no DNA was found, suggesting that the symptoms were mis-identified or that very small amounts of pathogen DNA were undetectable. The relatively high incidence of symptoms but low incidence of DNA at GS30-31 (cf. Morley) indicates that visual identification was still presenting problems.

In 1999 at Harper Adams, DNA of *T. acuformis* was found in all plots, and DNA of *T. yallundae* in fewer than half the plots at both pre-treatment sampling times (Table 3.3). At Morley, no DNA of *Tapesia* spp. was found. At Rothamsted, DNA of both eyespot fungi occurred in most plots of all cultivars, except Lynx, at both sampling times. Eyespot was not identified at GS12-22 at Harper Adams or Morley but was recorded at GS30-31, frequently at Harper Adams, and in both samples at Rothamsted. Eyespot symptoms were least frequent in cv. Lynx.

In the final sample, at GS75, in 1997 at Harper Adams, the regressions show a strong relationship between eyespot index and the amount of DNA of *T. acuformis*, the only eyespot pathogen present at this site (Table 3.4). The regression was not significant for cv. Lynx, which had least disease. There were no significant regressions of eyespot index on *T. acuformis* DNA at GS69 at Harper Adams in 1998. In 1999, there were significant regressions over all cultivars of eyespot index on DNA of *T. acuformis* and *T. yallundae* + *T. acuformis*; regression lines on these variates were parallel for the different cultivars. Regressions on *T. yallundae* DNA and *T. yallundae* + *T. acuformis* DNA were also significant for cv. Soissons (which had least visual symptoms, perhaps suggesting a problem with symptom identification in the other cultivars; in 1999, symptom identification was hampered by severe take-all that extended to the stem bases).

At GS77-83 at Morley in 1997, there was a significant regression of eyespot index on *T. acuformis* DNA over all cultivars, but none for individual cultivars except Soissons (Table 3.5). However, there were significant regressions for all cultivars at GS71-75 in 1998. In 1999, there were strong relationships over all cultivars between eyespot index and DNA of both *Tapesia* spp. (Table 3.6). The regression lines for *T. acuformis* were different for the different cultivars.

At GS75-77 at Rothamsted in 1997, the regression of eyespot index on *T. yallundae* DNA was significant over all cultivars but, of the individual cultivars, only on Mercia (Table 3.7). The regressions on *T. acuformis* DNA and on amounts of *T. yallundae* and *T. acuformis* DNA added together were significant over all cultivars and for Lynx and Mercia. The *T.*

acuformis regressions are the only set that show significant differences between cultivars, i.e. they were not the same line or parallel lines, suggesting different responses of different cultivars to eyespot. However, the Rothamsted 1997 data set had missing values and these observations may have been affected by small and uneven replication. At GS 73 in 1998, all regressions for all cultivars were significant (Table 3.8). In 1999, the regressions on *T. yallundae* DNA were significant for all cultivars except Lynx, which had least eyespot (Table 3.9). The regressions on *T. acuformis* were also significant, except for that on Mercia, and regressions for DNA of both fungi added together were significant for all cultivars.

There were few significant disease index-cultivar interactions. The percentage of the variance accounted for by each regression was sometimes small, suggesting that symptom identification was not always correct, that old symptoms were deficient in fungus or that some fungal DNA was not associated with symptoms.

3.1.2. Sharp eyespot

The highest frequencies of DNA of *Rhizoctonia cerealis* in samples taken before fungicide treatments were applied were usually recorded on those occasions on which symptoms of sharp eyespot were also recorded most frequently, i.e. at Harper Adams in 1998 (both sampling times), at Rothamsted in 1998 (both sampling times) and at Harper Adams and Rothamsted in 1999 (GS30-31) (Table 3.10). Exceptions were at Harper Adams in 1999 (GS22) and at Morley in 1998 (GS30-31), when symptoms were not recorded despite the frequent incidence of pathogen.

There were no significant regressions of sharp eyespot on *R. cerealis* DNA at GS75 at Harper Adams in 1997, when disease was very scarce (recorded on 2% of stems). At GS69 in 1998, regressions over all cultivars and for Brigadier and Mercia were highly significant (Table 3.11). In 1999, the regressions over all cultivars and for Abbot were highly significant. In 1998 and 1999, the cultivars had different regression lines but the relative amounts of disease on the cultivars differed between years.

At Morley in 1997, there was a significant regression of percentage stems with sharp eyespot on *R. cerealis* DNA only for Lynx among the individual cultivars, but the data for all cultivars formed a single, significant regression line (Table 3.12). In 1998, regressions over all cultivars and for individual cultivars except Brigadier were significant and the cultivar regressions were parallel. In 1999, the overall regression was again highly significant with data from all cultivars forming a single regression line.

At GS75-77 at Rothamsted in 1997, there were significant regressions of sharp eyespot index on *R. cerealis* DNA over all cultivars and for individual cultivars except Brigadier, the data for individual cultivars forming a single regression line (Table 3.13). In 1998, all

regressions were highly significant; those for individual cultivars were different but parallel. The situation in 1999 was similar to that in 1997 except that all regressions were significant.

Although the percentage of the variance accounted for by each regression was often small, as for eyespot, the regressions usually had more significance than those for eyespot (section 3.1.1). This suggests that visual identification of sharp eyespot at the late growth stages was more reliable than that of eyespot.

3.1.3. Brown foot rot

Brown foot rot was associated with the presence of *Microdochium nivale* rather than *Fusarium* spp. in all experiments and data only for this species are presented.

In samples taken before fungicide treatments in 1997, high incidences of DNA of *M. nivale* var. *nivale* (var. *majus* was rare) were recorded at Morley (both samples) and Rothamsted (GS30) (Table 3.14). The incidence of recorded brown foot rot varied greatly among these samples.

In pre-treatment samples in 1998 at Harper Adams, brown foot rot was associated with incidence of *M. nivale* var. *nivale* in the first sample and mainly with *M. nivale* var. *majus* in the second sample (Table 3.15). DNA of both fungi was more frequent at Morley than at Harper Adams, but that of *M. nivale* var. *nivale* was more frequent than that of var. *majus* in both early samples. At Rothamsted, the frequency of DNA was similar to that at Morley, but the greater frequency of symptoms was more similar to Harper Adams. Cultivar differences in both DNA and symptoms often reflected the NIAB ratings for eyespot severity.

In pre-treatment samples taken in 1999, the incidence of recorded brown foot varied among samples and sites (Table 3.16). The highest incidence of brown foot rot (at Harper Adams at GS22) was associated with the highest incidence of DNA of *M. nivale* var. *nivale*. At the other sites, *M. nivale* var. *majus* was the prevalent pathogen. The cultivar differences were less clear than in 1998.

Tables 3.17-3.21 show sets of regressions of brown foot rot symptoms on amounts of DNA of *M. nivale* for the final sample in each experiment, taken in summer. A full set of regressions for individual cultivars is shown only where at least one of them is significant. The relationships were often poor and were inconsistent. Sometimes the regressions were significant over all cultivars but the relationships of the regressions of the different cultivars varied among sites and years. The inconsistencies may be explained in part by the decline in DNA of *M. nivale* that often occurred in the summer (Figs 5.8-5.13). Because of this, and because DNA of *M. nivale* was often present in quantifiable amounts in early samples, relationships between brown foot rot and amounts of *M. nivale* DNA are also examined for the early samples.

A set of regressions is shown for an early sample (before the final, summer sample) only where that sample includes at least one regression that is statistically significant (Tables 3.22-3.32). Samples in which quantifiable amounts of DNA of *M. nivale* occurred, but for which regressions of incidence of brown foot rot on amount of DNA were not significant (and so are not shown), are:

GS22 at Harper Adams, 1999

GS12-22 and GS30-31 at Morley, 1997

GS22-26 and GS31 at Morley, 1998

GS12-22 at Morley, 1999

GS30-31 and GS32-33 at Rothamsted, 1997

GS22 and GS30-31 at Rothamsted, 1999.

Other samples for which regressions are not presented had insufficient DNA of *M. nivale* to quantify.

At Harper Adams in 1997, the regressions on *M. nivale* var. *nivale* DNA at GS39 (Table 3.22) were more significant and accounted for a greater percentage of the variance than those at GS75 (Table 3.17). In 1998, the regressions using data from the first three samples were less consistent (Tables 3.23-3.25), but the data collected over all cultivars fitted the regression models better than the data from the summer sample (Table 3.17). The same situation occurred in 1999, the regressions for GS32 (Table 3.26) being considerably more significant than those at GS85 (Table 3.17).

At Morley, there were significant regressions using *M. nivale* var. *nivale* data from samples taken in May (Tables 3.27, 3.28). They were more consistent than those using data from the summer samples (Table 3.18).

At Rothamsted, the regressions using data from the early samples in 1998 (Table 3.29-3.31) and from the May sample in 1999 (Table 3.32) were mostly better than those from the summer samples in those years (Tables 3.20-3.21).

3.2. Discussion

Disease assessments made up to GS31 often did not agree with the pathogen diagnoses using PCR. Some of these discrepancies were site-dependent. This was apparently because symptoms had different appearance and occurred in different combinations at the different sites and, presumably, because different personnel were involved. For these reasons, early visual diagnoses must be considered unreliable.

Visual diagnoses made on stems in summer were generally more successful but there were often discrepancies in relating these to amounts of pathogen present. Eyespot symptoms

may sometimes have been confounded with brown foot rot and relationships were less clear on some cultivars, usually those with least disease. Sharp eyespot symptoms usually had the strongest relationship to pathogen DNA. For all pathogens, the value of the constant in positive regression lines was often large. This might suggest that the pathogens occur, and cause symptoms, in amounts that are not quantifiable. However, it is more likely an indication that the data are inadequate to explain the relationships at low levels of disease. Interpretations should also be made with care because the regression often accounted for a small amount of the variance, suggesting that other factors contributed to the effects.

The causes of brown foot rot symptoms were difficult to verify. It seemed that the varieties of *M. nivale* were principally involved. Conditions during summer were insufficiently warm and dry to favour development of *Fusarium culmorum*, often the principal brown foot rot pathogen, during the years of these experiments. A particular problem was that the amount of *M. nivale* in the tissues tended to decline as the tissue aged (see section 5). This is supported by the generally stronger relationships between symptoms and pathogen DNA in May than in the summer. *M. nivale* appears to disappear partially from necrotic lesions to which it contributed. *M. nivale* is also expected to be a secondary coloniser of eyespot-infected tissue (Bateman, 1993) although this appeared not to be consistent either between years or with the presence of clear eyespot. However, some cultivar differences in incidence of DNA of *M. nivale* reflected their susceptibility to eyespot. This may be because the *M. nivale* was colonising eyespot-infected plants in proportion to the amount of eyespot present or because eyespot-resistance genes also confer resistance to *M. nivale*.

In the regressions of brown foot rot (which may include symptoms of other diseases, especially in early samples), there was no evidence that the different cultivars produced regression lines with different slopes but there was evidence of different susceptibilities of the cultivars, especially in the early samples.

The regressions give evidence of interactions among the pathogens in the development or suppression of disease symptoms, as well as between pathogens and cultivars. These are not explored further in this report.

4. Effects of cultivar and fungicides on stem-base pathogens, determined by PCR, and on diseases and yield of wheat

4.1. Results

The effects of cultivar and fungicide, and interactions between them, are presented for the last plant sample in each year, taken during anthesis or grain ripening. The comparisons are made on stem-base disease incidence and, where data are available, severity (more correctly referred to as disease intensity since the disease index is calculated from incidence and severity data) and on amounts of DNA of the main pathogens.

4.1.1. Harper Adams 1997

Incidence (Table 4.1) and severity (Table 4.2) of eyespot were less in Lynx than in other cultivars. Incidence overall was decreased by all fungicides except prochloraz but cyprodinil was most effective. Eyespot severity was decreased only by cyprodinil. Cultivar-fungicide interactions were not significant but results suggest that cyprodinil had least effect on cv. Lynx and that flusilazole was effective mainly on cv. Mercia. *Tapesia acuformis* was the only eyespot pathogen whose DNA was recovered in quantifiable amounts. DNA quantities were mostly in agreement with visual symptoms, except for a significant decrease in DNA of *T. acuformis* after prochloraz treatment, an effect evident in all cultivars except Brigadier (Table 4.3).

Sharp eyespot was scarce, occurring on only 2% of main stems, and was not affected by cultivar or fungicide (results not shown). DNA of *Rhizoctonia cerealis* was not present in quantifiable amounts.

Brown foot rot, present almost entirely as slight symptoms, was less frequent on cvs Mercia and Soissons than on Lynx and Brigadier (Table 4.4). Over all cultivars, incidence of brown foot rot was decreased by cyprodinil and increased by flusilazole; the effect of cyprodinil was least apparent on Brigadier and that of flusilazole was most apparent on Mercia, although the cultivar-fungicide interaction was not significant. DNA of *Microdochium nivale* var. *nivale* was recovered at an average of 0.54 pg ng^{-1} but was not affected by treatments. No other brown foot rot pathogens were detected in quantifiable amounts.

Grain yields of cvs Mercia and Soissons were less than those of the other cultivars (Table 4.5). There was a significant cultivar-fungicide interaction: prochloraz decreased yield in Lynx and increased it in Soissons; flusilazole decreased yield in Lynx and increased it in Mercia; cyprodinil and azoxystrobin increased yield in Mercia.

4.1.2. Harper Adams 1998

Eyespot was more frequent over all treatments on stems of Brigadier than of other cultivars, although there was a similar incidence on Soissons in the untreated plots (Table 4.6). Its incidence was decreased, over all cultivars, by prochloraz and, to a greater extent, especially in Soissons, by cyprodinil. Severity was least on cv. Lynx and most on Brigadier (Table 4.7). Severity was decreased over all cultivars by prochloraz and cyprodinil and increased by azoxystrobin; the effect of prochloraz was most marked in Brigadier, that of cyprodinil in Mercia and Soissons and that of azoxystrobin in Mercia. DNA of *T. acuformis* was quantifiable (Table 4.8). It was most abundant over all treatments in Mercia or, in the absence of fungicides, in Soissons. It was least over all treatments in Lynx and, in the absence of fungicides, in Brigadier. It was decreased over all cultivars by cyprodinil and increased by azoxystrobin. There was a significant cultivar-fungicide interaction. The cyprodinil effect occurred only in cv. Soissons and the azoxystrobin effect in Brigadier, whilst HGCA1 also increased DNA in Mercia.

Sharp eyespot was more frequent on Lynx and Mercia than on the other cultivars (Table 4.9). Its incidence was increased by prochloraz and flusilazole, with no clear cultivar interaction. Cultivar effects on severity (Table 4.10) were similar to those on incidence but severity was decreased overall by azoxystrobin, most notably in cv. Mercia. Effects of cultivar over all treatments on DNA of *R. cerealis* (Table 4.11) reflected those on symptoms. DNA was increased by prochloraz and cyprodinil, except in cv. Brigadier.

Incidence and severity of brown foot rot were not affected by cultivar or fungicide (Table 4.12). DNA of *M. nivale* var. *nivale* was more abundant in cvs Brigadier and Soissons than in other cultivars but was not affected by fungicides.

Grain yields averaged 10.14 t ha^{-1} and were not affected by treatments.

4.1.3. Harper Adams 1999

Eyespot incidence (Table 4.13) and severity (Table 4.14) were slightly greater overall in Abbot and Mercia than in other cultivars but were not affected by fungicides. DNA of *T. yallundae* was least in cv. Lynx and was decreased over all cultivars by cyprodinil (Table 4.15). *T. acuformis* was less in Lynx and Abbot than in other cultivars and was also decreased by cyprodinil (Table 4.16).

Sharp eyespot occurred at a low incidence (1.4% overall). It was almost absent where azoxystrobin was applied but was not affected by other treatments (results not shown). DNA of *R. cerealis* was quantified at 2.91 pg ng^{-1} on average. There were no differences between cultivars but DNA was decreased, over all cultivars, from 2.96 in untreated plants to 1.48 pg ng^{-1} after azoxystrobin treatment (SED = 0.620, $P = 0.002$).

The incidence of brown foot rot (23.2% overall) was not affected significantly by treatments but severity was less on Lynx than on other cultivars (Table 4.17). DNA of *M. nivale* was also not affected by fungicides but there was most DNA of var. *majus* in Mercia, and significantly more than in Lynx or Abbot, and more DNA of var. *nivale* in Mercia than in other cultivars.

Grain yields were small as a result of severe take-all. Lynx and Mercia yielded most and Soissons least (Table 4.18). Yields were increased by azoxystrobin and, less, by cyprodinil. These effects were seen most in Abbot and Soissons but cultivar-fungicide interactions were not significant.

4.1.4. Morley 1997

Eyespot incidence (Table 4.19) and severity (Table 4.20), and amounts of DNA of *T. acuformis* (Table 4.21) were least on cv. Lynx and most on Brigadier and Soissons. They were decreased by cyprodinil.

Sharp eyespot was least frequent on cv. Mercia and most frequent on cvs Brigadier and Soissons (Table 4.22). Amounts of DNA of *R. cerealis* are consistent with this (Table 4.23). Sharp eyespot incidence (Table 4.22), but not the amount of the pathogen's DNA (Table 4.23), was decreased by azoxystrobin.

Brown foot rot was recorded on 72% of main stems and DNA of *M. nivale* var. *nivale*, the only prevalent brown foot rot pathogen, occurred at 2.94 pg ng^{-1} overall; neither were affected by cultivar or fungicide.

Grain yields were least for cv. Mercia and were increased by cyprodinil and azoxystrobin, effects not apparent in cv. Lynx (Table 4.24).

4.1.5. Morley 1998

Eyespot was less frequent on stems of Lynx than of other cultivars (Table 4.25). It was decreased by cyprodinil and increased by azoxystrobin, the latter effect not apparent in Brigadier or Soissons. Effects on eyespot severity were similar except that it was less on Mercia than on Brigadier or Soissons (Table 4.26). There was also a significant cultivar-fungicide interaction, in which cyprodinil was effective on all cultivars except Lynx and severity was increased by azoxystrobin only on Lynx and Mercia and by HGCA1 on Lynx. DNA of *T. acuformis* was least abundant in Lynx and most abundant (in the absence of fungicides) in Soissons (Table 4.27). It was decreased by cyprodinil and, to a small extent, by azoxystrobin, an effect most apparent in Soissons.

The incidence of sharp eyespot (Table 4.28) and amount of DNA of *R. cerealis* (Table 4.29) were decreased only by azoxystrobin. There was less DNA in stems of cv. Brigadier than

of other cultivars whilst the greatest effect of azoxystrobin occurred in Soissons.

The incidence of brown foot rot was greatest overall in cv. Mercia but was not affected significantly by fungicides (Table 4.30). There were no differences in amounts of DNA of *M. nivale* var. *nivale* in different cultivars but an increase after prochloraz treatment was apparent only in Brigadier and Soissons (Table 4.31). There were also quantifiable amounts of DNA of *M. nivale* var. *majus* (Table 4.32). It was most abundant in Brigadier and Soissons but was not affected by fungicides.

Grain yields were greatest overall in cvs Brigadier and Soissons although untreated crops had similar yields (Table 4.33). Yields over all cultivars were increased by cyprodinil and azoxystrobin, the latter effect most apparent in Brigadier.

4.1.6. Morley 1999

Eyespot was more frequent in Abbot and Soissons than in the other cultivars (Table 4.34). Eyespot was least severe in Lynx and Mercia and most severe in Soissons (Table 4.35). Incidence and severity were decreased in all cultivars by cyprodinil and there was a suggestion of such an effect of prochloraz on cv. Mercia. DNA of *Tapesia* spp. was most abundant in cv. Soissons and least in cv. Lynx but the effect was not significant for *T. yallundae* (Tables 4.36, 4.37). DNA of *T. yallundae* was decreased over all cultivars by prochloraz and, more so, by cyprodinil (Table 4.36). *T. acuformis* DNA was decreased only by cyprodinil (Table 4.37); a significant cultivar-fungicide interaction showed this to be most apparent in Abbot and Soissons.

Sharp eyespot was least frequent in Lynx and most frequent in Abbot and Soissons (Table 4.38). Its incidence was decreased by azoxystrobin. There was least DNA of *R. cerealis* in cv. Mercia and most in Abbot and, overall, the amount was decreased only by azoxystrobin (Table 4.39).

Brown foot rot was most frequent in cv. Mercia and least frequent in Abbot but there were no effects of fungicides (Table 4.40). There was less DNA of *M. nivale* var. *nivale* in Abbot than in other cultivars (Table 4.41). It was decreased over all cultivars by azoxystrobin and HGCA1; a significant cultivar-fungicide interaction showed that this occurred mainly in cv. Mercia and that it was increased by prochloraz in cv. Soissons.

Grain yields were greater in cvs Mercia and Abbot than in Lynx and Soissons but were not affected by fungicides (Table 4.42).

4.1.7. Rothamsted 1997

Eyespot incidence (Table 4.43) and severity (Table 4.44) were least in cv. Lynx and most in Brigadier and Soissons. They were decreased by all treatments except azoxystrobin and most

by cyprodinil. DNA of both *Tapesia* spp. was quantified and available data suggest a correlation with eyespot symptoms (Table 4.45).

Sharp eyespot incidence (Table 4.46) and severity (Table 4.47) were less in Soissons than in other cultivars and were decreased by azoxystrobin. DNA of *R. cerealis* responded similarly to sharp eyespot symptoms (Table 4.45).

Brown foot rot incidence (Table 4.48) and severity (Table 4.49) were greater in Mercia and Soissons than in other cultivars and were decreased by cyprodinil and azoxystrobin. The fungicide effects were most marked in Soissons. The cultivar effects on disease were most similar to those on amounts of DNA of *M. nivale* var. *majus* while the effect of azoxystrobin was most apparent in amounts of DNA of *M. nivale* var. *nivale* (Table 4.45).

Grain yields of cvs Lynx and Brigadier were greater than those of Mercia and Soissons (Table 4.50). Grain yield over all cultivars was increased only by azoxystrobin, an effect most apparent in Lynx and Brigadier.

4.1.8. Rothamsted 1998

Eyespot incidence (Table 4.51) and severity (Table 4.52) were least in cv. Lynx and most in Brigadier and Soissons and were decreased by prochloraz and, to a slightly lesser extent, by cyprodinil. HGCA1 also decreased severity in Mercia and Soissons. DNA of *T. yallundae* responded as did eyespot symptoms except that there was most in Mercia and Soissons and HGCA1 was effective only in Mercia, in which cyprodinil was not effective (Table 4.53). There was less DNA of *T. acuformis*, which responded similarly to treatments except that cyprodinil was not less effective than prochloraz (Table 4.54).

Sharp eyespot incidence (Table 4.55) and severity (Table 4.56) were generally less frequent on Brigadier and Soissons than on Lynx and Mercia and were decreased over all cultivars by azoxystrobin. Amounts of DNA of *R. cerealis* showed similar responses (Table 4.57).

Brown foot rot incidence (Table 4.58) and severity (Table 4.59) were least in Soissons and most in Mercia. There were no overall differences between untreated and fungicide-treated plots but there was more disease after prochloraz than after azoxystrobin treatments. There was more DNA of *M. nivale* var. *nivale* in Brigadier than in other cultivars and least in Lynx and Mercia (Table 4.60); it was decreased by azoxystrobin. There was more DNA of *M. nivale* var. *majus* in Brigadier and Soissons than in the other cultivars but no effects of fungicides (Table 4.61).

Grain yields were greatest in cv. Brigadier and least in Mercia (Table 4.62). Yields were increased overall only by azoxystrobin although the effect was least marked in cv. Brigadier.

4.1.9. Rothamsted 1999

Eyespot incidence (Table 4.63) and severity (Table 4.64) were least in cv. Lynx and most in Soissons. Incidence and severity were both decreased by cyprodinil and increased by azoxystrobin in all cultivars. There was most DNA of *T. yallundae* in Mercia and Soissons and least in Lynx (Table 4.65). It was decreased overall by prochloraz and cyprodinil but there were cultivar differences: prochloraz was not significantly effective on Abbot, cyprodinil was not significantly effective on Lynx and HGCA1 was effective on Mercia. DNA of *T. acuformis* was not affected significantly by cultivar and was decreased on all cultivars by cyprodinil only (Table 4.66).

Incidence of sharp eyespot was least in cv. Mercia in untreated plots but least in Soissons over all treatments (Table 4.67). It was decreased overall by azoxystrobin, an effect significant only in Abbot, and increased overall by cyprodinil, an effect significant only in Mercia, in which it was also increased by prochloraz and HGCA1. The overall effects of cultivar and fungicides on sharp eyespot severity were similar to those on incidence, except that the overall decrease with azoxystrobin was not significant and there was an increase after prochloraz treatment (Table 4.68); cultivar-fungicide interactions were similar to those for incidence but were not significant. DNA of *R. cerealis* over all cultivars was less after azoxystrobin than after other treatments but was not significantly less than in the untreated (Table 4.69); this reflected the disease index results.

Incidence of brown foot rot was greatest in Lynx and Mercia and least in Soissons (although Abbot was similar to Soissons in untreated plots) and was decreased over all cultivars by all fungicides except cyprodinil, the effects being most apparent in Soissons (Table 4.70). There were similar effects on severity except that it was decreased over all cultivars by all fungicides (Table 4.71). There was an average of 1.77 pg ng^{-1} of DNA of *M. nivale* var. *majus* in stems but it was not affected by cultivars or fungicides. There was more DNA of var. *nivale* in stems of Mercia than of other cultivars and it was decreased over all cultivars by cyprodinil and, almost significantly, by azoxystrobin (Table 4.72).

Grain yields were not affected overall by cultivar or fungicides but cv. Mercia yielded less than Lynx in untreated plots and the yield of Mercia was increased by HGCA1 (Table 4.73).

4.1.10. Overall effects and interactions

Table 4.74 compares amounts of disease and of pathogen DNA in the different cultivars at the three locations. The data are from all fungicide treatments and so do not necessarily reflect cultivar differences in susceptibility to the diseases, although the order of cultivars is usually the

same when untreated plots are considered separately (see earlier tables). However, the order of apparent susceptibilities to eyespot and its pathogens is mostly as expected from NIAB ratings. There are a few discrepancies between eyespot severity and *Tapesia* DNA, probably indicating problems in making visual assessments (caused by e.g. mixed symptoms), but usually they are in agreement. There was good correspondence between sharp eyespot and its pathogen, *R. cerealis*. There were no consistent relationships between cultivars and brown foot rot or *M. nivale* varieties (the only pathogens found with quantifiable amounts of DNA) or between brown foot rot and *M. nivale*.

Tables 4.75-4.77 summarise the effects of fungicides on diseases and pathogens. Cyprodinil consistently decreased eyespot severity and amounts of *Tapesia* DNA. It was similarly effective against both pathogens. Prochloraz sometimes decreased eyespot, mostly where *T. yallundae* was present in quantifiable amounts, as at Rothamsted in 1997 and 1998, at Harper Adams in 1998 and at Morley in 1999. Prochloraz was not effective in the presence of *T. yallundae* at Harper Adams and Rothamsted in 1999. Significant amounts of rainfall were sometimes associated with eyespot control by prochloraz, as at Harper Adams and Rothamsted in 1998 and at Morley in 1999, and that seemed to have as much influence as the presence or absence of *T. yallundae* (Tables 4.78, 4.79).

Azoxystrobin consistently decreased sharp eyespot and its pathogen, *R. cerealis* (Table 4.75-4.77). Effects of fungicides on brown foot rot were not consistent with effects on *M. nivale*. The effects of fungicides on both were variable.

Grain yields were most often increased by azoxystrobin (Table 4.75, 4.76). These effects were not consistently related to decrease in any single disease or pathogen except sharp eyespot and *R. cerealis*. However, the severity of sharp eyespot was considered usually to be too little to have contributed to yield losses. On some occasions, control of eyespot by cyprodinil undoubtedly contributed to yield increases.

4.2. Discussion

The objectives of the research described in Section 4 were to apply quantitative PCR to the assessment of cultivars and fungicides on stem-base diseases and yields of wheat and to compare its performance with conventional disease assessment methods.

PCR showed that the benefits of cyprodinil, the most active fungicide against eyespot, resulted from its effectiveness against both eyespot pathogens. Its effects on disease, pathogens and yield were most significant on the cultivars most susceptible to eyespot but, even on these, yield increases were not usually achieved. Fungicides are therefore unlikely to give yield improvements to cultivars with adequate resistance to stem-base diseases in conditions similar

to those of the experiments.

Prochloraz was erratically effective against eyespot. This variability can not be explained by differences in application times; optimum timings can be variable but the best is usually about GS30-31 (Marshall & Ayers, 1986; Jørgensen & Nielsen, 1990). The performance of prochloraz against eyespot depends on its redistribution from foliage to the stem base in rainfall (Cooke *et al.*, 1989). Its half-life on unweathered foliage is about 6 days. Significant amounts of rainfall were sometimes associated with eyespot control, as at Harper Adams and Rothamsted in 1998 and at Morley in 1999. It may also sometimes be less effective where eyespot pathogen populations consist almost entirely of *Tapesia acuformis*, because these can include strains with less sensitivity than strains of *T. yallundae* (Bateman *et al.*, 1995). In the experiments described here, prochloraz was effective on more occasions at Rothamsted than elsewhere, Rothamsted being the only site at which *T. yallundae* was common. Even here, eyespot is not decreased in every crop to which prochloraz is applied (Bateman & Fitt, 1991). In these experiments, pathogen species and rainfall events may both have influenced the performance of prochloraz.

Increases in grain yield resulting from azoxystrobin application were not explained by its effects on particular pathogens as determined by PCR. Take-all was severe in some of the second wheat crops used in these experiments and was the main cause of the small yields at Harper Adams in 1999. Decreases in take-all severity resulting from azoxystrobin treatments may, in some cases, have contributed to yield increases (Jenkyn *et al.*, submitted paper).

PCR established that brown foot rot was not clearly associated with any pathogen. It has been suggested that *M. nivale* often behaves as an opportunistic coloniser of tissue that is already diseased, for example with eyespot (Bateman, 1993). It might therefore be expected that amounts of DNA of *M. nivale* would be associated with the amount of eyespot. Such an association was suggested on only a few occasions when cv. Lynx had least eyespot and least *M. nivale* (Table 4.74) but never convincingly. Further research is needed to establish the contribution, if any, of *M. nivale* to stem-base disease and yield losses.

There was some evidence of interactions between site/year and cultivar on the performance of fungicides and further research, as well as more detailed, in-depth analysis of the present data, are needed to elucidate these.

5. Rates of development of stem-base pathogens on different wheat cultivars determined by quantitative PCR

5.1. Results

Concentrations of DNA of pathogenic fungi, where present in amounts sufficient to quantify, in shoot or stem bases of plants untreated with fungicides were plotted against time. The time scale is the number of days from drilling the seed. The date and growth stage at which each sample was taken are shown in Table 2.1. The DNA concentrations for each cultivar are means of 20 plots in samples taken before fungicide treatments were applied and means of four plots (untreated only) in later samples. SEDs for comparing cultivars are taken from factorial ANOVAs that tested the effects of both cultivars and fungicides, except where the data were inadequate for analysis (e.g. because of missing plots in the sample). Decreases in DNA between samples sometimes occurred and are usually the result of loss of senescent outer leaf sheaths which the fungus had colonised first.

5.1.1. Tapesia *spp.*

At Harper Adams, *Tapesia yallundae* was present only in 1999, when it occurred throughout the sampling period (Fig. 5.1). Cultivar differences were closer to those expected from NIAB ratings (see 2.1) at GS32 than at GS85, when Abbot and Mercia had greatest amounts of DNA of this fungus. *T. acuformis* was present in all years (Fig. 5.2). This fungus began to develop only after 200 days (after fungicide treatments had been applied to other plots) in 1997 and 1998. In 1999, *T. acuformis* was present throughout the sampling period. It occurred in smaller amounts than *T. yallundae* in the early samples but in greater amounts in the later samples, especially in cvs Mercia and Soissons.

The development of *Tapesia* spp. at Morley (Figs 5.3, 5.4) was similar to that at Harper Adams except that both species appeared late in 1999 and were quantifiable only at GS 71-73 (257 days). In the last sample in each year, cv. Soissons contained most DNA of *T. acuformis* (Fig. 5.4), consistent with NIAB ratings for eyespot; the cultivar differences were less clear for *T. yallundae* (Fig. 5.3).

At Rothamsted in all years, *T. yallundae* (Fig. 5.5) developed earlier and was present in greater amounts than *T. acuformis* (Fig. 5.6). Cv. Mercia often contained more DNA of each fungus than did other cultivars at the final samples although not significantly more than cv. Soissons.

5.1.2. Rhizoctonia cerealis

DNA of *R. cerealis* was not found in 1997 at Harper Adams (Fig. 5.7) and was present only after 200 days, on stems, at Morley (Fig. 5.8) and Rothamsted (Fig. 5.9). It was present in small amounts in early samples at Harper Adams and Rothamsted in 1998 and at all sites in 1999. It tended to appear on stems soon after stem extension, in May, and sometimes then declined in the summer. There were no consistent cultivar differences although Mercia tended to become most infected at Harper Adams and Soissons at Morley.

5.1.3. Microdochium nivale

The development of *M. nivale* on shoot and stem bases showed little consistency over sites or years (Figs 5.10-5.15). *M. nivale* var. *nivale* sometimes decreased on young plants, before stem extension, as the leaf sheaths senesced, as at Harper Adams in 1997 (Fig. 5.10) and Rothamsted in 1998 (Fig. 5.14). *M. nivale* var. *majus* sometimes behaved similarly, as at Harper Adams (Fig. 5.11) and Rothamsted (Fig. 5.15) in 1999. A relatively large amount of either fungus on stems in May was usually followed by a decrease as the plants matured; this occurred with var. *nivale* at all sites in 1997 (Figs 5.10, 5.12, 5.14) and with var. *majus* in all years at Harper Adams (Fig. 5.11) and in 1997 at Rothamsted (Fig. 5.15). A late-season increase in var. *nivale* in 1999 at Morley (Fig. 5.12) was accompanied by a decrease in var. *majus* (Fig. 5.13).

Effects of cultivar were usually most apparent when there was most DNA present in the stems; cv. Soissons often contained most DNA while Lynx contained least. The cultivar effects were similar for each of the varieties of the fungus.

5.2. Discussion

Where *T. yallundae* was present in quantifiable amounts, it usually developed earlier than *T. acuformis*. These results using PCR confirm earlier results using other methods (Goulds & Fitt, 1990; Bateman *et al.*, 1990).

Cultivar differences in amounts of *M. nivale* were most clear in stems during internode extension and when relatively large amounts of DNA were present. In these circumstances, the cultivar differences approximated to the NIAB ratings for eyespot susceptibility (see 2.1), Soissons containing most and Lynx least DNA. This suggests a relationship between genetic resistance to eyespot and *M. nivale*, which may result from a facility for the latter to invade tissues already damaged or weakened by pathogens (Bateman, 1993). This seems not to have been reported before and, subject to further research to understand the role of *M. nivale* in yield losses, may have relevance to cereal breeding programmes. The late-season decreases in *M. nivale* suggest that brown foot rot symptoms attributable to this fungus will have fully developed earlier; this was supported by regressions of the extent of disease symptoms on

amounts of DNA at successive samples (see 3.1.3).

The development of a pathogen may have been suppressed by the presence of other pathogens. Such suppression has been demonstrated on wheat shoots and may be influenced by the sequence of infection by the different fungi (Bateman & Munnery, 1995). More frequent sampling would have been necessary to demonstrate clearly the sequence of infections in the present experiments.

Eyespot is recognised as the most important stem-base disease of wheat and the principal target for fungicides applied at the beginning of stem extension. *T. acuformis* was the only eyespot pathogen that occurred in quantifiable amounts in all nine of the field experiments described. This fungus tends to develop late, as it did in most of the experiments described here, and so was not detectable in many of the samples taken before GS31. Its late development also results in smaller yield losses than the earlier developing *T. yallundae* (Rothamsted data, unpublished). Consequently, early infection by the pathogens that would indicate risk and a need to apply fungicides was not often encountered (see 6.1).

6. Evaluation of quantitative PCR as an aid to decision-making in applying fungicides to control stem-base diseases

6.1. Results

Regressions of grain yield on the severity (where data are available) or incidence of stem-base diseases are presented. This was a means of determining which diseases, and hence which pathogens, decreased yield and so should be targets for control by fungicides. The relationships between disease control, yield increases and the presence of quantifiable DNA at early growth stages, when decisions on applying fungicides need to be made, were then examined.

6.1.1. Effects of diseases on yield

Over all cultivars and fungicide treatments, there were no significant ($P \leq 0.05$) negative relationships between grain yield and eyespot severity (Table 6.1). There were negative relationships between yield and brown foot severity (i.e. disease was associated with decreased yield) at Rothamsted in 1997 and between yield and sharp eyespot severity at Rothamsted in 1998. There were significant effects of fungicides on these diseases and on yields on these occasions, mostly associated with the use of cyprodinil or azoxystrobin (Tables 4.49, 4.50, 4.56 and 4.62). In each case the percentage of the variance accounted for by the regression was small (Table 6.1).

There were significant positive relationships between yield and eyespot index at Harper Adams in 1999 and between yield and percentage stems with brown foot rot at Morley in 1999 (i.e. disease was associated with increased yield) (Table 6.1). Each regression accounted for only a small percentage of the variance.

Table 6.2 compares regressions of yield on disease symptoms for individual cultivars where a significant regression occurred for at least one cultivar or over all cultivars. Relationships among each of the four regression lines in each set and their significance, determined by the analysis, are stated in the table. Significant negative relationships between grain yield and eyespot occurred on cvs Lynx and Soissons at Harper Adams in 1998 and on cv. Mercia at Rothamsted in 1997. There was also a significant negative relationship between yield and sharp eyespot on cv. Abbot at Morley in 1999, on cv. Brigadier at Rothamsted in 1997 and on cvs Lynx and Soissons at Rothamsted in 1998. The overall significant regression of yield on brown foot rot at Rothamsted in 1997 (Table 6.1) was clearly an effect of differences between cultivars, regardless of fungicide treatments, since none of the individual regressions was significant (P=0.7-1.0) and the lines were significantly parallel and close to horizontal (not shown). In 1999 at Rothamsted, there were positive relationships between yield and brown foot

rot (i.e. disease was associated with increased yield) on cvs Abbot and Mercia (Table 6.2). Significant positive regressions over all cultivars (eyespot at Harper Adams and brown foot rot at Morley in 1999, see above) were to some extent reflected in the regressions for individual cultivars, most of which were also positive but not significant; they were, however, significantly parallel.

In conclusion, there were only few occasions on which benefits would have resulted from applying fungicides.

6.1.2. Relationships between pathogen DNA and effects of fungicides

Over all cultivars, quantifiable amounts of *Tapesia* DNA were found up to GS31 at Harper Adams in 1999, Morley in 1998 and Rothamsted in 1997 and 1999 (Table 6.3a). In each of these experiments, cyprodinil, the most effective eyespot fungicide (see section 4), decreased eyespot by a large amount, usually significantly, and increased yield, usually not significantly (Table 6.3b). Cyprodinil also decreased eyespot significantly in all the other experiments and increased yield significantly at Morley in 1999, when *Tapesia* DNA was not detected in quantifiable amounts up to GS31.

Relationships between early incidence of quantifiable *Tapesia* DNA and subsequent eyespot control will now be considered on individual cultivars for those situations in which significant regressions of yield on disease have already been established (Table 6.2).

DNA of *Tapesia* spp. was not present in quantifiable amounts at Harper Adams in 1998 (Table 6.4a). Eyespot was decreased significantly in cv. Soissons by cyprodinil or HGCA1 but there were no associated yield increases (Table 6.4b). Therefore the significant yield increase with decreased eyespot severity in cvs Lynx and Soissons (Table 6.2) is not clearly related to the use of fungicides although the effects of cyprodinil or HGCA1 may have contributed, especially on Soissons.

Quantifiable amounts of DNA of *Tapesia yallundae* were found on all cultivars at GS30-31 at Rothamsted in 1997, and the amounts of DNA were greatest in cvs Brigadier and Soissons (Table 6.4a). Eyespot was decreased significantly on cv. Brigadier by prochloraz or cyprodinil, on Mercia by cyprodinil and on Soissons by prochloraz, cyprodinil or flusilazole (Table 6.4b). There were no associated increases in grain yield. Therefore the significant yield increase with decreased eyespot severity in cv. Mercia (Table 6.2) is not clearly related to the use of fungicides although the effect of cyprodinil may have contributed.

Over all cultivars, quantifiable amounts of DNA of *Rhizoctonia cerealis* were found up to GS31 at Harper Adams and Rothamsted in 1998 and at all sites in 1999 (Table 6.5a). Little sharp eyespot developed subsequently at Harper Adams and the disease at this site is not considered further. At Morley, no sharp eyespot was identified and no quantifiable amounts of

DNA of *R. cerealis* were found in early samples in 1997 and 1998. Sharp eyespot developed subsequently here and was usually decreased by azoxystrobin (Table 6.5b). Greatest yield increases occurred with azoxystrobin and in one case (1998) this was associated with decreased sharp eyespot. At Rothamsted, decreases in sharp eyespot with azoxystrobin in 1997 and 1998 were associated with significant increases in grain yield. This is consistent with the significant regression of grain yield on sharp eyespot index that occurred only in 1998 (Table 6.1). However, the small sharp eyespot index (Table 6.5a) suggests that this association may be spurious.

Relationships between early incidence of quantifiable *Rhizoctonia cerealis* DNA and subsequent sharp eyespot control will now be considered on individual cultivars for those situations in which significant regressions of yield on disease have already been established.

Quantifiable DNA of *R. cerealis* was found in early samples at Morley in 1999, when no symptoms were recorded, but the amounts in different cultivars did not relate to subsequent incidence of sharp eyespot (Table 6.6a). Sharp eyespot was decreased by azoxystrobin, notably in cv. Abbot (Table 6.6b). The effect in this cultivar may have influenced the significant yield-disease regression (Table 6.2) but the yield response to treatment was not significant. There was quantifiable DNA of *R. cerealis* at Rothamsted in 1998 (Table 6.6a). The amounts of DNA in the early samples did not relate to the amounts of sharp eyespot that developed subsequently in the different cultivars. Sharp eyespot was decreased significantly only by azoxystrobin, in all cultivars except Soissons in 1997 and in Lynx only in 1998 (Table 6.6b). These effects were associated with significant yield increases in cv. Brigadier in 1997 and cv. Lynx in 1998. The effects appear to explain the significant regressions of grain yield on sharp eyespot index (Table 6.2) but, again, the small sharp eyespot indices suggest that the effect may be spurious; it is likely that effects of azoxystrobin other than those on sharp eyespot contributed to the yield increases.

6.2. Discussion

Stem-base diseases were associated with decreased yields in very few instances. Where a regression of yield on disease incidence or severity was significant, the regression accounted for only a small percentage of the variance, suggesting that other factors were contributing.

Cyprodinil, effective in every experiment, often contributed to the yield increases, largely as a result of its effects in decreasing eyespot. However, this was not always related to the presence of quantifiable amounts of DNA of the eyespot pathogens before the fungicide was applied.

Azoxystrobin was the most effective fungicide in increasing yields. It is unlikely to

have contributed to yield increases through its effects on stem-base diseases except, to a small extent, by controlling sharp eyespot. Its effects on sharp eyespot and yield were not related to amounts of DNA of the sharp eyespot pathogen present before the fungicide was applied. There is evidence that some of the effects of azoxystrobin on yield resulted from its effects on decreasing take-all (Jenkyn *et al.*, submitted paper). Take-all was present in most of the second wheat crops used in the experiments and was particularly severe at Harper Adams in 1999, where it caused the very small yields.

We conclude that, where eyespot develops relatively late in winter wheat, as in these experiments, determining amounts of pathogen DNA in the shoot bases does not provide a precise means of assessing risk. It is not possible, therefore, to determine threshold amounts of fungal DNA on which to base a decision to spray. DNA quantification will be useful, when available as a routine test, as a means of determining the extent of early infection in those situations in which symptoms are obscure, as they commonly are. Unlike visual assessments, it can be used on bulked samples rather than on individual plants, provided an adequate sampling procedure was used on the crop. The presence of DNA in amounts that are sufficient to quantify indicate that the infection is extensive.

7. Assessment of the sampling procedure

7.1. Results

The variance components of sampling units were estimated only for disease variates at Rothamsted in the first two samples taken in 1998. The estimated values of the variance components usually decreased with increasing size of the sampling unit. Variability between the smallest sample units (groups of about three plants within plots) was much greater than that between plots (Table 7.1).

7.2. Discussion

REML analysis to compare the variability of differently sized sampling units was done on two occasions. The results suggest that the sampling procedure used (along two parallel zig-zag transects in each plot) was adequate, consistent with experimentation on sampling procedures reported earlier (Parker *et al.*, 1997), and that routine analysis of variance based on plot means is appropriate.

A similar procedure should be adopted for field-scale sampling, ensuring adequate coverage by adjusting the number of sampling points in proportion to the area of the field.

8. Conclusions

1. PCR procedures identified the fungal pathogens associated with symptoms on shoot bases of wheat plants before stem extension and at a time when decisions on fungicide applications need to be made. The symptoms at this time were in many cases difficult to identify and were often identified incorrectly.

PCR on stems of mature wheat plants usually confirmed the visual identification of eyespot and sharp eyespot symptoms and some instances of mis-identification of symptoms were resolved.

Fusarium spp. were scarce and brown foot rot symptoms were associated with *Microdochium nivale*. However, relationships between symptoms and the pathogen, and their significance, are obscure and need further investigation.

A potential for using quantitative PCR in understanding interactions among pathogens and variations in behaviour among different wheat cultivars was identified but not explored.

2. Quantitative PCR clarified the effects of fungicides on stem-base diseases by identifying which pathogens contributed to symptoms and which were controlled. The eyespot pathogens *Tapesia yallundae* (where present) and *T. acuformis* were both controlled by cyprodinil, the most effective eyespot fungicide. Consequently, cyprodinil sometimes contributed to yield increases, especially in cultivars most susceptible to eyespot. Prochloraz was only sometimes effective against eyespot and this was usually associated with the presence of *T. yallundae* and, to some extent, with rainfall events soon after its application. The good performance of azoxystrobin against sharp eyespot and its pathogen, *Rhizoctonia cerealis*, were confirmed but large yield increases suggested that the fungicide had other effects; these were not identified but may have included decreased take-all.

No fungicide effectively or consistently decreased brown foot rot or the pathogen *Microdochium nivale*, whose development may have been associated with that of eyespot in some cases.

3. Quantitative PCR confirmed the earlier development of *T. yallundae* than of *T. acuformis*. Late development of *T. acuformis*, the predominant pathogen in most experiments, may have contributed to the scarcity of effects of fungicides on grain yields. A relationship between cultivar susceptibility to eyespot and to infection by *M. nivale* was indicated. The value of, and potential for, quantitative PCR in etiological and epidemiological studies was further emphasised.

4. Quantitative PCR provided clarification of the causes of symptoms and the extent of infection at early growth stages. However, it is suggested that neither this method nor any other is capable of providing *precise* threshold information to enable decisions to be made on the application of fungicides. This is because of varying rates of disease development after the beginning of stem extension and the absence of a relationship between early amounts of pathogen and ultimate disease severity and yield loss.

Quantitative PCR will provide evidence of extensive infection before the time of fungicide applications (the beginning of stem extension), even when symptoms are obscure because of e.g. mixed infections. In such situations, rarely seen in the experiments described, risk from yield loss will have been correctly identified.

5. A sampling procedure for plants before the time of fungicide applications was based on taking small subsamples from a large number of positions along zig-zag transects. This proved to be adequate for small plots and should be scaled-up for whole-field situations.

Acknowledgements

All the statistical analyses presented here were done by A. D. Todd in the Statistics department at IACR-Rothamsted. M. Scrancher contributed to the DNA analyses at John Innes Centre.

References

Bateman GL (1993) Development of disease symptoms and fungal pathogens on shoot bases in continuous winter wheat, and effects of fungicides. *Plant Pathology* **42**, 595-608.

Bateman GL, Fitt BDL (1991) Effects of fungicides on eyespot in five successive crops of winter wheat in plots with different initial or fungicide-selected populations of *Pseudocercosporella herpotrichoides*. *Crop Protection* **10**, 479-484.

Bateman GL, Goulds A, Ainsley A (1990) Comparison of infection by W-type and R-type isolates of the eyespot pathogen, *Pseudocercosporella herpotrichoides*, in relation to host species, and cultivar, temperature, and watering regime in controlled environments. *Journal of Phytopathology* **129**, 271-282.

Bateman GL, Landau S, Welham SJ (1995) Senstivity to prochloraz in populations of the eyespot fungus, *Pseudocercosporella herpotrichoides*, in relation to fungicide treatments and their efficacy in continuous winter wheat. *Annals of Applied Biology* **126**, 235-247.

Bateman GL, Munnery IC (1995) Development of eyespot and brown foot rot in wheat plants inoculated with mixtures of *Pseudocercosporella herpotrichoides* types and *Fusarium* species. *Journal of Phytopathology* **143**, 147-151.

Burnett FJ, Oxley SJP, Harling R (1992) The use of PCR diagnostics to monitor development of eyespot in winter wheat. *HGCA Report No. 50.*

Cooke BK, Hislop EC, Jordan VWL, Western NM, Herrington RJ (1989) Redistribution of foliar surface deposits of prochloraz by simulated rainfall and the control of eyespot disease of winter wheat. *Crop Protection* **8**, 373-379.

Don RH, Cox PT, Wainwright BJ, Baker K, Mattick JS (1991) 'Touchdown' PCR to circumvent spurious priming during gene amplification. *Nucleic Acids Research* **19,** 4008.

Doohan FM, Parry DW, Jenkinson P, Nicholson P (1998) The use of species-specific PCR-based assays to analyse *Fusarium* ear blight of wheat. *Plant Pathology* **47**, 197-205.

Förster E (1994) An improved general method to generate internal standards for competitive PCR. *Biotechniques* **16,** 18-20.

Goulds A, Fitt BDL (1990) The development of W-type and R-type isolates of *Pseudocercosporella herpotrichoides* on seedling leaf sheaths in winter wheat and winter barley crops. *Journal of Phytopathology* **130**, 161-173.

Goulds A, Fitt BDL (1991) Prediction of eyespot on winter wheat or winter barley inoculated with W-type or R-type isolates of *Pseudocercosporella herpotrichoides*. *Journal of Phytopathology* **132**, 105-115.

Goulds A, Fitt BDL, Polley RW (1988) Eyespot (*Pseudocercosporella herpotrichoides*) epidemiology in relation to prediction of disease severity and yield loss in winter wheat – a review. *Plant Pathology* **37**, 311-328.

Hopwood A, Oldroyd N, Fellows S, Ward R, Owen SA, Sullivan K (1997). Rapid quantification of DNA samples extracted from buccal scrapes prior to DNA profiling. *BioTechniques* **23,** 18-20.

Jørgensen LN, Nielsen BJ (1990) Control of eyespot (*Pseudocercosporella herpotrichoides* (Fron) Deighton) using prochloraz. *Tidsskrift for Planteavl* **94**, 233-239.

Jørgensen LN, Bødker L, Schulz H (1990) Validation of the threshold for eyespot (*Pseudocercosporella herpotrichoides*) in winter wheat and winter rye assessed in spring and July. *Tidsskrift for Planteavl* **94**, 223-232.

Marshall J, Ayres RJ (1986) Timing of prochloraz sprays for control of cereal stem-base diseases. *Proceedings of the British Crop Protection Conference. Pests and Diseases – 1986* **3**, 1185-1192.

Nicholson P, Parry DW (1996) Development and use of a PCR assay to detect *Rizoctonia cerealis* the cause of sharp eyespot in wheat. *Plant pathology* **45**, 872-873.

Nicholson P, Lees AK, Maurin N, Parry DW (1996) Development of a PCR assay to identify and quantify *Microdochium nivale* var. *nivale* and *Microdochium nivale* var. *majus* in wheat. *Physiological and Molecular Plant Pathology* **48**, 257-271.

Nicholson P, Rezanoor HN, Simpson DR, Joyce D (1997) Differentiation and quantification of the cereal eyespot fungi *Tapesia yallundae* and *Tapesia acuformis* using a PCR assay. *Plant Pathology* **46,** 842-856

Nicholson P, Simpson DR, Weston G, Rezanoor HN, Lees AK, Parry DW, Joyce D (1998) Detection and quantification of *Fusarium culmorum* and *Fusarium graminearum* in cereals using PCR assays. *Physiological and Molecular Plant Pathology* **53,** 17-37

Parker SR, Shaw MW, Royle DJ (1997) Measurements of spatial patterns of disease in winter wheat crops and the implications for sampling. *Plant Pathology* **46**, 470-480.

Parry DW, Nicholson P (1996) Development of a PCR assay to detect *Fusarium poae* in wheat. *Plant Pathology* **45**, 383-391.

Scott PR, Hollins TW (1974) Effects of eyespot on the yield of winter wheat. *Annals of Applied Biology* **78**, 269-279.

Turner AS, Lees AK, Rezanoor HN, Nicholson P (1998) Refinement of a PCR-detection of *Fusarium avenaceum* and evidence from DNA marker studies for phenetic relatedness to *Fusarium tricinctum*. *Plant Pathology* **47**, 278-288.

Wales R, Newman BJ, Rose SA, Pappin D, Gray JC (1989). Characterisation of cDNA clones encoding the extrinsic 23 kDa polypeptide of the oxygen evolving complex of photosystem-II in pea. *Plant Molecular Biology* **13,** 573-582.

Zadoks JC, Chang TT, Konzak CF (1974) A decimal code for the growth stages of cereals. *Weed Research* **14**, 415-421.

Table 2.1. *Dates and growth stages (GS) of main husbandry operations, experimental fungicide treatments and plants samples in field experiments on winter wheat at three locations in three cropping seasons*

	Harper Adams			Morley			Rothamsted		
Operation	1996/7	1997/8	1998/9	1996/7	1997/8	1998/9	1996/7	1997/8	1998/9
Seed drilled	18 Oct	20 Oct	6 Oct	4 Oct	29 Sep	9 Oct	9 Oct	10 Oct	12 Oct
Sample	20 Mar (22)	2 Mar (24)	16 Feb (22)	11 Feb (12-22)	17 Feb (22-26)	16 Feb (12-22)	3-5 Mar (22)	24 Feb (23)	16 Feb (22)
Sample	10 Apr (30)	30 Mar (30)	18 Mar (30)	15 Apr (30-31)	6 Apr (31)	7 Apr (30)	7 Apr (30-31)	1 Apr (30)	8 Apr (30-31)
Fungicide treatments	15 Apr	31 Mar	30 Mar	18 Apr	13 Apr	15 Apr	8 Apr	7 Apr	9 Apr
Sample	28 Apr (32)	13 May (37)	4 May (32)	8 May (32-37)	11 May (33-45)	11 May (33-41)	24 Apr (32-33)	7 May (34)	6 May (34)
Sample	22 May (39)	-	-	20 May (37-55)	-	-	28 May (53-57)	-	-
Epoxycon-azole applied	29 May	-	-	23 May	21 May	24 May	30 May	12 May	-
Sample	7 Jul (75)	23 Jun (69)	27 Jul (85)	14 Jul (77-83)	23 Jun (71-75)	23 Jun (71-73)	4 Jul (75-77)	1 Jul (73)	2 Jul (73-77)
Combine harvest	4 Sep	20 Aug	20 Aug	17 Aug	16 Aug	30 Aug	21 Aug	10 Aug	30 Jul

Table 3.1. *Incidence (number of plots out of 20) of DNA of* Tapesia *spp. and incidence of suspected eyespot (logit % plants) in samples taken before application of fungicides, 1997*

	GS22-26			GS30-31		
	TY	TA	Eyespot	TY	TA	Eyespot
Cultivar						
Harper Adams						
LY	0	0	-1.83 (2.0)	0	0	-1.79 (2.2)
BR	0	0	-1.47 (4.5)	0	0	-1.09 (9.8)
ME	0	0	-1.55 (3.8)	0	0	-1.54 (3.9)
SO	0	0	-1.41 (5.2)	0	0	-1.35 (5.8)
SED (57 df)			0.124			0.136
Morley						
LY	0	0	-2.03 (0.1)	0	0	-1.97 (0.3)
BR	0	0	-1.94 (0.4)	0	0	-1.83 (0.9)
ME	0	0	-1.82 (1.0)	0	0	-2.00 (0.2)
SO	0	0	-1.66 (1.9)	0	0	-1.82 (1.0)
SED (57 df)			0.085			0.078
Rothamsted						
LY	0	0	-1.95 (1.5)	16	0	-2.00 (1.3)
BR	0	0	-1.39 (5.4)	19	0	-0.71 (19.0)
ME	0	0	-1.36 (5.7)	18	0	-1.25 (7.1)
SO	0	0	-1.32 (6.2)	20	0	-0.94 (12.9)
SED (73 df)			0.133			0.139

Cultivars: LY, Lynx; BR, Brigadier; ME, Mercia; SO, Soissons.
Fungi: TY, *Tapesia yallundae*,; TA, *T. acuformis*.
Means percentages back-transformed from logits are shown in parentheses.

Table 3.2. *Incidence (number of plots out of 20) of DNA of* Tapesia *spp. and incidence of suspected eyespot (logit % plants) in samples taken before application of fungicides, 1998*

	GS22-26			GS30-31		
	TY	TA	Eyespot	TY	TA	Eyespot
Cultivar						
Harper Adams						
LY	0	0	-	0	19	-
BR	0	0	-	0	15	-
ME	0	0	-	0	18	-
SO	0	0	-	0	18	-
Morley						
LY	0	3	-3.47 (0.1)	0	20	-3.13 (0.2)
BR	0	6	-2.67 (0.5)	1	20	-1.36 (6.2)
ME	0	1	-1.73 (3.1)	0	19[a]	-2.20 (1.2)
SO	0	5	-2.04 (1.7)	2	20	-1.06 (10.6)
SED (57 df)			0.348			0.251
Rothamsted						
LY	0	0	-1.13 (9.5)	0	0	-1.28 (7.2)
BR	0	0	-0.57 (24.3)	2	1	-1.18 (8.7)
ME	0	0	-1.04 (11.1)	3	1	-1.04 (11.2)
SO	0	0	-0.38 (31.8)	1	1	-1.06 (10.8)
SED (73 df)			0.133			0.148

Cultivars: LY, Lynx; BR, Brigadier; ME, Mercia; SO, Soissons.
Fungi: TY, *Tapesia yallundae*,; TA, *T. acuformis*.
[a]out of 19 plots.
-, no symptoms identified.
Means percentages back-transformed from logits are shown in parentheses.

Table 3.3. *Incidence (number of plots out of 20) of DNA of* Tapesia *spp. and incidence of suspected eyespot (logit % plants) in samples taken before application of fungicides, 1999*

	GS12-26			GS30-31		
	TY	TA	Eyespot	TY	TA	Eyespot
Cultivar						
Harper Adams						
LY	3	20	-	5	20	-1.61 (3.3)
AB	7	20	-	4	20	-0.16 (41.4)
ME	6	20	-	7	20	-0.80 (16.2)
SO	6	20	-	7	20	0.11 (44.2)
SED (57 df)			-			0.134
Morley						
LY	0	0	-	4	0	-1.97 (1.4)
AB	0	0	-	2	0	-1.80 (2.2)
ME	0	0	-	0	0	-1.92 (1.6)
SO	0	0	-	2	0	-1.74 (2.5)
SED (57 df)						0.097
Rothamsted						
LY	13	8	-1.51 (4.2)	8	16	-0.96 (12.3)
AB	19	14	0.46 (71.1)	20	19	0.64 (77.9)
ME	17	13	0.28 (63.2)	19	20	0.21 (59.7)
SO	19	14	0.61 (76.7)	19	20	0.42 (69.4)
SED (73 df)			0.109			0.113

Cultivars: LY, Lynx; AB, Abbot; ME, Mercia; SO, Soissons.
Fungi: TY, *Tapesia yallundae*,; TA, *T. acuformis.*
-, no symptoms identified.
Means percentages back-transformed from logits are shown in parentheses.

Table 3.4. *Regressions of eyespot indices on amounts of DNA of* Tapesia *spp. in wheat stem bases at, Harper Adams*

Cultivar	Mean index	Regression equation	Variance accounted for (%)[a]	VR[a]	*P*
GS75, 1997. Eyespot index on Tapesia acuformis *DNA*					
All	10.8	y = 0.64 + 5.375x	56.0	101.47	<0.001
Lynx	4.0	y = 2.90 + 1.770x	-	0.60	0.4
Brigadier	12.1	y = 0.85 + 4.570x	47.2	18.02	<0.001
Mercia	11.1	y = -0.61 + 7.201x	72.9	52.19	<0.001
Soissons	16.2	y = 0.31 + 5.500x	46.5	17.53	<0.001
Data from all cultivars represent a single line					
GS69, 1998. Eyespot index on Tapesia acuformis *DNA*					
All	69.9	y = 20.9 + 0.182x	0.6	1.47	0.2
GS85, 1999.					
Eyespot index on Tapesia yallundae *DNA*					
All	27.8	y = 25.00+ 0.013x	0.5	1.39	0.2
Lynx	26.0	y = 20.67 + 0.068x	-	0.89	0.4
Abbot	32.5	y = 29.00 + 0.015x	-	0.58	0.5
Mercia	33.2	y = 33.00 + 0.001x	-	0.00	1.0
Soissons	19.4	y = 9.33 + 0.034x	22.1	6.41	0.02
Overall regression not significant					
Eyespot index on Tapesia acuformis *DNA*					
All	27.8	y = 21.67 + 0.018x	5.4	5.47	0.02
Lynx	26.0	y = 18.67 + 0.043x	7.4	2.52	0.1
Abbot	32.5	y = 21.67 + 0.037x	10.2	3.15	0.09
Mercia	33.2	y = 25.67 + 0.016x	1.2	1.23	0.3
Soissons	19.4	y = 14.00 + 0.015x	-	0.95	0.3
Cultivar regression lines are parallel					
Eyespot index on Tapesia yallundae + T. acuformis *DNA*					
All	27.8	y = 21.33 + 0.012x	4.6	4.84	0.03
Lynx	26.0	y = 17.00 + 0.030x	5.7	2.16	0.2
Abbot	32.5	y = 20.67 + 0.023x	9.3	2.95	0.1
Mercia	33.2	y = 26.33 + 0.010x	-	0.74	0.4
Soissons	19.4	y = 5.33 + 0.021x	19.1	5.48	0.03
Cultivar regression lines are parallel					

[a]Df = 78 for all cultivars and df = 18 for individual cultivars.
-, residual variance exceeds the variance of the response variate.
Where no regressions are significant, those for individual cultivars are not shown.

Table 3.5. *Regressions of eyespot indices on amounts of DNA of* Tapesia *spp. in wheat stem bases at Morley*

Cultivar	Mean index	Regression equation	Variance accounted for (%)	VR[a]	*P*
Eyespot index on Tapesia acuformis *DNA*					
GS77-83, 1997					
All	18.7	y = 12.03 + 1.987x	34.7	43.05	<0.001
Lynx	8.5	y = 5.77 + 2.670x	3.5	1.70	0.2
Brigadier	26.7	y = 20.62 + 1.277x	9.7	3.05	0.1
Mercia	16.2	y = 13.30 + 0.977x	14.2	4.15	0.06
Soissons	23.5	y = 15.78 + 1.636x	31.3	9.68	0.006
Cultivar regression lines are parallel					
GS71-75, 1998					
All	28.5	y = 17.7 + 3.579x	44.4	64.02	<0.001
Lynx	14.3	y = 9.06 + 4.680x	45.9	17.13	<0.001
Brigadier	37.8	y = 28.93 + 2.783x	27.8	8.33	0.01
Mercia	28.3	y = 19.01 + 2.500x	30.2	9.22	0.007
Soissons	33.4	y = 20.82 + 3.124x	52.5	22.00	<0.001
Cultivar regression lines are parallel					

[a]Df = 78 for all cultivars and df = 18 for individual cultivars.

Table 3.6. *Regressions of eyespot indices on amounts of DNA of* Tapesia *spp. in wheat stem bases a GS71-73, Morley1999*

Cultivar	Mean index	Regression equation	Variance accounted for (%)	VR[a]	*P*
Eyespot index on Tapesia yallundae *DNA*					
All	18.7	y = 13.67 + 0.738x	12.2	12.00	<0.001
Lynx	13.9	y = 12.90 + 0.219x	-	0.20	0.7
Abbot	21.5	y = 15.45 + 0.814x	9.1	2.90	0.1
Mercia	11.4	y = 7.34 + 0.585x	31.6	9.78	0.006
Soissons	27.9	y = 23.75 + 0.515x	0.9	1.17	0.3
Cultivar regression lines are parallel					
Eyespot index on Tapesia acuformis *DNA*					
All	18.7	y = 12.72 + 0.984x	41.7	57.44	<0.001
Lynx	13.9	y = 8.41 + 2.302x	29.2	8.83	0.008
Abbot	21.5	y = 12.46 + 1.562x	35.7	11.56	0.003
Mercia	11.4	y = 4.45 + 2.276x	60.9	30.62	<0.001
Soissons	27.9	y = 20.92 + 0.547x	26.8	7.96	0.01
Cultivars have different regression lines					
Eyespot index on Tapesia yallundae + T. acuformis *DNA*					
All	18.7	y = 9.67 + 0.701x	42.2	58.59	<0.001
Lynx	13.9	y = 10.35 + 0.506x	4.7	1.94	0.2
Abbot	21.5	y = 12.32 + 0.694x	25.3	7.43	0.01
Mercia	11.4	y = 5.70 + 0.570x	47.3	18.03	<0.001
Soissons	27.9	y = 17.28 + 0.503x	31.1	9.57	0.006
Cultivar regression lines are parallel					

[a]Df = 78 for all cultivars and df = 18 for individual cultivars.
-, residual variance exceeds the variance of the response variate.

Table 3.7. *Regressions of eyespot indices on amounts of DNA of* Tapesia *spp. in wheat stem bases at GS 75-77, Rothamsted 1997*

Cultivar	Mean index	Regression equation	Variance accounted for (%)	VR[a]	*P*
Eyespot index on Tapesia yallundae *DNA*					
All	15.7	y = 6.08 + 1.379x	52.5	38.62 (33)	<0.001
Lynx	7.4	y = 4.02 + 2.620x	13.9	2.94 (11)	0.1
Brigadier	20.0	y = 11.90 + 1.392x	70.1	5.69 (1)	0.3
Mercia	12.4	y = 1.31 + 1.616x	69.8	21.76 (8)	0.002
Soissons	22.8	y = 14.21 + 0.728x	2.9	1.24 (7)	0.3
Data from all cultivars represent a single line.					
Eyespot index on Tapesia acuformis *DNA*					
All	15.7	y = 5.91 + 4.342x	52.9	39.22 (33)	<0.001
Lynx	7.4	y = 1.46 + 7.730x	79.9	48.63 (11)	<0.001
Brigadier	20.0	y = 51.90 + 3.000x	-	0.51 (1)	0.6
Mercia	12.4	y = 2.98 + 3.644x	71.5	23.54 (8)	0.001
Soissons	22.8	y = 12.97 + 3.290x	25.4	3.73 (7)	0.1
Cultivars have different regression lines					
Eyespot index on Tapesia yallundae *plus* T. acuformis *DNA*					
All	15.7	y = 3.96 + 1.262x	64.1	61.58 (33)	<0.001
Lynx	7.4	y = -0.06 + 2.897x	79.9	49.70 (11)	0.004
Brigadier	20.0	y = 8.80 + 1.188x	18.3	1.45 (1)	0.4
Mercia	12.4	y = 0.68 + 1.253x	80.1	37.30 (8)	<0.001
Soissons	22.8	y = 7.08 + 1.045x	23.0	3.39 (7)	0.1
Data from all cultivars represent a single line.					

[a]Degrees of freedom are shown in parentheses.
-, residual variance exceeds the variance of the response variate.

Table 3.8. *Regressions of eyespot indices on amounts of DNA of* Tapesia *spp. in wheat stem bases at GS73, Rothamsted 1998*

Cultivar	Mean index	Regression equation	Variance accounted for (%)	VR[a]	*P*
Eyespot index on Tapesia yallundae *DNA*					
All	37.8	y = 21.9 + 0.645x	51.9	82.90	<0.001
Lynx	27.7	y = 14.0 + 0.997x	59.9	29.38	<0.001
Brigadier	40.7	y = 19.7 + 1.015x	71.7	43.99	<0.001
Mercia	38.9	y = 26.0 + 0.447x	34.9	10.67	0.005
Soissons	44.0	y = 21.0 + 0.660x	47.7	18.30	<0.001
Cultivar regression lines are parallel					
Eyespot index on Tapesia acuformis *DNA*					
All	37.7	y = 24.0 + 7.74x	46.5	66.93	<0.001
Lynx	27.7	y = 14.1 + 10.02x	57.3	26.48	<0.001
Brigadier	40.7	y = 27.7 + 7.81x	45.5	15.21	0.001
Mercia	38.9	y = 25.8 + 6.82x	31.2	9.14	0.008
Soissons	44.0	y = 28.8 + 6.01x	43.2	15.42	<0.001
Cultivar regression lines are parallel					
Eyespot index on Tapesia yallundae + T. acuformis *DNA*					
All	37.7	y = 21.1 + 0.629x	54.6	92.48	<0.001
Lynx	27.7	y = 13.8 + 0.924x	60.9	30.55	<0.001
Brigadier	40.7	y = 19.1 + 0.961x	73.9	49.04	<0.001
Mercia	38.9	y = 24.8 + 0.457x	38.3	12.19	0.003
Soissons	44.0	y = 20.5 + 0.630x	50.4	20.28	<0.001
Cultivar regression lines are parallel					

[a]Df = 78 for all cultivars and df = 18 for individual cultivars.

Table 3.9. *Regressions of eyespot indices on amounts of DNA of* Tapesia *spp. in wheat stem bases at GS73-77, Rothamsted 1999*

Cultivar	Mean index	Regression equation	Variance accounted for (%)	VR[a]	*P*
Eyespot index on Tapesia yallundae *DNA*					
All	45.7	y = 23.7 + 2.702x	35.5	44.49	<0.001
Lynx	36.7	y = 25.1 + 2.920x	8.4	2.75	0.1
Abbot	43.7	y = 18.6 + 2.985x	32.8	10.26	0.005
Mercia	45.6	y = 18.6 + 2.770x	27.7	8.29	0.01
Soissons	56.8	y = 27.2 + 2.810x	26.1	7.72	0.01
Data from all cultivars represent a single line					
Eyespot index on Tapesia acuformis *DNA*					
All	45.7	y = 25.5 + 2.874x	27.4	30.88	<0.001
Lynx	36.7	y = 18.3 + 2.651x	29.6	9.01	0.008
Abbot	43.7	y = 19.4 + 3.620x	50.4	20.31	<0.001
Mercia	45.6	y = 28.4 + 2.310x	14.1	4.11	0.06
Soissons	56.8	y = 38.3 + 2.682x	25.5	7.49	0.01
Cultivar regression lines are parallel					
Eyespot index on Tapesia yallundae + T. acuformis *DNA*					
All	45.7	y = 12.3 + 2.197x	50.6	81.92	<0.001
Lynx	36.7	y = 14.4 + 2.043x	31.4	9.68	0.006
Abbot	43.7	y = 12.8 + 2.044x	52.3	21.83	<0.001
Mercia	45.6	y = 10.2 + 2.056x	36.6	11.97	0.003
Soissons	56.8	y = 9.6 + 2.690x	56.5	25.69	<0.001
Data from all cultivars represent a single line					

[a]Df = 78 for all cultivars and df = 18 for individual cultivars.

Table 3.10. *Incidence (number of plots out of 20; determined by quantitative PCR) of DNA of* Rhizoctonia cerealis *and incidence of suspected sharp eyespot (logit % plants) in samples taken before application of fungicides*

	GS22-26, 1997		GS30-31, 1997		GS22-26, 1998		GS30-31, 1998		GS22-26, 1999		GS30-31, 1999	
Cv.	RC	Sharp eyespot	RC	Sharp eyespot	RC	Sharp eyespot	RC	Sharp eyespot	RC	Sharp eyespot	RC	Sharp eyespot
Harper Adams												
LY	0	-2.03 (1.2)	0	-2.03 (1.2)	13	-0.88 (14.7)	12	-0.81 (16.4)	19	-	19	-1.31 (6.3)
B/A	0	-1.82 (2.1)	0	-1.89 (1.7)	3	-1.34 (6.4)	10	-1.20 (8.3)	17	-	18	-1.08 (9.9)
ME	0	-1.84 (1.9)	0	-1.86 (1.9)	10	-0.75 (18.2)	11	-0.66 (21.1)	15	-	17	-1.00 (4.2)
SO	0	-1.94 (1.5)	0	-1.86 (1.9)	3	-1.29 (7.1)	10	-1.25 (7.5)	20	-	16	-1.51 (4.2)
SED (57 df)		0.076		0.080		0.169		0.146				0.130
Morley												
LY	0	-	0	-	4	-	16	-	0	-	0	-
B/A	0	-	0	-	1	-	16	-	0	-	0	-
ME	0	-	0	-	3	-	12	-	0	-	0	-
SO	0	-	0	-	2	-	15	-	0	-	0	-
Rothamsted												
LY	0	-1.77 (2.3)	0	-1.53 (4.0)	5	-0.79 (17.2)	11	-0.86 (15.2)	15	-1.60 (2.4)	17	-0.77 (17.1)
B/A	0	-1.56 (3.7)	0	-1.28 (6.7)	14	-0.52 (26.2)	13	-1.26 (7.4)	12	-1.56 (3.7)	19	-1.04 (10.6)
ME	0	-1.62 (3.3)	0	-1.66 (3.0)	6	-0.95 (13.0)	14	-1.18 (8.7)	10	-1.24 (7.3)	15	-1.06 (10.3)
SO	0	-1.67 (2.9)	0	-1.43 (4.9)	12	-0.88 (14.7)	18	-1.26 (7.4)	11	-1.49 (4.3)	16	-1.01 (11.2)
SED (73 df)		0.134		0.134		0.131		0.165		0.154		0.122

Cultivars: LY, Lynx; B/A, Brigadier (1997, 1998), Abbot (1999); ME, Mercia; SO, Soissons.
RC, *Rhizoctonia cerealis.*
-, no symptoms identified. Percentages back-transformed from logits are shown in parentheses.

Table 3.11. *Regressions of sharp eyespot indices on amounts of DNA of* Rhizoctonia cerealis *in wheat stem bases at Harper Adams*

Cultivar	Mean index	Regression equation	Variance accounted for (%)	VR[a]	*P*
GS69, 1998					
All	21.3	y = 0.42 + 0.775x	29.1	33.42	<0.001
Lynx	29.7	y = 7.36 + 0.233x	1.2	1.24	0.3
Brigadier	9.2	y = -2.37 + 0.968x	62.9	33.26	<0.001
Mercia	41.5	y = 1.81 + 1.173x	51.6	21.29	<0.001
Soissons	5.0	y = 1.68 - 0.001x	-	0.00	1.0
All regression lines significantly different					
GS85, 1999					
All	34.9	y = -0.38 + 0.012x	18.0	18.29	<0.001
Lynx	25.7	y = -0.21 + 0.009x	8.6	2.79	0.1
Abbot	64.3	y = -1.96 + 0.030x	39.2	13.27	0.002
Mercia	21.0	y = 0.12 + 0.005x	2.7	1.52	0.2
Soissons	25.2	y = 0.21 + 0.004x	1.9	1.38	0.3
All regression lines significantly different					

[a]Df = 78 for all cultivars and df = 18 for individual cultivars.
-, residual variance exceeds the variance of the response variate.

Table 3.12 *Regressions of sharp eyespot incidence (% plants) on amounts of DNA of* Rhizoctonia cerealis *in wheat stem bases at Morley*

Cultivar	Mean % plants	Regression equation	Variance accounted for (%)	VR[a]	*P*
GS77-83, 1997					
All	11.6	y = 3.28 + 2.832x	29.5	34.03	<0.001
Lynx	9.0	y = -6.36 + 7.220x	43.9	15.89	<0.001
Brigadier	13.5	y = 7.34 + 1.960x	8.0	2.66	0.1
Mercia	6.7	y = 3.09 + 1.720x	-	0.89	0.4
Soissons	17.0	y = 8.48 + 1.982x	19.5	5.60	1.0
Data from all cultivars represent a single line					
GS71-75, 1998					
All	15.4	y = 10.66 + 0.906x	19.9	20.62	<0.001
Lynx	12.0	y = 5.85 + 0.965x	27.3	8.14	0.01
Brigadier	16.4	y = 14.96 + 0.570x	-	0.16	0.7
Mercia	15.7	y = 10.53 + 0.750x	29.0	8.77	0.008
Soissons	17.7	y = 6.20 + 2.116x	61.4	31.21	<0.001
Cultivar regression lines are parallel					
GS71-73, 1999					
All	11.9	y = 6.44 + 0.378x	19.2	19.81	<0.001
Lynx	8.5	y = 6.63 + 0.130x	-	0.28	0.6
Abbot	15.3	y = 8.28 + 0.346x	18.7	5.37	0.03
Mercia	10.1	y = 3.70 + 0.829x	36.7	12.03	0.003
Soissons	13.8	y = 9.08 + 0.300x	14.1	4.12	0.06
Data from all cultivars represent a single line					

[a]Df = 78 for all cultivars and df = 18 for individual cultivars.
-, residual variance exceeds the variance of the response variate.

Table 3.13. *Regressions of sharp eyespot indices on amounts of DNA of* Rhizoctonia cerealis *in wheat stem bases at, Rothamsted*

Cultivar	Mean index	Regression equation	Variance accounted for (%)	VR[a]	*P*
GS75-77, 1997					
All	7.4	y = 5.03 + 1.226x	26.1	16.55 (43)	<0.001
Lynx	7.1	y = 5.39 + 1.311x	23.2	4.93 (12)	0.05
Brigadier	10.3	y = 7.05 + 0.524x	-	0.76 (9)	0.4
Mercia	9.0	y = 4.92 + 1.733x	38.9	6.73 (8)	0.03
Soissons	3.2	y = 2.04 + 1.518x	52.1	10.79 (8)	0.01
Data from all cultivars represent a single line					
GS73, 1998					
All	9.7	y = 4.340x – 1.46	63.3	130.15 (74)	<0.001
Lynx	15.6	y = – 0.21 + 4.841x	62.3	30.71 (17)	<0.001
Brigadier	6.2	y = – 0.71 + 2.908x	50.9	18.61 (16)	<0.001
Mercia	11.6	y = 0.53 + 3.694x	54.4	22.44 (17)	<0.001
Soissons	5.6	y = – 1.24 + 3.726x	58.9	28.26 (18)	<0.001
Cultivar regression lines are parallel					
GS73-77, 1999					
All	6.5	y = 1.87 + 1.503x	38.1	49.71 (78)	<0.001
Lynx	6.6	y = 3.25 + 1.067x	20.8	5.99 (18)	0.03
Abbot	8.1	y = 1.33 + 1.699x	38.6	12.96 (18)	0.002
Mercia	7.2	y = 1.78 + 1.951x	50.9	20.73 (18)	<0.001
Soissons	4.1	y = 1.55 + 1.056x	23.7	6.89 (18)	0.02
Data from all cultivars represent a single line					

[a]Degrees of freedom are shown in parentheses.
-, residual variance exceeds the variance of the response variate.

Table 3.14. *Incidence (number of plots out of 20, determined by quantitative PCR) of DNA of* Microdochium nivale. *and incidence of suspected brown foot rot (% plants) in samples taken before application of fungicides, 1997*

	GS 22-26			GS 30-31		
	MNN	MNM	Brown foot rot	MNN	MNM	Brown foot rot
Cultivar						
Harper Adams						
LY	0	0	-1.13 (8.9)	0	0	-1.00 (11.5)
BR	0	0	-1.05 (10.4)	0	0	-0.95 (12.6)
ME	0	0	-0.92 (13.1)	0	0	-1.16 (8.5)
SO	0	0	-0.78 (17.0)	0	0	-1.13 (9.0)
SED (57 df)			0.121			0.137
Morley						
LY	20	0	-	20	0	-1.74 (1.4)
BR	20	0	-	20	0	-1.63 (2.2)
ME	20	0	-	20	0	-1.80 (1.1)
SO	20	0	-	20	0	-1.83 (0.9)
SED (57 df)						0.111
Rothamsted						
LY	0	0	-0.92 (13.3)	20	0	-0.60 (22.6)
BR	0	0	-1.02 (11.0)	20	0	-0.74 (18.0)
ME	0	0	-1.13 (9.0)	20	0	-0.65 (21.0)
SO	0	0	-1.10 (9.5)	20	0	-0.45 (28.3)
SED (73 df)			0.099			0.098

Cultivars: LY, Lynx; BR, Brigadier; ME, Mercia; SO, Soissons.
Fungi: MNN, *Microdochium nivale* var. *nivale*; MNM, *M. nivale* var. *majus*.
Analyses had 57 df where subsequent fungicide treatments were used as a factor, otherwise df = 73, which excluded the fungicide factor and allowed for missing plots.

Table 3.15. *Incidence (number of plots out of 20) of DNA of* Microdochium nivale. *and incidence of suspected brown foot rot (% plants) in samples taken before application of fungicides, 1998*

	GS 22-26			GS 30-31		
	MNN	MNM	Brown foot rot	MNN	MNM	Brown foot rot
Cultivar						
Harper Adams						
LY	3	0	-1.41 (5.7)	1	7	-1.59 (4.0)
BR	16	1	-0.32 (34.7)	7	19	0.03 (51.3)
ME	3	0	-1.48 (4.9)	1	8	-1.42 (5.5)
SO	15	0	0.07 (53.5)	6	19	0.38 (68.0)
SED (57 df)			0.198			0.157
Morley						
LY	18[a]	11	-2.46 (0.7)	20	5	-2.01 (1.4)
BR	20	16	-1.63 (3.7)	20	15	-2.16 (1.3)
ME	19[b]	10	-2.01 (1.8)	19[b]	6	-2.32 (1.0)
SO	20	17	-1.86 (2.4)	20	13	-1.45 (5.2)
SED (57 df)			0.317			0.285
Rothamsted						
LY	15	7	-0.95 (13.0)	11	11	-0.63 (22.1)
BR	20	16	-0.31 (32.8)	18	18	0.41 (69.3)
ME	14	8	-0.92 (13.8)	17	16	-0.61 (22.9)
SO	18	16	-0.20 (40.0)	20	20	0.22 (60.9)
SED (73 df)			0.100			0.089

Cultivars: LY, Lynx; BR, Brigadier; ME, Mercia; SO, Soissons.
Fungi: MNN, *Microdochium nivale* var. *nivale*; MNM, *M. nivale* var. *majus*.
[a]out of 18 plots.
[b]out of 19 plots.

Table 3.16. *Incidence (number of plots out of 20) of DNA of* Microdochium nivale. *and incidence of suspected brown foot rot (% plants) in samples taken before application of fungicides, 1999*

	GS 12-26			GS 30-31		
	MNN	MNM	Brown foot rot	MNN	MNM	Brown foot rot
Cultivar						
Harper Adams						
LY	9	3	-0.58 (23.4	9	14	-1.00 (11.4)
AB	5	1	0.16 (57.5)	7	15	-0.90 (13.8)
ME	17	4	-0.08 (45.5)	13	17	-0.43 (29.1)
SO	6	2	0.51 (73.0)	9	12	-0.35 (32.7)
SED (57 df)			0.086			0.120
Morley						
LY	13	10	-1.87 (1.8)	11	14	-1.51 (4.1)
AB	9	14	-1.91 (1.6)	5	13	-1.67 (2.9)
ME	14	19	-1.62 (3.3)	10	8	-1.24 (7.2)
SO	14	16	-1.76 (2.4)	5	14	-1.24 (7.3)
SED (57 df)			0.102			0.111
Rothamsted						
LY	0	14	-0.69 (19.5)	0	20	-0.35 (32.6)
AB	0	11	-1.47 (4.5)	0	16	-1.28 (6.7)
ME	0	15	-1.08 (9.9)	0	20	-0.63 (21.7)
SO	0	13	-1.26 (7.0)	0	17	-0.82 (15.6)
SED (73 df)			0.121			0.107

Cultivars: LY, Lynx; AB, Abbot; ME, Mercia; SO, Soissons.
Fungi: MNN, *Microdochium nivale* var. *nivale*; MNM, *M. nivale* var. *majus*.

Table 3.17. *Regressions of brown foot rot on fungal DNA concentrations in wheat stem bases in summer at Harper Adams*

Cultivar	Mean index/%	Regression equation	Variance accounted for (%)	VR[a]	*P*
Percentage plants with brown foot rot on Microdochium nivale *var.* nivale *DNA at GS75, 1997*					
All	52.4	y = 45.7 + 11.80x	5.0	5.05 (76)	0.03
Lynx	55.8	y = 46.7 + 18.97x	16.6	4.78 (18)	0.04
Brigadier	61.2	y = 60.6 + 0.60x	-	0.00 (17)	1.0
Mercia	48.7	y = 36.9 + 18.04x	17.9	5.13 (18)	0.04
Soissons	43.8	y = 33.2 + 17.00x	7.2	2.40 (17)	0.1
Cultivar regression lines are parallel					
Brown foot rot index on M. nivale *var.* nivale *DNA, GS69, 1998*					
All	69.7	y = 22.8 + 0.072x	-	0.28 (78)	0.6
Lynx	65.0	y = 19.0 + 1.665x	10.7	3.28 (18)	0.09
Brigadier	73.0	y = 18.0 + 0.799x	33.7	10.67 (18)	0.004
Mercia	76.8	y = 23.6 + 1.600x	-	0.85 (18)	0.4
Soissons	64.0	y = 23.0 - 0.187x	0.5	1.10 (18)	0.3
All regression lines significantly different					
Brown foot rot index on M. nivale *var.* majus *at GS85, 1999*					
All	10.0	y = 10.4 – 0.006x	-	0.30 (78)	0.6
Lynx	6.0	y = 3.8 + 0.040x	19.1	5.49 (18)	0.03
Abbot	11.9	y = 11.6 + 0.006x	-	0.04 (18)	0.8
Mercia	10.9	y = 14.4 – 0.030x	14.2	4.14 (18)	0.06
Soissons	11.0	y = 12.1 – 0.013x	-	0.44 (18)	0.5
No significant regression over all cultivars					
Brown foot rot index on M. nivale *var.* nivale *at GS85, 1999*					
All	10.0	y = 9.95 + 0.001x	-	0.00 (78)	1.0

[a]Degrees of freedom are shown in parentheses.
-, residual variance exceeds the variance of the response variate.
Where no regressions are significant, those for individual cultivars are not shown.

Table 3.18. *Regressions of percentage plants with brown foot rot on fungal DNA concentrations in wheat stem bases in summer at Morley*

Cultivar	Mean %	Regression equation	Variance accounted for (%)	VR[a]	*P*
Percentage plants with brown foot rot on Microdochium nivale *var.* nivale *DNA at GS 77-83, 1997*					
All	71.8	y = 68.14 + 1.24x	-	0.29	0.3
Lynx	69.2	y = 69.14 + 0.01x	-	0.00	1.0
Brigadier	77.3	y = 73.64 + 1.23x	-	0.28	0.6
Mercia	70.5	y = 68.10 + 0.84x	-	0.07	0.8
Soissons	70.1	y = 61.23 + 3.00x	1.1	1.21	0.3
No significant regression over all cultivars					
Percentage plants with brown foot rot on M. nivale *var.* nivale *DNA at GS73-75, 1998*					
All	23.2	y = 23.2 – 0.026x	-	0.00	1.0
Lynx	25.2	y = 17.8 + 19.31x	28.5	8.58	0.009
Brigadier	19.8	y = 18.7 + 0.75x	-	0.45	0.5
Mercia	28.3	y = 28.1 + 0.40x	-	0.01	0.9
Soissons	19.6	y = 20.4 – 0.80x	-	0.31	0.6
All regression lines significantly different					
Percentage plants with brown foot rot on M. nivale *var.* nivale and M. nivale *var.* majus *DNA at GS73-75, 1998*					
All	23.2	y = 20.8 + 0.396x	0.9	1.73	0.2
Lynx	25.2	y = 18.8 + 1.373x	10.4	3.21	0.09
Brigadier	19.8	y = 11.8 + 0.976x	13.9	4.08	0.06
Mercia	28.3	y = 19.8 + 2.446x	21.9	6.33	0.02
Soissons	19.6	y = 15.0 + 0.569x	1.2	1.24	0.3
No significant regression					
Percentage plants with brown foot rot on M. nivale *var.* nivale *DNA at GS71-73, 1999*					
All	35.7	y = 33.0 + 0.459x	1.6	2.28	0.1
Lynx	36.7	y = 37.0 – 0.631x	-	0.00	1.0
Abbot	23.1	y = 21.3 + 0.597	-	0.00	0.6
Mercia	52.7	y = 52.7 + 0.012x	-	0.00	1.0
Soissons	30.2	y = 25.9 + 0.564x	16.7	4.80	0.04
Cultivar regression lines are parallel					

[a]Df = 78 for all cultivars and df = 18 for individual cultivars.
-, residual variance exceeds the variance of the response variate.

Table 3.19. *Regressions of brown foot rot indices on fungal DNA concentrations in wheat stem bases at GS 75-77, Rothamsted 1997*

Cultivar	Mean index	Regression equation	Variance accounted for (%)	VR[a]	*P*
Brown foot rot index on Microdochium nivale *var.* majus *DNA*					
All	6.2	y = 3.86 + 3.08x	10.0	5.89 (43)	0.02
Lynx	1.5	y = -0.44 + 13.88x	8.4	2.12 (12)	0.2
Brigadier	2.1	y = 2.78 - 7.80x	16.2	2.93 (9)	0.1
Mercia	11.1	y = 7.20 + 4.32x	34.6	5.76 (8)	0.04
Soissons	10.1	y = 9.48 - 0.42x	-	0.03 (8)	0.9
Cultivar regression lines are parallel					
Brown foot rot index on M. nivale *var.* nivale *DNA*					
All	6.2	y = 4.34 + 2.36x	7.6	4.62 (43)	0.04
Lynx	1.5	y = 1.45 - 2.26x	-	0.61 (12)	0.5
Brigadier	2.1	y = 1.51 + 0.65x	-	0.32 (9)	0.6
Mercia	11.1	y = 8.12 + 2.14x	32.3	5.30 (8)	0.05
Soissons	10.1	y = 9.68 - 5.30x	-	0.11 (8)	0.8
Cultivar regression lines are parallel					
Brown foot rot index on M. nivale *var.* majus *plus* M. nivale *var.* nivale *DNA*					
All	6.2	y = 3.81 + 1.87x	13.0	7.58 (43)	0.009
Lynx	1.5	y = 1.47 - 1.13x	-	0.14 (12)	0.7
Brigadier	2.1	y = 1.56 + 0.27x	-	0.05 (9)	0.8
Mercia	11.1	y = 7.79 + 1.45x	33.9	5.62 (8)	0.05
Soissons	10.1	y = 9.63 - 0.55x	-	0.05 (8)	0.8
Cultivar regression lines are parallel					

[a]Degrees of freedom are shown in parentheses.
-, residual variance exceeds the variance of the response variate.

Table 3.20. *Regressions of brown foot rot indices on fungal DNA concentrations in wheat stem bases GS 73, Rothamsted 1998*

Cultivar	Mean index	Regression equation	Variance accounted for (%)	VR[a]	*P*
Brown foot rot index on Microdochium nivale *var.* majus *DNA*					
All	8.3	y = 10.10 – 0.843x	5.7	5.63 (75)	0.02
Lynx	8.4	y = 8.98 – 0.371x	-	0.17 (18)	0.7
Brigadier	7.2	y = 7.77 – 0.324x	-	0.28 (16)	0.6
Mercia	12.1	y = 15.70 – 2.073x	29.3	8.45 (17)	0.01
Soissons	5.4	y = 3.51 + 0.619x	3.1	1.61 (18)	0.2
All regression lines significantly different					
Brown foot rot index on M. nivale *var.* nivale *DNA*					
All	8.3	y = 9.17 – 1.38x	0.0	1.02 (75)	0.3
Brown foot rot index on M. nivale *var.* majus *and* M. nivale *var.* nivale *DNA*					
All	8.3	y = 10.34 – 0.723x	5.5	5.38 (75)	0.02
Lynx	8.4	y = 9.42 – 0.470x	-	0.28 (18)	0.6
Brigadier	7.2	y = 7.04 – 0.029x	-	0.00 (16)	1.0
Mercia	12.1	y = 16.32 – 1.901x	29.7	8.60 (17)	0.009
Soissons	5.4	y = 3.06 + 0.613x	5.0	2.01 (18)	0.2
All regression lines significantly different					

[a]Degrees of freedom are shown in parentheses.
-, residual variance exceeds the variance of the response variate.
Where no regressions are significant, only the regression for all cultivars is shown.

Table 3.21. *Regressions of brown foot rot indices on fungal DNA concentrations in wheat stem bases GS 73-77, Rothamsted 1999*

Cultivar	Mean index	Regression equation	Variance accounted for (%)	VR[a]	*P*
Brown foot rot index on Microdochium nivale *var.* majus *DNA*					
All	12.4	y = 12.03 + 0.213x	-	0.12	0.7
No significant regression over all cvs but there was a significant (*P*=0.04) negative regression for cv. Lynx					
Brown foot rot index on M. nivale *var.* nivale *DNA*					
All	12.4	y = 10.90 + 0.787x	4.3	4.51	0.04
Lynx	15.5	y = 14.76 + 0.780x	-	0.29	0.6
Abbot	10.8	y = 12.73 – 1.079x	2.6	1.51	0.2
Mercia	18.5	y = 15.90 + 0.789x	11.1	3.38	0.08
Soissons	4.9	y = 4.44 + 0.302x	-	0.34	0.6
Cultivar regression lines are parallel					

[a]Df = 78 for all cultivars and df = 18 for individual cultivars.
-, residual variance exceeds the variance of the response variate.
Where no regressions are significant, only the regression for all cultivars is shown.

Table 3.22. *Regressions of percentage main stems with brown foot rot on fungal DNA concentrations in wheat stem bases at GS39, Harper Adams 1997*

Cultivar	Mean %	Regression equation	Variance accounted for (%)	VR[a]	*P*
Percentage stems with brown foot rot on Microdochium nivale *var.* majus *DNA*					
All	24.6	y = 23.55 + 1.02x	-	0.98	0.3
Lynx[b]	23.5				
Brigadier	27.3	y = 27.59 - 0.13x	-	0.01	0.9
Mercia	21.8	y = 16.15 + 7.30x	17.5	5.04	0.04
Soissons	25.8	y = 21.13 + 5.11x	4.6	1.91	0.2
No significant regression					
Percentage plants with brown foot rot on M. nivale *var.* nivale *DNA*					
All	24.6	y = 18.36 + 3.72x	21.1	22.17	<0.001
Lynx	23.5	y = 13.70 + 6.31x	37.9	12.59	0.002
Brigadier	27.3	y = 22.79 + 2.02x	3.4	1.66	0.2
Mercia	21.8	y = 16.47 + 4.38x	13.6	3.99	0.06
Soissons	25.8	y = 17.06 + 5.10x	37.6	12.45	0.002
Data from all cultivars represent a single line					
Percentage plants with brown foot rot on M. nivale *var.* nivale and M. nivale *var.* majus *DNA*					
All	24.6	y = 19.23 + 1.97x	13.0	12.82	<0.001
Lynx	23.5	y = 10.23 + 6.31x	37.9	12.59	0.002
Brigadier	27.3	y = 24.67 + 0.63x	-	0.45	0.6
Mercia	21.8	y = 15.09 +3.37x	19.8	5.70	0.03
Soissons	25.8	y = 11.84 + 5.30x	49.8	19.83	<0.001
All regression lines significantly different					

[a] D.f. = 78 for all cultivars together, 18 for individual cultivars.
[b]No regression for Lynx because all DNA values were the same.
-, residual variance exceeds the variance of the response variate.

Table 3.23. *Regressions of percentage plants with brown foot rot on fungal DNA concentrations in wheat shoot bases at GS24, Harper Adams 1998*

Cultivar	Mean %	Regression equation	Variance accounted for (%)	VR[a]	*P*
Percentage plants with brown foot rot on Microdochium nivale *var.* majus *DNA*					
All	27.7	y = 11.16 + 18.29x	35.1	43.66	<0.001
Lynx	8.4	y = 12.42 - 9.90x	-	0.86	0.4
Brigadier	39.2	y = 24.43 + 13.41x	21.7	6.25	0.02
Mercia	7.2	y = 12.06 - 15.20x	1.2	1.24	0.3
Soissons	56.0	y = 56.73 - 0.41x	-	0.01	0.9
All regression lines significantly different					
Percentage plants with brown foot rot on M. nivale *var.* nivale *DNA*					
All	27.7	y = 19.85 + 2.00x	0.1	1.07	0.3
Percentage plants with brown foot rot on M. nivale *var.* nivale and M. nivale *var.* majus					
All	27.7	y = 2.23 + 5.30x	12.9	12.68	<0.001
Lynx	8.4	y = 28.50 - 6.03x	14.2	4.16	0.06
Brigadier	39.2	y = 22.6 + 2.99x	2.9	1.57	0.2
Mercia	7.2	y = 16.83 - 2.13x	2.9	1.56	0.2
Soissons	56.0	y = 40.40 - 2.70x	0.1	1.02	0.3
Cultivar regression lines are parallel					

[a] D.f. = 78 for all cultivars together, 18 for individual cultivars.
-, residual variance exceeds the variance of the response variate.
Where no regressions are significant, only the regression for all cultivars is shown.

Table 3.24. *Regressions of percentage plants with brown foot rot on fungal DNA concentrations in wheat shoot bases at GS30, Harper Adams 1998*

Cultivar	Mean %	Regression equation	Variance accounted for (%)	VR[a]	*P*
Percentage plants with brown foot rot on Microdochium nivale *var.* majus *DNA*					
All	32.3	y = 25.20 + 0.74x	5.1	5.25	0.025
Lynx	4.2	y = 2.78 + 0.31x	0.5	1.09	0.3
Brigadier	51.5	y = 50.86 + 0.07x	-	0.02	0.9
Mercia	6.5	y = 8.18 - 0.17x	10.1	3.12	0.09
Soissons	67.2	y = 63.16 + 0.26x	-	0.36	0.6
Cultivar regression lines are parallel					
Percentage plants with brown foot rot on M. nivale *var.* nivale *DNA*					
All	32.3	y = 20.16 + 7.64x	25.9	28.57	<0.001
Lynx	4.2	y = 3.74 + 0.50x	5.01	0.47	0.5
Brigadier	51.5	y = 49.16 + 1.01x	-	0.23	0.6
Mercia	6.5	y = 3.49 + 7.74x	4.0	1.79	0.2
Soissons	67.2	y = 59.24 + 2.81x	13.1	3.88	0.065
Cultivar regression lines are parallel					

Regressions of brown foot rot on *M. nivale* var. *majus* + *M. nivale* var. *nivale* DNA were similar.

[a] D.f. = 78 for all cultivars together, 18 for individual cultivars.
-, residual variance exceeds the variance of the response variate.

Table 3.25. *Regressions of percentage main stems with brown foot rot on fungal DNA concentrations in wheat stem bases at GS37, Harper Adams 1998*

Cultivar	Mean %	Regression equation	Variance accounted for (%)	VR[a]	*P*
Percentage stems with brown foot rot on Microdochium nivale *var.* majus *DNA*					
All	34.4	y = 24.81 + 1.43x	16.7	16.79	<0.001
Lynx	14.7	y = 11.95 + 0.62x	-	0.97	0.3
Brigadier	47.3	y = 47.63 - 0.04x	-	0.00	1.0
Mercia	22.8	y = 16.37 + 2.28x	11.0	3.35	0.08
Soissons	52.7	y = 43.09 + 0.76x	7.1	2.44	0.1
Cultivar regression lines are parallel					
Percentage stems with brown foot rot on M. nivale *var.* nivale *DNA*					
All	34.4	y = 30.97 + 0.21x	9.2	8.96	0.004
Lynx	14.7	y = 11.54 + 1.88x	20.6	5.94	0.03
Brigadier	47.3	y = 43.33 + 0.11x	4.7	1.93	0.2
Mercia	22.8	y = 20.59 + 0.27x	3.3	1.65	0.2
Soissons	52.7	y = 56.27 - 0.17x	-	0.57	0.5
Cultivar regression lines are parallel					

Regressions of brown foot rot on *M. nivale* var. *majus* + *M. nivale* var. *nivale* DNA were similar.

[a] D.f. = 78 for all cultivars together, 18 for individual cultivars.
-, residual variance exceeds the variance of the response variate.

Table 3.26. *Regressions of percentage main stems with brown foot rot on fungal DNA concentrations in wheat stem bases at Harper Adams, 1999*

Cultivar	Mean %	Regression equation	Variance accounted for (%)	VR[a]	*P*
Percentage stems with brown foot rot on Microdochium nivale *var.* majus *DNA at GS30*					
All	23.3	y = 21.19 + 13.05x	3.6	3.96	0.05
Lynx	13.3	y = 9.63 + 31.49x	34.1	10.82	0.004
Abbot	15.0	y = 13.76 + 10.69x	3.8	1.75	0.2
Mercia	30.2	y = 28.11 + 6.00x	-	0.69	0.4
Soissons	34.5	y = 28.68 + 100.6x	5.2	2.03	0.2
Cultivar regression lines are parallel					
Percentage stems with brown foot rot on M. nivale *var.* majus *DNA at GS32*					
All	18.3	y = 13.62 + 1.54x	17.8	18.12	<0.001
Lynx	12.5	y = 12.11 + 0.14x	-	0.05	0.8
Abbot	24.0	y = 20.13 + 2.06x	7.2	2.47	0.1
Mercia	25.0	y = 13.08 + 1.96x	38.8	13.03	0.002
Soissons	11.8	y = 10.83 + 0.67x	-	0.57	0.5
Cultivar regression lines are parallel					
The regression on DNA of var. *majus* + var. *nivale* is similar					
Percentage stems with brown foot rot on M. nivale *var.* nivale *DNA at GS32*					
All	18.3	y = 14.04 + 17.98x	20.1	20.60	<0.001
Lynx	12.5	y = 9.92 + 15.09x	25.1	7.36	0.01
Abbot	24.0	y = 8.57 + 108.2x	32.1	9.52	0.007
Mercia	25.0	y = 18.45 + 13.75x	21.0	6.06	0.02
Soissons	11.8	y = -0.58 + 107.8x	20.5	5.89	0.03

[a] D.f. = 78 for all cultivars together, 18 for individual cultivars.
-, residual variance exceeds the variance of the response variate.

Table 3.27. *Regressions of percentage main stems with brown foot rot on fungal DNA concentrations in wheat stem bases at Morley, 1997 and 1998*

Cultivar	Mean %	Regression equation	Variance accounted for (%)	VR[a]	*P*
Percentage main stems with brown foot rot on Microdochium nivale *var.* nivale *DNA at GS37-41, 1997*					
All	28.0	y = 18.42 + 1.71x	37.5	48.44	<0.001
Lynx	25.7	y = 19.87 + 1.70x	11.6	3.50	0.08
Brigadier	28.5	y = 17.58 + 1.92x	54.6	23.88	<0.001
Mercia	28.5	y = 17.04 + 2.13x	33.4	10.52	0.005
Soissons	29.2	y = 16.13 + 1.66x	43.7	15.74	<0.001
Data from all cultivars represent a single line					
Percentage main stems with brown foot rot on Microdochium nivale *var.* nivale *DNA at GS33-45, 1998*					
All	8.6	y = 6.44 + 2.44x	5.4	5.48	0.02
Lynx	6.0	y = 1.40 + 6.84x	11.9	3.57	0.08
Brigadier	6.3	y = 5.76 + 0.81x	-	0.04	0.8
Mercia	8.7	y = 7.04 + 1.44x	3.8	1.75	0.2
Soissons	13.5	y = 12.01 + 1.40x	-	0.15	0.7
Cultivar regression lines are parallel					

[a] D.f. = 78 for all cultivars together, 18 for individual cultivars.
-, residual variance exceeds the variance of the response variate.

Table 3.28. *Regressions of percentage plants with brown foot rot on fungal DNA concentrations at Morley, 1999*

Cultivar	Mean %	Regression equation	Variance accounted for (%)	VR[a]	*P*
Percentage stems with brown foot rot on Microdochium nivale *var.* majus *DNA at GS30*					
All	5.3	y = 4.47 + 5.780x	8.4	8.26	0.005
Percentage stems with brown foot rot on Microdochium nivale *var.* majus *DNA at GS32*					
All	10.2	y = 9.26 + 0.319x	8.4	8.27	0.005
Percentage stems with brown foot rot on Microdochium nivale *var.* nivale *DNA at GS32*					
All	10.2	y = 9.09 + 1.094x	12.1	11.88	<0.001
Percentage stems with brown foot rot on M. nivale *var.* majus + M. nivale *var.* nivale *DNA at GS32*					
All	10.2	y = 8.66 + 0.383x	15.1	15.01	<0.001
Lynx	9.0	y = 6.92 + 1.070x	8.8	2.84	0.1
Abbot	9.0	y = 7.61 + 0.261x	14.1	4.12	0.06
Mercia	14.3	y = 11.54 + 0.437x	22.8	6.61	0.02
Soissons	8.7	y = 7.94 + 0.244x	-	0.69	04

Data from all cultivars represent a single line

[a] D.f. = 78 for all cultivars together, 18 for individual cultivars.
-, residual variance exceeds the variance of the response variate.
Where no regressions for individual cultivars are significant, only the regression for all cultivars is shown.

Table 3.29. *Regressions of percentage plants with brown foot rot on fungal DNA concentrations in wheat shoot bases at GS23, Rothamsted, 1998*

Cultivar	Mean %	Regression equation	Variance accounted for (%)	VR[a]	*P*
Percentage plants with brown foot rot on M. nivale *var.* majus *DNA*					
All	26.3	y = 21.22 + 13.36x	10.4	9.78	0.003
Lynx	13.9	y = 10.34 + 15.16x	8.4	2.74	0.1
Brigadier	35.7	y = 33.87 + 6.30x	-	0.34	0.6
Mercia	15.2	y = 20.57 - 19.32x	14.3	3.99	0.06
Soissons	40.3	y = 38.97 + 2.04x	-	0.20	0.7
Cultivar regression lines are parallel					
Percentage plants with brown foot rot on Microdochium nivale *var.* nivale *DNA*					
All	26.3	y = 21.28 + 6.44x	17.4	17.05	<0.001
Lynx	13.9	y = 11.68 + 9.64x	2.50	1.48	0.2
Brigadier	35.7	y = 35.71 + 0.49x	-	0.02	0.9
Mercia	15.2	y = 14.22 + 3.44x	5.0	1.94	0.2
Soissons	40.3	y = 39.46 + 0.62x	-	0.09	0.8
Cultivar regression lines are parallel					

Regressions of brown foot rot on *M. nivale* var. *majus* + *M. nivale* var. *nivale* DNA were similar.

[a] D.f. = 78 for all cultivars together, 18 for individual cultivars.
-, residual variance exceeds the variance of the response variate.

Table 3.30. *Regressions of percentage plants with brown foot rot on fungal DNA concentrations in wheat shoot bases at GS30, Rothamsted, 1998*

Cultivar	Mean %	Regression equation	Variance accounted for (%)	VR[a]	*P*
Percentage plants with brown foot rot on M. nivale *var.* majus *DNA*					
All	44.3	y = 39.04 + 13.08x	3.8	3.98	0.05
Lynx	22.9	y = 22.91 – 0.10x	-	0.00	1.0
Brigadier	68.9	y = 72.34 - 7.24x	-	0.83	0.4
Mercia	24.8	y = 29.26 - 16.00x	-	0.83	0.4
Soissons	60.6	y = 62.59 - 3.06x	-	0.51	0.5
Cultivar regression lines are parallel					
Percentage plants with brown foot rot on Microdochium nivale *var.* nivale *DNA*					
All	44.3	y = 34.84 + 11.45x	25.7	27.31	<0.001
Lynx	22.9	y = 20.41 + 10.96x	1.9	1.38	0.3
Brigadier	68.9	y = 72.27 - 2.15x	-	0.76	0.4
Mercia	24.8	y = 23.15 + 5.05x	2.4	1.44	0.2
Soissons	60.6	y = 55.26 + 3.92x	18.7	5.36	0.03
Cultivar regression lines are parallel					

Regressions of brown foot rot on *M. nivale* var. *majus* + *M. nivale* var. *nivale* DNA were similar.

[a] D.f. = 78 for all cultivars together, 18 for individual cultivars.
-, residual variance exceeds the variance of the response variate.

Table 3.31. *Regressions of percentage main stems with brown foot rot on fungal DNA concentrations in wheat stem bases at GS34, Rothamsted, 1998*

Cultivar	Mean %	Regression equation	Variance accounted for (%)	VR[a]	*P*
Percentage stems with brown foot rot on M. nivale *var.* majus *DNA*					
All	10.8	y = 35.26 + 3.78x	10.3	9.75	0.03
Lynx	5.4	y = 25.43 + 3.05x	12.2	3.63	0.07
Brigadier	10.1	y = 59.30 - 0.60x	-	0.12	0.7
Mercia	13.0	y = 19.58 + 2.51x	9.2	2.82	0.1
Soissons	14.7	y = 51.97 + 2.20x	2.2	1.43	0.2
Cultivar regression lines are parallel					

[a] D.f. = 78 for all cultivars together, 18 for individual cultivars.
-, residual variance exceeds the variance of the response variate.

Table 3.32. *Regressions of percentage main stems with brown foot rot on fungal DNA concentrations in wheat stem bases at GS34, Rothamsted, 1999*

Cultivar	Mean %	Regression equation	Variance accounted for (%)	VR[a]	*P*
Percentage plants with brown foot rot on M. nivale *var.* majus *DNA*					
All	17.3	y = 13.66 + 6.26x	10.3	10.10	0.002
Lynx	27.6	y = 22.13 + 10.99x	5.2	2.05	0.2
Abbot	11.6	y = 8.48 + 6.11x	15.8	4.56	0.05
Mercia	18.9	y = 12.01 + 6.68x	16.7	4.80	0.04
Soissons	11.2	y = 6.92 + 6.84x	40.1	13.70	0.002
Cultivar regression lines are parallel					
The regression on DNA of var. *majus* + var. *nivale* is similar but with slightly smaller *P* values					
Percentage plants with brown foot rot on Microdochium nivale *var.* nivale *DNA*					
All	17.3	y = 13.95 + 3.40x	11.5	11.09	0.001
Lynx	27.6	y = 23.64 + 4.80x	0.2	1.04	0.3
Abbot	11.6	y = 10.94 + 1.78x	-	0.08	0.8
Mercia	18.9	y = 12.05 + 3.81x	31.6	9.79	0.006
Soissons	11.2	y = 10.05 + 1.51x	0.6	1.11	0.3
Cultivar regression lines are parallel					

[a] D.f. = 78 for all cultivars together, 18 for individual cultivars.
-, residual variance exceeds the variance of the response variate.

Table 4.1. *Incidence of eyespot at GS75, Harper Adams 1997*

	Logit % main stems with eyespot (back-transformed means)				
Cultivar...	Lynx	Brigadier	Mercia	Soissons	All
Fungicide					
None	-1.30 (6.5)	-0.32 (33.9)	-0.24 (37.7)	-0.32 (33.9)	-0.55 (24.6)
Prochloraz	-1.05 (10.5)	-0.43 (29.3)	-0.71 (19.0)	-0.50 (26.4)	-0.67 (20.2)
Cyprodinil	-1.70 (2.7)	-1.59 (3.5)	-1.27 (6.8)	-1.37 (5.6)	-1.48 (4.4)
Azoxystrobin	-1.34 (5.9)	-0.69 (19.6)	-0.60 (22.5)	-0.70 (19.4)	-0.83 (15.4)
Flusilazole	-1.22 (7.5)	-0.34 (33.0)	-1.16 (8.5)	-0.71 (18.9)	-0.86 (14.7)
SED (57 df)		0.278			0.139
P		0.2 (interaction)			<0.001
All	-1.32 (6.1)	-0.68 (20.1)	-0.80 (16.4)	-0.72 (18.7)	
SED (57 df)		0.124			
P		<0.001			

Table 4.2. *Severity of eyespot at GS75, Harper Adams 1997*

	Eyespot index (0-100)				
Cultivar...	Lynx	Brigadier	Mercia	Soissons	All
Fungicide					
None	3.9	16.1	20.3	22.2	15.6
Prochloraz	5.8	15.0	10.8	19.4	12.8
Cyprodinil	0.8	1.9	3.9	3.1	2.4
Azoxystrobin	5.0	11.7	13.9	20.0	12.6
Flusilazole	4.4	15.8	6.7	16.4	10.8
SED (57 df)		5.35			2.68
P		0.6 (interaction)			<0.001
All	4.0	12.1	11.1	16.2	
SED (57 df)		2.39			
P		<0.001			

Table 4.3. *Amounts of DNA (pg ng^{-1}) of* Tapesia acuformis, *Harper Adams 1997*

Cultivar...	Lynx	Brigadier	Mercia	Soissons	All
Fungicide					
None	1.29	3.22	2.58	4.93	3.00
Prochloraz	0.50	3.33	1.24	2.64	1.93
Cyprodinil	0.17	0.25	0.40	0.41	0.31
Azoxystrobin	0.63	2.93	2.51	3.24	2.33
Flusilazole	0.54	2.59	1.41	3.25	1.95
SED (57 df)			0.842		0.421
P			0.3 (interaction)		<0.001
All	0.62	2.46	1.63	2.89	
SED (57 df)			0.376		
P			<0.001		

Table 4.4. *Incidence of brown foot rot at GS75, Harper Adams 1997*

	Logit % main stems (back-transformed means)				
Cultivar...	Lynx	Brigadier	Mercia	Soissons	All
Fungicide					
None	0.29 (63.4)	0.17 (58.0)	-0.02 (48.6)	-0.12 (43.7)	0.08 (53.5)
Prochloraz	0.02 (50.4)	0.12 (55.3)	-0.10 (44.4)	0.07 (53.0)	0.03 (50.8)
Cyprodinil	-0.11 (44.1)	0.10 (54.4)	-0.34 (33.1)	-0.47 (27.8)	-0.20 (39.4)
Azoxystrobin	0.08 (53.6)	0.39 (68.3)	0.02 (50.3)	-0.20 (39.8)	0.07 (53.2)
Flusilazole	0.32 (64.9)	0.38 (67.5)	0.30 (63.8)	0.07 (53.0)	0.27 (62.5)
SED (57 df)			0.154		0.077
P			0.3 (interaction)		<0.001
All	0.12 (55.4)	0.23 (60.9)	-0.03 (48.0)	-0.13 (43.2)	
SED (57 df)			0.069		
P			<0.001		

Table 4.5. *Grain yields (t ha^{-1} at 85% dry matter) at Harper Adams 1997*

Cultivar...	Lynx	Brigadier	Mercia	Soissons	All
Fungicide					
None	9.97	9.21	7.91	8.29	8.84
Prochloraz	8.93	9.68	8.40	9.06	9.02
Cyprodinil	9.31	9.77	8.70	8.57	9.09
Azoxystrobin	10.04	9.59	8.78	8.58	9.24
Flusilazole	9.19	9.49	8.73	8.35	8.94
SED (57 df)		0.375			0.187
P		0.04			0.3
All	9.49	9.55	8.50	8.57	
SED (57 df)		0.168			
P		<0.001			

Table 4.6. *Incidence of eyespot at GS69, Harper Adams 1998*

	Logit % main stems (back-transformd means)				
Cultivar...	Lynx	Brigadier	Mercia	Soissons	All
Fungicide					
None	-0.46 (28.6)	0.19 (59.5)	-0.34 (33.5)	0.15 (57.2)	-0.12 (44.2)
Prochloraz	-0.65 (21.4)	-0.20 (40.4)	-0.38 (31.8)	-0.19 (40.8)	-0.35 (33.0)
Cyprodinil	-0.68 (20.5)	-0.09 (45.3)	-0.83 (15.9)	-0.87 (14.8)	-0.62 (22.5)
Azoxystrobin	-0.17 (41.6)	0.31 (64.8)	0.06 (52.8)	-0.04 (48.2)	0.04 (52.0)
HGCA1	-0.26 (37.3)	0.14 (56.9)	0.08 (54.1)	-0.39 (31.3)	-0.11 (44.6)
SED (57 df)		0.221			0.111
P		0.1 (interaction)			<0.001
All	-0.44 (29.2)	0.07 (53.5)	-0.28 (36.2)	-0.27 (36.9)	
SED (57 df)		0.099			
P		<0.001			

Table 4.7. *Severity of eyespot at GS69, Harper Adams 1998*

	Eyespot index (0-100)				
Cultivar...	Lynx	Brigadier	Mercia	Soissons	All
Fungicide					
None	17.5	33.6	21.1	30.8	25.8
Prochloraz	11.7	22.5	19.7	20.0	18.5
Cyprodinil	11.9	24.4	9.7	8.6	13.7
Azoxystrobin	23.3	38.1	36.7	28.3	31.6
HGCA1	27.8	30.8	37.8	16.7	26.9
SED (57 df)			5.73		2.87
P			0.06 (interaction)		<0.001
All	17.4	29.9	24.9	20.9	
SED (57 df)			2.56		
P			<0.001		

Table 4.8. *Amounts of DNA (pg ng^{-1}) of* Tapesia acuformis *at Harper Adams, 1998*

Cultivar..	Lynx	Brigadier	Mercia	Soissons	All
Fungicide					
None	1.63	1.13	2.68	3.77	2.30
Prochloraz	1.18	1.57	3.44	2.20	2.10
Cyprodinil	1.40	1.27	2.09	0.60	1.34
Azoxystr.	2.16	5.55	5.19	1.29	3.55
HGCA1	1.92	1.91	6.56	2.50	3.22
SED (57 df)			1.262		0.631
P			0.02 (interaction)		0.007
All	1.66	2.29	3.99	2.07	
SED (57 df)			0.564		
P			<0.001		

Table 4.9. *Incidence of sharp eyespot at GS69, Harper Adams 1998*

Logit % main stems (back-transformed mean)

Cultivar..	Lynx	Brigadier	Mercia	Soissons	All
Fungicide					
None	-0.86 (15.2)	-1.41 (5.6)	-1.06 (10.7)	-1.91 (2.1)	-1.31 (6.8)
Prochloraz	-0.45 (28.9)	-1.37 (6.1)	-0.56 (24.7)	-1.52 (4.6)	-0.97 (12.5)
Cyprodinil	-0.95 (12.9)	-1.37 (6.1)	-0.34 (33.7)	-1.91 (2.1)	-1.14 (9.2)
Azoxystr.	-1.19 (8.4)	-1.77 (2.8)	-1.45 (5.2)	-1.64 (3.7)	-1.51 (4.6)
HGCA1	-0.80 (16.9)	-1.45 (5.2)	-0.75 (18.1)	-1.17 (8.8)	-1.04 (11.1)
SED (57 df)			0.278		0.139
P			0.09 (interaction)		0.002
All	-0.85 (15.4)	-1.47 (5.0)	-0.83 (15.9)	-1.63 (3.7)	
SED			0.125		
P			<0.001		

Table 4.10. *Severity of sharp eyespot at GS 69, Harper Adams 1998*

Disease index (0-100)

Cultivar..	Lynx	Brigadier	Mercia	Soissons	All
Fungicide					
None	10.0	3.6	10.8	0.6	6.2
Prochloraz	15.7	3.9	16.7	2.5	9.7
Cyprodinil	8.3	4.7	24.7	0.3	9.5
Azoxystr.	4.7	0.6	3.1	1.1	2.4
HGCA1	10.8	2.5	13.9	3.9	7.8
SED (57 df)			3.61		1.81
P			0.01 (interaction)		<0.001
All	9.9	3.1	13.8	1.7	
SED (57 df)			1.62		
P			<0.001		

Table 4.11. *Amounts of DNA (pg ng^{-1}) of* Rhizoctonia cerealis *at HarperAdams 1998*

Cultivar..	Lynx	Brigadier	Mercia	Soissons	All
Fungicide					
None	6.05	6.30	7.04	5.91	6.33
Prochloraz	12.94	5.87	13.00	8.65	10.11
Cyprodinil	17.48	5.84	13.73	11.68	12.18
Azoxystr.	5.16	3.94	6.19	4.74	5.00
HGCA1	10.15	5.33	9.35	7.05	7.97
SED (57 df)			2.918		1.459
P			0.5 (interaction)		<0.001
All	10.36	5.46	9.86	7.60	
SED (57 df)			1.305		
P			0.001		

Table 4.12. *Incidence and severity of brown foot rot, and amounts of DNA of* Microdochium nivale *var.* nivale *at GS69, Harper Adams 1998*

	Brown foot rot		
	Logit % main stems (back-transformed means)	Disease index (0-100)	DNA (pg ng^{-1})
Cultivar			
Lynx	-0.17 (41.7)	21.7	1.61
Brigadier	-0.03 (48.5)	24.3	7.96
Mercia	-0.17 (41.6)	25.6	1.26
Soissons	-0.05 (47.6)	21.3	12.34
SED (57 df)	0.116	3.05	2.496
P	0.5	0.4	<0.001
Fungicide			
None	-0.06 (47.3)	25.1	6.26
Prochloraz	-0.10 (44.9)	23.0	7.32
Cyprodinil	-0.09 (45.8)	21.9	7.61
Azoxystr.	-0.28 (36.5)	19.9	3.94
HGCA1	0.00 (50.1)	26.3	3.83
SED (57 df)	0.129	3.41	2.791
P	0.3	0.4	0.5
P (interaction)	0.3	0.4	0.3

Table 4.13. *Incidence of eyespot at GS75, Harper Adams 1999*

	Logit % main stems (back-transformed means)				
Cultivar...	Lynx	Abbot	Mercia	Soissons	All
Fungicide					
None	0.05 (52.1)	-0.04 (47.5)	-0.13 (43.1)	-0.16 (41.6)	-0.07 (46.1)
Prochloraz	-0.12 (43.5)	0.20 (59.4)	0.24 (61.5)	-0.18 (40.9)	0.04 (51.4)
Cyprodinil	-0.38 (31.6)	-0.09 (45.0)	-0.08 (45.4)	-0.60 (22.6)	-0.29 (35.5)
Azoxystr.	-0.18 (40.6)	0.20 (59.1)	0.08 (53.6)	-0.28 (35.8)	-0.05 (47.2)
HGCA1	-0.20 (39.5)	-0.04 (47.6)	-0.03 (48.2)	-0.20 (39.6)	-0.12 (43.7)
SED (57 df)		0.258			0.129
P		1.0 (interaction)			0.2
All	-0.17 (41.3)	0.05 (51.8)	0.02 (50.4)	-0.28 (35.7)	
SED (57 df)		0.116			
P		0.02			

Table 4.14. *Severity of eyespot at GS75, Harper Adams 1999*

	Eyespot index (0-100)				
Cultivar...	Lynx	Abbot	Mercia	Soissons	All
Fungicide					
None	34.7	31.1	25.1	21.8	28.2
Prochloraz	24.2	36.6	42.6	21.4	31.2
Cyprodinil	18.1	25.0	26.4	9.5	19.7
Azoxystr.	29.0	38.7	39.1	21.7	32.1
HGCA1	23.9	31.0	32.6	22.7	27.6
SED (57 df)		8.82			4.41
P		0.9 (interaction)			0.06
All	26.0	32.5	33.2	19.4	
SED (57 df)		3.94			
P		0.003			

Table 4.15. *Amounts of DNA (pg ng^{-1}) of* Tapesia yallundae *at GS75, Harper Adams 1999*

Cultivar...	Lynx	Abbot	Mercia	Soissons	All
Fungicide					
None	2.84	9.24	9.00	7.14	7.06
Prochloraz	2.26	6.08	7.01	10.07	6.36
Cyprodinil	1.54	4.39	4.90	4.76	3.90
Azoxystr.	3.08	7.69	7.38	14.36	8.13
HGCA1	2.46	5.36	8.13	8.20	6.04
SED (57 df)			2.441		1.221
P			0.4 (interaction)		0.02
All	2.44	6.55	7.28	8.91	
SED (57 df)			1.092		
P			<0.001		

Table 4.16. *Amounts of DNA (pg ng^{-1}) of* Tapesia acuformis *at GS75, Harper Adams 1999*

Cultivar...	Lynx	Abbot	Mercia	Soissons	All
Fungicide					
None	7.88	8.87	15.78	17.32	12.46
Prochloraz	6.82	9.96	12.12	12.05	10.24
Cyprodinil	2.30	3.84	6.03	3.97	4.03
Azoxystr.	8.42	8.65	19.59	13.32	12.50
HGCA1	7.53	12.83	16.71	9.67	11.68
SED (57 df)			2.635		1.318
P			0.09 (interaction)		<0.001
All	6.59	8.33	14.05	11.27	
SED (57 df)			1.179		
P			<0.001		

Table 4.17. *Effects of cultivar on the severity of brown foot rot and on amounts of DNA (ng pg^{-1}) of* Microdochium nivale *varieties at GS75, Harper Adams 1999*

Cultivar	Brown foot rot index (0-100)	*M. nivale* DNA	
		var. *majus*	var. *nivale*
Lynx	6.0	1.70	1.00
Abbot	11.9	1.73	0.60
Mercia	10.9	3.42	2.03
Soissons	11.0	2.66	0.34
SED (57 df)	1.89	0.657	0.480
P	0.01	0.03	0.005

Table 4.18. *Grain yields (t ha^{-1} at 85% dry matter) at Harper Adams, 1999*

Cultivar...	Lynx	Abbot	Mercia	Soissons	All
Fungicide					
None	2.91	2.36	3.12	2.15	2.64
Prochloraz	2.83	2.32	3.01	1.81	2.49
Cyprodinil	3.20	2.93	3.31	2.74	3.05
Azoxystr.	3.40	3.51	3.76	3.09	3.44
HGCA1	3.03	2.51	2.85	2.05	2.61
SED (57 df)			0.332		0.166
P			0.9(interaction)		<0.001
All	3.07	2.73	3.21	2.37	
SED (57 df)			0.148		
P			<0.001		

Table 4.19. *Incidence of eyespot at GS77-83, Morley 1997*

Logit % main stems (back-transformed means)

Cultivar...	Lynx	Brigadier	Mercia	Soissons	All
Fungicide					
None	-0.63 (21.1)	0.24 (62.0)	-0.34 (33.2)	0.10 (55.2)	-0.16 (41.9)
Prochloraz	-0.50 (26.2)	0.09 (54.6)	-0.27 (36.6)	-0.18 (41.1)	-0.21 (39.2)
Cyprodinil	-1.02 (10.2)	-0.30 (35.1)	-0.76 (16.9)	-0.39 (30.8)	-0.62 (21.6)
Azoxystr.	-0.71 (18.4)	0.16 (58.2)	-0.47 (27.2)	0.02 (51.1)	-0.25 (37.3)
Flusilazole	-1.16 (7.6)	0.07 (53.4)	-0.28 (35.8)	-0.28 (36.2)	-0.41 (29.8)
SED (57 df)		0.525			0.131
P		0.8 (interaction)			0.006
All	-0.80 (15.6)	0.05 (52.6)	-0.42 (29.4)	-0.14 (42.6)	
SED (57 df)		0.117			
P		<0.001			

Table 4.20. *Severity of eyespot at GS77-83, Morley 1997*

Eyespot index (0-100)

Cultivar...	Lynx	Brigadier	Mercia	Soissons	All
Fungicide					
None	10.3	33.9	18.6	29.7	23.1
Prochloraz	11.9	29.2	18.6	24.2	21.0
Cyprodinil	6.7	15.3	8.6	13.6	11.0
Azoxystr.	8.9	28.1	13.3	29.6	20.0
Flusilazole	4.7	26.9	21.9	20.6	18.5
SED (57 df)		5.45			2.73
P		0.5 (interaction)			<0.001
All	8.5	26.7	16.2	23.5	
SED (57 df)		2.44			
P		<0.001			

Table 4.21. *Amounts of DNA (pg ng^{-1}) of* Tapesia acuformis *at GS77-83, Morley 1997*

Cuultivar...	Lynx	Brigadier	Mercia	Soissons	All
Fungicide					
None	1.50	4.49	1.39	6.57	3.49
Prochloraz	1.46	6.63	2.37	6.17	4.16
Cyprodinil	0.51	2.53	0.80	0.98	1.20
Azoxystr.	0.73	3.65	4.86	5.91	3.79
Flusilazole	0.91	6.40	5.53	4.05	4.22
SED (57 df)			1.976		0.988
P			0.3 (interaction)		0.02
All	1.02	4.74	2.99	4.74	
SED (57 df)			0.884		
P			<0.001		

Table 4.22. *Incidence of sharp eyespot at GS77-83, Morley 1997*

Logit % main stems (back-transformed means)

Cuultivar...	Lynx	Brigadier	Mercia	Soissons	All
Fungicide					
None	-1.19 (7.1)	-1.01 (10.5)	-1.37 (4.7)	-0.97 (11.4)	-1.13 (8.1)
Prochloraz	-0.84 (14.6)	-1.06 (9.4)	-1.24 (6.3)	-0.78 (16.2)	-0.98 (11.1)
Cyprodinil	-1.12 (8.2)	-1.04 (9.8)	-1.04 (9.8)	-0.67 (19.7)	-0.97 (11.3)
Azoxystr.	-1.77 (1.2)	-1.02 (10.2)	-1.91 (0.5)	-1.01 (10.3)	-1.43 (3.9)
Flusilazole	-1.24 (6.3)	-0.84 (14.5)	-1.16 (7.6)	-0.77 (16.7)	-1.00 (10.6)
SED (57 df)			0.286		0.143
P			0.6 (interaction)		0.01
All	-1.23 (6.4)	-1.00 (10.8)	-1.34 (4.9)	-0.84 (14.6)	
SED (57 df)			0.128		
P			<0.001		

Table 4.23. *Amounts of DNA (pg ng^{-1}) of* Rhizoctonia cerealis *at GS77-83, Morley 1997*

Cuultivar...	Lynx	Brigadier	Mercia	Soissons	All
Fungicide					
None	1.84	3.07	1.84	4.49	2.81
Prochloraz	2.72	2.56	2.01	5.00	3.07
Cyprodinil	2.41	5.22	2.37	3.80	3.45
Azoxystr.	1.84	2.66	1.84	4.16	2.62
Flusilazole	1.84	2.22	2.36	4.14	2.64
SED (57 df)			1.095		0.548
P			0.7 (interaction)		0.5
All	2.13	3.15	2.08	4.32	
SED (57 df)			0.490		
P			<0.001		

Table 4.24. *Grain yields (t ha^{-1}) at Morley 1997*

Cultivar...	Lynx	Brigadier	Mercia	Soissons	All
Fungicide					
None	8.74	8.12	6.44	7.59	7.72
Prochloraz	8.52	8.13	6.56	7.92	7.78
Cyprodinil	8.87	8.41	8.87	8.27	8.10
Azoxystrobin	8.68	8.74	6.82	8.35	8.15
Flusilazole	8.46	8.41	6.50	7.89	7.81
SED (57 df)			0.173		0.086
P			0.1 (interaction)		<0.001
All	8.65	8.36	6.64	8.00	
SED (57 df)			0.077		
P			<0.001		

Table 4.25. *Incidence of eyespot on main stems at GS71-75, Morley 1998*

Logit % main stems (back-transformed mean)

Cultivar..	Lynx	Brigadier	Mercia	Soissons	All
Fungicide					
None	-0.72 (19.1)	0.46 (71.7)	0.06 (53.1)	0.26 (62.9)	0.02 (50.9)
Prochloraz	-0.53 (25.7)	0.28 (63.7)	0.02 (50.9)	0.28 (63.5)	0.01 (50.6)
Cyprodinil	-1.16 (8.9)	-0.13 (43.5)	-0.67 (20.8)	-0.63 (22.0)	-0.65 (21.5)
Azoxystrobin	-0.20 (40.4)	0.35 (66.9)	0.49 (72.7)	0.26 (62.8)	0.23 (61.2)
HGCA1	-0.10 (44.9)	0.61 (77.1)	0.12 (56.1)	0.13 (56.3)	0.19 (59.3)
SED (57 df)		0.195			0.097
P		0.1 (interaction)			<0.001
All	-0.54 (25.3)	0.31 (65.2)	0.01 (50.3)	0.06 (53.0)	
SED (57 df)		0.087			
P		<0.001			

Table 4.26. *Severity of eyespot at GS71-75, Morley 1998*

Eyespot index (0-100)

Cultivar..	Lynx	Brigadier	Mercia	Soissons	All
Fungicide					
None	8.9	43.1	28.6	41.4	30.5
Prochloraz	13.9	38.1	30.8	40.3	30.8
Cyprodinil	4.7	24.2	10.3	12.5	12.9
Azoxystrobin	21.4	37.3	41.5	37.5	34.4
HGCA1	22.8	46.4	30.4	35.3	33.7
SED (57 df)		4.47			2.24
P		0.003 (interaction)			<0.001
All	14.3	37.8	28.3	33.4	
SED (57 df)		2.00			
P		<0.001			

Table 4.27. *Amounts of DNA (pg ng^{-1}) of* Tapesia acuformis *at GS71-75, Morley 1998*

Cultivar..	Lynx	Brigadier	Mercia	Soissons	All
Fungicide					
None	0.31	3.33	4.62	6.62	3.72
Prochloraz	1.58	4.42	6.72	4.80	4.38
Cyprodinil	0.09	0.76	0.19	0.77	0.45
Azoxystr.	2.09	2.57	2.37	2.54	2.39
HGCA1	1.57	4.87	4.73	5.38	4.14
SED (57 df)			1.313		0.656
P			0.07 (interaction)		<0.001
All	1.13	3.19	3.72	4.02	
SED (57 df)			0.587		
P			<0.001		

Table 4.28. *Incidence of sharp eyespot at GS71-75, Morley 1998*

Logit % main stems (back-transformed mean)

Cultivar..	Lynx	Brigadier	Mercia	Soissons	All
Fungicide					
None	-1.58 (4.1)	-0.82 (16.3)	-0.94 (13.3)	-0.35 (33.4)	-0.92 (13.7)
Prochloraz	-0.96 (12.9)	-0.63 (22.0)	-0.73 (18.9)	-0.74 (18.5)	-0.76 (17.8)
Cyprodinil	-0.99 (12.2)	-1.00 (11.9)	-0.87 (15.0)	-1.14 (9.3)	-1.00 (11.9)
Azoxystrobin	-1.93 (2.1)	-1.66 (3.5)	-1.02 (11.6)	-1.88 (2.3)	-1.62 (3.8)
HGCA1	-0.94 (13.3)	-1.47 (5.0)	-1.14 (9.4)	-0.85 (15.5)	-1.10 (10.0)
SED (57 df)			0.509		0.254
P			0.6 (interaction)		0.02
All	-1.28 (7.2)	-1.12 (9.7)	-0.94 (13.3)	-0.99 (12.1)	
SED (57 df)			0.227		
P			0.5		

Table 4.29. *Amounts of DNA (pg ng^{-1}) of* Rhizoctonia cerealis *at GS71-75, Morley 1998*

Cultivar..	Lynx	Brigadier	Mercia	Soissons	All
Fungicide					
None	4.59	2.31	3.75	9.90	5.14
Prochloraz	5.90	1.10	11.57	6.63	6.30
Cyprodinil	11.30	4.03	12.21	4.44	8.00
Azoxystrobin	3.44	1.22	2.27	0.37	1.82
HGCA1	6.63	3,53	4.33	5.89	5.09
SED (57 df)			3.188		1.594
P			0.1 (interaction)		0.006
All	6.37	2.44	6.83	5.45	
SED (57 df)			1.426		
P			0.01		

Table 4.30. *Incidence of brown foot rot at GS71-75, Morley 1998*

Logit % main stems (back-transformed mean)

Cultivar..	Lynx	Brigadier	Mercia	Soissons	All
Fungicide					
None	-0.44 (29.3)	-0.59 (23.4)	-0.28 (36.2)	-0.52 (26.3)	-0.46 (28.6)
Prochloraz	-0.74 (18.7)	-0.94 (13.3)	-0.56 (24.7)	-0.89 (14.4)	-0.78 (17.4)
Cyprodinil	-0.83 (16.0)	-0.66 (21.3)	-0.52 (26.0)	-0.91 (13.9)	-0.73 (18.9)
Azoxystrobin	-0.42 (30.2)	-0.70 (19.8)	-0.60 (23.0)	-0.94 (13.3)	-0.66 (20.9)
HGCA1	-0.56 (24.7)	-1.03 (11.4)	-0.56 (24.7)	-0.56 (24.7)	-0.68 (20.6)
SED (57 df)			0.232		0.116
P			0.6 (interaction)		0.08
All	-0.60 (23.3)	-0.78 (17.3)	-0.51 (26.7)	-0.76 (17.9)	
SED (57 df)			0.104		
P			0.03		

Table 4.31. *Amounts of DNA (pg ng^{-1}) of* Microdochium nivale *var.* nivale *at GS71-75, Morley 1998*

Cultivar..	Lynx	Brigadier	Mercia	Soissons	All
Fungicide					
None	1.06	2.52	2.81	1.13	1.88
Prochloraz	0.62	14.96	0.90	11.39	6.97
Cyprodinil	0.27	9.43	2.79	2.18	3.67
Azoxystr.	0.24	0.20	0.13	0.06	0.16
HGCA1	1.43	0.60	0.49	1.16	0.92
SED (57 df)			4.581		2.291
P			0.4 (interaction)		0.03
All	0.72	5.54	1.42	3.19	
SED (57 df)			2.049		
P			0.1		

Table 4.32. *Amounts of DNA (pg ng^{-1}) of* Microdochium nivale *var.* majus *at GS71-75, Morley 1998*

Cultivar..	Lynx	Brigadier	Mercia	Soissons	All
Fungicide					
None	2.97	7.29	3.84	8.42	5.63
Prochloraz	2.74	5.44	1.91	6.90	4.25
Cyprodinil	3.84	6.85	3.31	11.07	6.27
Azoxystr.	4.08	8.98	0.93	3.88	4.47
HGCA1	7.76	5.38	4.54	5.83	5.88
SED (57 df)			2.123		1.062
P			0.06 (interaction)		0.2
All	4.28	6.79	2.90	7.22	
SED (57 df)			0.949		
P			<0.001		

Table 4.33. *Grain yields (t ha^{-1}) at Morley, 1998*

Cultivar..	Lynx	Brigadier	Mercia	Soissons	All
Fungicide					
None	8.25	8.36	7.83	8.39	8.21
Prochloraz	7.71	8.38	8.09	8.23	8.10
Cyprodinil	8.41	8.79	8.27	9.08	8.64
Azoxystrobin	8.69	9.33	8.35	8.41	8.69
HGCA1	8.28	8.91	7.96	8.70	8.46
SED (57 df)		0.380			0.190
P		0.6			0.01
All	8.27	8.75	8.10	8.56	
SED (57 df)		0.170			
P		0.002			

Table 4.34. *Incidence of eyespot at GS71-73, Morley 1999*

	Logit % main stems (back-transformed means)				
Cultivar...	Lynx	Abbot	Mercia	Soissons	All
Fungicide					
None	-0.38 (31.3)	0.07 (52.9)	-0.26 (37.0)	0.19 (58.7)	-0.10 (44.7)
Prochloraz	-0.35 (32.5)	-0.06 (46.6)	-0.86 (14.7)	0.04 (51.5)	-0.31 (34.6)
Cyprodinil	-1.19 (8.0)	-1.11 (9.4)	-1.88 (1.8)	-0.67 (20.2)	-1.21 (7.7)
Azoxystr.	-0.47 (27.7)	-0.14 (42.5)	-0.56 (24.1)	0.10 (54.4)	-0.27 (36.5)
HGCA1	-0.11 (43.8)	0.12 (55.2)	-0.38 (31.3)	0.31 (64.5)	-0.12 (48.6)
SED (57 df)		0.284			0.142
P		0.9 (interaction)			<0.001
All	-0.50 (26.4)	-0.22 (38.5)	-0.79 (16.7)	-0.01 (49.1)	
SED (57 df)		0.127			
P		<0.001			

Table 4.35. *Severity of eyespot at GS71-73, Morley 1999*

	Eyespot index (0-100)				
Cultivar...	Lynx	Abbot	Mercia	Soissons	All
Fungicide					
None	15.3	28.3	18.4	33.1	23.8
Prochloraz	15.4	24.0	7.5	30.0	19.2
Cyprodinil	4.5	3.8	2.2	8.9	4.9
Azoxystr.	12.8	20.8	12.7	31.9	19.5
HGCA1	21.7	30.6	16.4	35.8	26.1
SED (57 df)			4.08		2.04
P			0.1 (interaction)		<0.001
All	13.9	21.5	11.4	27.9	
SED (57 df)			1.82		
P			<0.001		

Table 4.36. *Amounts of DNA (pg ng^{-1}) of* Tapesia yallundae *at GS71-73, Morley 1999*

Cultivar...	Lynx	Abbot	Mercia	Soissons	All
Fungicide					
None	3.49	9.54	12.81	10.92	9.19
Prochloraz	4.26	4.58	2.54	8.75	5.03
Cyprodinil	2.75	2.24	2.56	2.25	2.45
Azoxystr.	5.39	13.16	11.71	10.82	10.27
HGCA1	7.52	7.73	5.38	7.79	7.11
SED (57 df)			3.503		1.751
P			0.4 (interaction)		<0.001
All	4.68	7.45	7.00	8.11	
SED (57 df)			1.567		
P			0.2		

Table 4.37. *Amounts of DNA (pg ng^{-1}) of* Tapesia acuformis *at GS71-73, Morley 1999*

Cultivar…	Lynx	Abbot	Mercia	Soissons	All
Fungicide					
None	1.81	9.99	5.12	14.29	7.80
Prochloraz	2.42	4.41	1.79	20.98	7.40
Cyprodinil	0.41	0.47	0.46	0.49	0.46
Azoxystr.	3.55	6.02	2.78	8.13	5.12
HGCA1	3.80	8.10	5.20	21.28	9.60
SED (57 df)			3.851		1.926
P			0.03 (interaction)		<0.001
All	2.40	5.80	3.07	13.03	
SED (57 df)			1.722		
P			<0.001		

Table 4.38. *Incidence of sharp eyespot at GS71-73, Morley 1999*

Logit % main stems (back-transformed means)

Cultivar…	Lynx	Abbot	Mercia	Soissons	All
Fungicide					
None	-2.43 (0.3)	-0.81 (15.9)	-1.25 (7.1)	-0.97 (12.0)	-1.37 (5.6)
Prochloraz	-1.16 (8.4)	-0.72 (18.6)	-1.23 (7.4)	-0.91 (13.4)	-1.01 (11.3)
Cyprodinil	-0.97 (12.1)	-0.95 (12.6)	-0.87 (14.5)	-1.00 (11.5)	-0.95 (12.6)
Azoxystr.	-2.74 (0)	-1.96 (1.4)	-1.82 (2.1)	-1.27 (6.8)	-1.95 (1.5)
HGCA1	-1.35 (5.8)	-0.74 (17.9)	-2.55 (0.1)	-0.79 (16.7)	-1.36 (5.7)
SED (57 df)			0.523		0.262
P			0.07 (interaction)		0.003
All	-1.73 (2.5)	-1.04 (10.7)	-1.54 (3.9)	-0.99 (11.7)	
SED (57 df)			0.234		
P			0.004		

Table 4.39. *Amounts of DNA (pg ng^{-1}) of Rhizoctonia cerealis at GS71-73, Morley 1999*

Cultivar...	Lynx	Abbot	Mercia	Soissons	All
Fungicide					
None	19.10	23.17	7.07	21.94	17.82
Prochloraz	12.74	21.13	7.89	18.96	15.18
Cyprodinil	19.82	25.14	15.53	21.16	20.41
Azoxystr.	6.28	9.55	3.10	4.18	5.78
HGCA1	13.77	23.01	5.05	12.53	13.59
SED (57 df)			5.876		2.938
P			0.9 (interaction)		<0.001
All	14.34	20.40	7.73	15.76	
SED (57 df)			2.628		
P			<0.001		

Table 4.40. *Incidence of brown foot rot at GS71-73, Morley 1999*

Logit % main stems (back-transformed means)

Cultivar…	Lynx	Abbot	Mercia	Soissons	All
Fungicide					
None	-0.26 (36.8)	-0.67 (20.8)	0.01 (50.1)	-0.32 (33.8)	-0.31 (34.6)
Prochloraz	-0.29 (35.2)	-0.72 (18.8)	0.25 (61.9)	-0.34 (33.2)	-0.27 (36.2)
Cyprodinil	-0.33 (33.6)	-0.60 (22.7)	-0.04 (47.6)	-0.60 (2.8)	-0.39 (30.9)
Azoxystr.	-0.07 (46.2)	-0.54 (24.8)	0.08 (53.5)	-0.56 (24.0)	-0.27 (36.2)
HGCA1	-0.48 (27.3)	-0.77 (17.2)	-0.02 (48.7)	-0.37 (31.6)	-0.41 (30.1)
SED (57 df)		0.195			0.097
P		0.7 (interaction)			0.5
All	-0.29 (35.6)	-0.66 (20.7)	0.06 (52.4)	-0.44 (28.9)	
SED (57 df)		0.087			
P		<0.001			

Table 4.41. *Amounts of DNA (pg ng^{-1}) of Microdochium nivale var.* nivale *at GS71-73, Morley 1999*

Cultivar…	Lynx	Abbot	Mercia	Soissons	All
Fungicide					
None	9.97	5.22	10.69	5.99	7.97
Prochloraz	6.50	3.62	5.62	17.67	8.35
Cyprodinil	6.41	1.16	6.00	7.29	5.21
Azoxystr.	9.99	2.83	3.00	1.97	4.45
HGCA1	5.43	2.31	1.84	5.22	3.70
SED (57 df)		2.959			1.480
P		0.005 (interaction)			0.006
All	7.66	3.03	5.43	7.63	
SED (57 df)		1.324			
P		0.002			

Table 4.42. *Grain yields (t ha^{-1} at 85% dry matter) at Morley, 1999*

Cultivar..	Lynx	Abbot	Mercia	Soissons	All
Fungicide					
None	6.67	7.76	8.29	7.12	7.48
Prochloraz	6.95	7.79	8.13	7.53	7.60
Cyprodinil	7.09	8.23	8.06	7.25	7.66
Azoxystr.	7.33	8.37	8.29	7.11	7.77
HGCA1	6.87	7.78	8.35	7.18	7.54
SED (57 df)			0.385		0.193
P			0.9 (interaction)		0.6
All	7.00	7.98	8.22	7.24	
SED (57 df)			0.172		
P			<0.001		

Table 4.43. *Incidence of eyespot at GS75-77, Rothamsted 1997*

	Logit % main stems (back-transformed means)				
Cultivar...	Lynx	Brigadier	Mercia	Soissons	All
Fungicide					
None	-0.28 (35.7)	0.10 (54.3)	-0.19 (40.3)	0.04 (51.6)	-0.08 (45.4)
Prochloraz	-0.66 (20.7)	-0.52 (25.5)	-0.37 (31.9)	-0.27 (36.6)	-0.45 (28.3)
Cyprodinil	-1.19 (8.0)	-0.78 (16.8)	-0.85 (14.9)	-0.78 (16.8)	-0.90 (13.7)
Azoxystr.	-0.35 (32.9)	0.29 (63.4)	-0.44 (28.8)	0.12 (55.3)	-0.10 (44.7)
Flusilazole	-0.80 (16.3)	-0.19 (40.1)	-0.64 (21.2)	-0.36 (37.3)	-0.50 (26.5)
SED (57 df)			0.303		0.152
P			0.9 (interaction)		<0.001
All	-0.66 (20.7)	-0.22 (38.6)	-0.50 (26.5)	-0.25 (37.3)	
SED (57 df)			0.136		
P			0.01		

Table 4.44. *Severity of eyespot at GS75-77, Rothamsted 1997*

	Eyespot index (0-100)				
Cultivar..	Lynx	Brigadier	Mercia	Soissons	All
Fungicide					
None	16.1	28.2	20.4	30.7	23.8
Prochloraz	8.1	14.3	16.8	19.0	14.5
Cyprodinil	3.6	10.4	7.6	10.9	8.1
Azoxystrobin	13.1	30.9	14.4	27.8	21.6
Flusilazole	7.1	20.4	10.5	19.7	14.4
SED (57 df)			5.32		2.66
P			0.7 (interaction)		<0.001
All	9.6	20.8	13.9	21.6	
SED (57 df)			2.38		
P			<0.001		

Table 4.45. *Amounts of DNA (pg ng^{-1}) of stem-base pathogens at GS75-77, Rothamsted 1997*

Cultivar.. Fungicide	Lynx	Brigadier	Mercia	Soissons	All
Tapesia yallundae					
None	3.47	*	7.62	8.02	5.21
Prochloraz	1.55	*	*	13.03	10.16
Cyprodinil	2.36	*	1.88	5.23	2.53
Azoxystrobin	2.36	17.30	8.97	17.25	10.19
Flusilazole	1.93	16.19	6.66	11.80	8.14
All	2.49	16.93	6.25	12.27	7.32
Tapesia acuformis					
None	2.07	*	4.74	7.51	3.69
Prochloraz	1.24	*	*	1.58	1.49
Cyprodinil	0.35	*	0.68	0.80	0.53
Azoxystrobin	1.87	4.31	2.55	3.63	2.88
Flusilazole	0.40	7.82	3.09	3.75	3.19
All	1.17	5.48	2.31	3.09	2.36
Rhizoctonia cerealis					
None	3.00	5.98	0.41	0.33	3.10
Prochloraz	2.44	0.59	*	1.14	1.48
Cyprodinil	3.49	0.45	1.57	0.36	1.84
Azoxystrobin	0.29	0.28	0.33	0.23	0.29
Flusilazole	2.25	1.01	6.03	3.74	3.01
All	2.37	1.58	1.85	1.24	1.81
M. nivale var. *nivale*					
None	0.083	1.153	0.001	0.005	0.366
Prochloraz	0.001	0.053	*	0.092	0.055
Cyprodinil	0.268	0.020	0.244	0.026	0.172
Azoxystrobin	0.004	0.008	0.024	0.002	0.011
Flusilazole	0.005	0.052	2.847	0.312	0.721
All	0.096	0.235	0.652	0.096	0.254
M. nivale var. *majus*					
None	0.12	0.14	0.43	0.08	0.16
Prochloraz	0.16	0.05	*	0.55	0.34
Cyprodinil	0.09	0.23	0.21	1.83	0.47
Azoxystrobin	0.15	0.22	0.17	0.23	0.19
Flusilazole	0.11	0.04	1.81	0.67	0.59
All	0.12	0.14	0.54	0.72	0.35

These data were not analysed statistically because of the large number of missing plot values.

Table 4.46. *Incidence of sharp eyespot at GS75-77, Rothamsted 1997*

	Logit % main stems (back-transformed means)				
Cuultivar...	Lynx	Brigadier	Mercia	Soissons	All
Fungicide					
None	-0.54 (24.8)	-0.32 (34.1)	-0.48 (27.2)	-1.71 (2.7)	-0.76 (17.4)
Prochloraz	-0.66 (20.5)	-0.47 (27.6)	-0.65 (21.0)	-1.23 (7.3)	-0.75 (17.6)
Cyprodinil	-0.62 (22.0)	-0.31 (34.4)	-0.76 (17.5)	-1.00 (11.3)	-0.67 (20.2)
Azoxystr.	-1.35 (5.8)	-1.53 (4.0)	-1.15 (8.5)	-1.98 (1.4)	-1.50 (4.2)
Flusilazole	-0.28 (35.9)	-0.50 (26.5)	-0.46 (28.0)	-1.01 (11.2)	-0.56 (24.0)
SED (57 df)		0.233			0.116
P		0.1 (interaction)			<0.001
All	-0.69 (19.6)	-0.63 (21.8)	-0.70 (19.3)	-1.39 (5.4)	
SED (57 df)		0.104			
P		<0.001			

Table 4.47. *Severity of sharp eyespot at GS75-77, Rothamsted 1997*

	Sharp eyespot index (0-100)				
Cultivar..	Lynx	Brigadier	Mercia	Soissons	All
Fungicide					
None	9.8	16.0	14.7	0.9	10.4
Prochloraz	8.0	11.7	10.1	4.2	8.5
Cyprodinil	9.1	15.0	8.9	5.6	9.7
Azoxystrobin	2.1	2.0	3.1	0.3	1.9
Flusilazole	12.8	11.8	13.5	6.2	11.1
SED (57 df)		2.97			1.49
P		0.2 (interaction)			<0.001
All	8.4	11.3	10.1	3.5	
SED (57 df)		1.33			
P		<0.001			

Table 4.48. *Incidence of brown foot rot at GS75-77, Rothamsted 1997*

Logit % main stems (back-transformed means)

Cuultivar...	Lynx	Brigadier	Mercia	Soissons	All
Fungicide					
None	-1.48 (4.4)	-1.27 (6.9)	-0.70 (19.2)	-0.30 (34.9)	-0.94 (12.8)
Prochloraz	-1.34 (5.9)	-1.20 (7.8)	-0.44 (28.9)	-0.44 (29.0)	-0.85 (14.9)
Cyprodinil	-1.81 (2.1)	-1.9 (1.3)	-1.03 (10.7)	-1.27 (6.8)	-1.53 (4.0)
Azoxystr.	-1.90 (1.7)	-1.60 (3.4)	-0.53 (25.3)	-1.06 (10.1)	-1.27 (6.8)
Flusilazole	-2.15 (0.8)	-1.36 (5.7)	-0.30 (34.9)	-0.44 (28.9)	-1.06 (10.2)
SED (57 df)		0.275			0.138
P		0.1 (interaction)			<0.001
All	-1.74 (2.5)	-1.48 (4.4)	-0.60 (22.6)	-0.70 (19.2)	
SED (57 df)		0.123			
P		<0.001			

Table 4.49. *Severity of brown foot rot at GS75-77, Rothamsted 1997*

Brown foot rot index (0-100)

Cultivar..	Lynx	Brigadier	Mercia	Soissons	All
Fungicide					
None	2.2	3.4	9.4	16.9	8.0
Prochloraz	2.6	3.6	13.3	12.3	8.0
Cyprodinil	0.9	0.2	5.1	2.4	2.1
Azoxystrobin	0.7	1.5	10.2	3.9	4.1
Flusoilazole	0.0	2.8	15.8	13.0	7.9
SED (57 df)		2.36			1.18
P		<0.001 (interaction)			<0.001
All	1.3	2.3	10.8	9.7	
SED (57 df)		1.06			
P		<0.001			

Table 4.50. *Grain yields (t ha^{-1}) at Rothamsted, 1997*

	Lynx	Brigadier	Mercia	Soissons	All
Fungicide					
None	9.83	8.53	8.07	7.97	8.60
Prochloraz	9.20	9.11	7.94	7.85	8.53
Cyprodinil	9.89	8.65	8.37	8.32	8.81
Azoxystrobin	10.29	10.58	7.86	8.53	9.31
Flusilazole	9.58	9.35	7.95	8.17	8.76
SED (57 df)			0.474		0.237
P			0.10 (interaction)		0.02
All	9.76	9.24	8.04	8.17	
SED (57 df)			0.212		
P			<0.001		

Table 4.51. *Eyespot incidence at GS73, Rothamsted 1998*

Logit % main stems (back-transformed means)

Cuultivar...	Lynx	Brigadier	Mercia	Soissons	All
Fungicide					
None	0.45 (70.9)	1.16 (91.1)	0.90 (85.7)	1.48 (95.1)	1.00 (88.0)
Prochloraz	-0.13 (43.5)	0.19 (59.5)	-0.03 (48.4)	0.10 (54.8)	0.03 (51.6)
Cyprodinil	-0.12 (44.1)	0.57 (75.8)	0.51 (73.7)	0.10 (54.8)	0.27 (63.0)
Azoxystr.	0.42 (70.0)	1.35 (93.7)	0.89 (85.6)	1.46 (94.9)	1.03 (88.7)
HGCA1	0.83 (67.7)	1.01 (88.3)	0.77(82.5)	1.16 (91.0)	0.83 (84.0)
SED (57 df)			0.238		0.119
P			0.1 (interaction)		<0.001
All	0.20 (59.8)	0.86 (84.8)	0.61 (77.2)	0.86 (84.8)	
SED (57 df)			0.106		
P			<0.001		

Table 4.52. *Eyespot severity at GS73, Rothamsted 1998*

	Eyespot index (0-100)				
Cuultivar...	Lynx	Brigadier	Mercia	Soissons	All
Fungicide					
None	34.7	46.9	52.1	60.8	48.6
Prochloraz	17.1	23.1	20.7	25.4	21.6
Cyprodinil	17.8	32.4	32.1	23.6	26.5
Azoxystr.	34.2	54.1	46.5	59.7	48.6
HGCA1	34.8	47.0	43.1	50.7	43.9
SED (57 df)			4.63		2.31
P			0.02 (interaction)		<0.001
All	27.2	40.7	38.9	44.8	
SED (57 df)			2.07		
P			<0.001		

Table 4.53. *Amounts of DNA (pg ng^{-1}) of* Tapesia yallundae *at GS73, Rothamsted 1998*

Cultivar..	Lynx	Brigadier	Mercia	Soissons	All
Fungicide					
None	17.2	21.2	41.9	36.0	29.1
Prochloraz	8.3	11.5	12.5	17.2	12.4
Cyprodinil	4.2	13.5	40.4	23.7	20.5
Azoxystr.	19.3	35.0	37.7	51.5	35.9
HGCA1	19.7	25.2	20.3	45.9	27.8
SED (57 df)			8.30		4.15
P			0.05 (interaction)		<0.001
All	13.8	21.3	30.5	34.9	
SED (57 df)			3.71		
P			<0.001		

Table 4.54. *Amounts of DNA (pg ng^{-1}) of* Tapesia acuformis *at GS73, Rothamsted 1998*

Cultivar..	Lynx	Brigadier	Mercia	Soissons	All
Fungicide					
None	1.87	2.23	3.67	2.82	2.65
Prochloraz	0.84	1.12	0.84	1.30	1.02
Cyprodinil	0.43	0.56	0.85	0.32	0.54
Azoxystr.	1.73	2.59	2.14	4.42	2.72
HGCA1	1.93	2.43	2.31	3.77	2.61
SED (57 df)			0.724		0.362
P			0.1 (interaction)		<0.001
All	1.36	1.79	1.96	2.53	
SED (57 df)			0.324		
P			0.007		

Table 4.55. *Incidence of sharp eyespot at GS73, Rothamsted 1998*

Logit % main stems (back-transformed means)

Cuultivar...	Lynx	Brigadier	Mercia	Soissons	All
Fungicide					
None	-0.20 (40.3)	-1.16 (8.9)	-0.59 (23.5)	-1.00 (12.0)	-0.74 (18.6)
Prochloraz	-0.11 (44.6)	-0.67 (20.8)	-0.41 (30.7)	-1.23 (7.8)	-0.60 (32.0)
Cyprodinil	-0.50 (26.8)	-1.11 (9.8)	-0.71 (19.6)	-0.61 (22.9)	-0.73 (18.8)
Azoxystr.	-0.93 (13.5)	-1.47 (5.1)	-1.19 (8.6)	-2.01 (1.8)	-1.40 (5.8)
HGCA1	-0.87 (15.0)	-1.07 (10.6)	-0.46 (28.4)	-1.24 (7.7)	-0.91 (13.9)
SED (57 df)			0.322		0.161
P			0.3 (interaction)		<0.001
All	-0.52 (26.1)	-1.09 (10.1)	-0.67 (20.7)	-1.22 (8.0)	
SED (57 df)			0.144		
P			<0.001		

Table 4.56. *Severity of sharp eyespot at GS73, Rothamsted 1998*

	Sharp eyespot index				
Cuultivar...	Lynx	Brigadier	Mercia	Soissons	All
Fungicide					
None	21.6	4.0	12.0	6.3	11.0
Prochloraz	23.8	13.7	17.5	7.0	15.5
Cyprodinil	17.5	6.6	11.4	10.6	11.5
Azoxystr.	5.5	2.1	5.3	0.2	3.3
HGCA1	9.7	4.5	11.7	3.6	7.4
SED (57 df)			5.03		2.51
P			0.7 (interaction)		<0.001
All	15.6	6.2	11.6	5.6	
SED (57 df)			2.25		
P			<0.001		

Table 4.57. *Amounts of DNA (pg ng^{-1}) of* Rhizoctonia cerealis *at GS73, Rothamsted 1998*

Cultivar..	Lynx	Brigadier	Mercia	Soissons	All
Fungicide					
None	3.75	2.53	2.34	2.03	2.66
Prochloraz	4.61	3.09	3.18	1.81	3.18
Cyprodinil	3.80	3.17	3.37	2.59	3.23
Azoxystr.	1.87	1.50	2.21	0.87	1.61
HGCA1	2.45	1.14	3.98	1.82	2.35
SED (57 df)			1.064		0.532
P			0.7 (interaction)		0.02
All	3.30	2.29	3.02	1.82	
SED (57 df)			0.476		
P			0.01		

Table 4.58. *Incidence of brown foot rot at GS73, Rothamsted 1998*

Logit % main stems (back-transformed mean)

Cultivar..	Lynx	Brigadier	Mercia	Soissons	All
Fungicide					
None	-0.73 (19.0)	-0.71 (19.5)	-0.50 (27.1)	-0.99 (12.2)	-0.73 (18.9)
Prochloraz	-0.89 (14.4)	-0.34 (33.5)	-0.30 (35.5)	-0.45 (29.1)	-0.50 (27.1)
Cyprodinil	-0.78 (17.3)	-0.79 (17.0)	-0.52 (26.0)	-0.54 (25.3)	-0.66 (21.1)
Azoxystrobin	-0.71 (19.5)	-1.00 (12.9)	-0.05 (47.3)	-1.41 (5.6)	-0.78 (17.3)
HGCA1	-0.53 (25.9)	-0.66 (21.0)	-0.44 (29.5)	-1.37 (6.1)	-0.75 (18.3)
SED (57 df)		0.265			0.133
P		0.01 (interaction)			0.01
All	-0.73 (19.0)	-0.69 (20.0)	-0.36 (32.7)	-0.95 (13.0)	
SED (57 df)		0.119			
P		<0.001			

Table 4.59. *Severity of brown foot rot at GS73, Rothamsted 1998*

Brown foot rot index (0-100)

Cultivar...	Lynx	Brigadier	Mercia	Soissons	All
Fungicide					
None	7.4	6.6	10.2	4.3	7.1
Prochloraz	5.7	11.8	13.1	9.8	10.1
Cyprodinil	7.8	6.3	9.3	8.6	8.0
Azoxystr.	9.7	4.1	17.2	1.6	8.2
HGCA1	11.1	7.1	11.0	2.6	7.9
SED (54 df)		3.02			1.51
P		0.02 (interaction)			0.4
All	8.4	7.2	12.1	5.4	
SED (54.df)		1.35			
P		<0.001			

Table 4.60. *Amounts of DNA (pg ng^{-1}) of* Microdochium nivale *var.* nivale *at GS73, Rothamsted, 1998*

Cultivar..	Lynx	Brigadier	Mercia	Soissons	All
Fungicide					
None	0.80	0.99	0.47	1.07	0.83
Prochloraz	0.44	0.86	0.34	0.97	0.65
Cyprodinil	0.52	1.15	0.47	0.66	0.70
Azoxystr.	0.38	0.54	0.31	0.52	0.44
HGCA1	0.77	1.31	0.78	0.65	0.88
SED (57 df)			0.264		0.132
P			0.6 (interaction)		0.01
All	0.58	0.97	0.47	0.77	
SED (57 df)			0.118		
P			<0.001		

Table 4.61. *Amounts of DNA (pg ng^{-1}) of* Microdochium nivale *var.* majus *at GS73, Rothamsted 1998*

Cultivar..	Lynx	Brigadier	Mercia	Soissons	All
Fungicide					
None	1.10	3.98	2.20	3.71	2.75
Prochloraz	1.23	3.21	1.82	3.75	2.50
Cyprodinil	1.62	1.86	1.95	2.02	1.86
Azoxystr.	2.79	3.13	0.69	2.51	2.28
HGCA1	1.79	3.07	1.69	3.04	2.40
SED (57 df)			1.232		0.616
P			0.8 (interaction)		0.7
All	1.71	3.05	1.67	3.00	
SED (57 df)			0.551		
P			0.01		

Table 4.62. *Grain yields (t ha^{-1}) at Rothamsted, 1998*

Cultivar…	Lynx	Brigadier	Mercia	Soissons	All
Fungicide					
None	9.13	9.61	8.68	8.44	8.96
Prochloraz	9.73	9.83	8.97	8.78	9.33
Cyprodinil	9.44	9.52	8.07	9.32	9.09
Azoxystr.	10.69	9.81	9.43	10.16	10.02
HGCA1	8.84	9.80	8.86	9.34	9.21
SED (54 df)			0.276		0.552
P			0.4 (interaction)		0.003
All	9.56	9.72	8.80	9.21	
SED (54 df)			0.247		
P			0.002		

Table 4.63. *Incidence of eyespot at GS73, Rothamsted 1999*

Logit % main stems (back-transformed means)

Cultivar…	Lynx	Abbot	Mercia	Soissons	All
Fungicide					
None	0.29 (63.6)	0.52 (73.3)	0.58 (75.8)	1.01 (87.7)	0.60 (76.3)
Prochloraz	0.33 (65.6)	0.43 (69.7)	0.35 (66.4)	0.92 (85.8)	0.51 (72.9)
Cyprodinil	-0.23 (38.3)	-0.23 (38.2)	0.06 (52.5)	0.17 (58.0)	-0.06 (46.7)
Azoxystr.	0.77 (81.9)	1.17 (90.6)	1.00 (87.6)	1.56 (95.3)	1.13 (90.0)
HGCA1	0.39 (68.2)	0.75 (81.2)	0.53 (73.9)	1.01 (89.5)	0.69 (79.5)
SED (57 df)			0.211		0.106
P			0.9 (interaction)		<0.001
All	0.31 (64.6)	0.53 (73.6)	0.51 (72.8)	0.95 (86.5)	
SED (57 df)			0.094		
P			<0.001		

Table 4.64. *Eyespot severity at GS73, Rothamsted 1999*

	Eyespot index (0-100)				
Cultivar…	Lynx	Abbot	Mercia	Soissons	All
Fungicide					
None	37.3	42.5	47.6	58.6	46.5
Prochloraz	41.1	41.2	41.2	60.6	46.0
Cyprodinil	17.3	15.3	25.3	29.5	21.8
Azoxystr.	52.0	66.9	67.7	69.1	63.9
HGCA1	35.7	52.5	46.5	66.2	50.2
SED (57 df)			5.92		2.96
P			0.2 (interaction)		<0.001
All	36.7	43.7	45.6	56.8	
SED (57 df)			2.65		
P			<0.001		

Table 4.65. *Amounts of DNA (pg ng^{-1}) of* Tapesia yallundae *at GS73, Rothamsted 1999*

Cultivar..	Lynx	Abbot	Mercia	Soissons	All
Fungicide					
None	5.57	8.65	13.75	11.65	9.91
Prochloraz	2.22	6.82	6.06	7.47	5.64
Cyprodinil	2.70	5.55	8.21	8.21	6.17
Azoxystr.	5.30	13.51	10.92	13.88	10.90
HGCA1	4.02	7.42	9.90	11.34	8.71
SED (57 df)			1.454		0.727
P			0.05 (interaction)		<0.001
All	3.96	8.39	9.77	10.51	
SED (57 df)			0.650		
P			<0.001		

Table 4.66. *Amounts of DNA (pg ng^{-1}) of* Tapesia acuformis *at GS73, Rothamsted 1999*

Cultivar..	Lynx	Abbot	Mercia	Soissons	All
Fungicide					
None	8.18	6.38	7.32	7.90	7.45
Prochloraz	6.17	7.86	7.75	9.91	7.92
Cyprodinil	2.84	2.14	2.98	2.93	2.72
Azoxystr.	8.20	9.74	8.22	7.00	8.29
HGCA1	9.21	7.33	10.97	7.41	8.73
SED (57 df)			1.809		0.904
P			0.4 (interaction)		<0.001
All	6.92	6.69	7.45	7.03	
SED (57 df)			0.809		
P			0.8		

Table 4.67. *Incidence of sharp eyespot at GS73, Rothamsted 1999*

	Logit % main stems with sharp eyespot (back-transformed means)				
Cultivar…	Lynx	Abbot	Mercia	Soissons	All
Fungicide					
None	-1.18 (8.1)	-0.93 (13.1)	-1.56 (3.7)	-1.20 (7.8)	-1.22 (7.6)
Prochloraz	-1.04 (10.6)	-0.54 (24.8)	-0.74 (18.1)	-1.27 (6.8)	-0.90 (13.7)
Cyprodinil	-0.67 (20.1)	-0.55 (24.6)	-0.65 (21.0)	-0.95 (12.4)	-0.71 (19.1)
Azoxystr.	-1.11 (9.3)	-2.18 (0.8)	-1.24 (7.2)	-1.78 (2.3)	-1.58 (3.6)
HGCA1	-1.00 (11.5)	-0.70 (19.4)	-0.81 (16.0)	-1.59 (3.5)	-1.02 (10.9)
SED (57 df)			0.324		0.162
P			0.03 (interaction)		<0.001
All	-1.00 (11.4)	-0.98 (11.9)	-1.00 (11.4)	-1.36 (5.7)	
SED (57 df)			0.145		
P			0.03		

Table 4.68. *Sharp eyespot severity at GS73, Rothamsted 1999*

	Sharp eyespot index (0-100)				
Cultivar…	Lynx	Abbot	Mercia	Soissons	All
Fungicide					
None	6.0	6.2	2.6	4.2	4.7
Prochloraz	7.7	13.8	12.2	5.4	9.8
Cyprodinil	8.7	11.5	10.5	7.8	9.6
Azoxystr.	4.7	0.0	3.3	0.7	2.2
HGCA1	6.2	9.1	7.4	2.6	6.3
SED(57df)			3.30		1.65
P			0.6 (interaction)		<0.001
All	6.6	8.1	7.2	4.1	
SED (57 df)			1.47		
P			0.06		

Table 4.69. *Amounts of DNA (pg ng^{-1}) of* Rhizoctonia cerealis *at GS73, Rothamsted 1999*

Cultivar..	Lynx	Abbot	Mercia	Soissons	All
Fungicide					
None	3.08	3.56	1.87	2.41	2.73
Prochloraz	2.94	4.92	2.59	3.49	3.49
Cyprodinil	2.41	6.00	4.97	3.21	4.15
Azoxystr.	2.42	1.58	1.39	0.68	1.52
HGCA1	5.03	3.93	2.99	2.45	3.60
SED (57 df)			1.381		0.691
P			0.5		0.004
All	3.17	4.00	2.76	2.45	
SED (57 df)			0.618		
P			0.08		

Table 4.70. *Incidence of brown foot rot at GS73, Rothamsted 1999*

	Logit % main stems (back-transformed means)				
Cultivar...	Lynx	Abbot	Mercia	Soissons	All
Fungicide					
None	-0.15 (42.2)	-0.61 (22.5)	0.12 (55.4)	-0.58 (23.2)	-0.30 (34.7)
Prochloraz	-0.39 (31.1)	-0.71 (18.9)	-0.20 (39.8)	-1.22 (7.6)	-0.63 (21.7)
Cyprodinil	-0.27 (36.1)	-0.28 (35.9)	-0.09 (45.2)	-0.80 (16.3)	-0.36 (32.3)
Azoxystr.	-0.44 (28.8)	-0.65 (20.8)	-0.44 (28.8)	-1.53 (4.0)	-0.77 (17.3)
HGCA1	-0.37 (31.6)	-0.68 (20.1)	-0.19 (40.4)	-1.67 (2.9)	-0.73 (18.4)
SED (57 df)		0.257			0.128
P		0.3 (interaction)			<0.001
All	-0.32 (33.8)	-0.59 (23.2)	-0.16 (41.7)	-1.16 (8.5)	
SED (57 df)		0.115			
P		<0.001			

Table 4.71. *brown foot rot severity at GS73, Rothamsted 1999*

	Brown foot rot index (0-100)				
Cultivar...	Lynx	Abbot	Mercia	Soissons	All
Fungicide					
None	22.0	12.3	23.3	10.7	17.1
Prochloraz	12.8	8.7	18.0	3.2	10.7
Cyprodinil	13.9	14.7	19.0	6.1	13.4
Azoxystr.	13.6	10.4	14.3	2.7	10.3
HGCA1	15.0	7.7	17.9	1.8	10.6
SED (57 df)		3.62			1.81
P		0.8 (interaction)			0.001
All	15.5	10.8	18.5	4.9	
SED (57 df)		1.62			
P		<0.001			

Table 4.72. *Amounts of DNA (pg ng^{-1}) of* Microdochium nivale *var.* nivale *at GS73, Rothamsted 1999*

Cultivar..	Lynx	Abbot	Mercia	Soissons	All
Fungicide					
None	1.82	1.84	4.17	2.74	2.64
Prochloraz	0.80	3.57	2.22	2.24	2.20
Cyprodinil	0.27	0.87	1.24	0.61	0.75
Azoxystr.	0.36	1.31	2.59	0.81	1.27
HGCA1	1.13	1.59	6.12	1.77	2.65
SED (57 df)			1.410		0.705
P			0.5		0.03
All	0.88	1.84	3.27	1.63	
SED (57 df)			0.630		
P			0.004		

Table 4.73. *Grain yields (t ha^{-1}) at Rothamsted, 1999*

Cultivar...	Lynx	Abbot	Mercia	Soissons	All
Fungicide					
None	7.01	6.50	5.61	6.11	6.31
Prochloraz	6.32	6.00	6.31	6.67	6.32
Cyprodinil	7.12	6.61	6.68	5.51	6.48
Azoxystr.	5.99	6.49	6.67	7.26	6.60
HGCA1	6.57	7.20	7.02	5.05	6.46
SED (57 df)			0.636		0.318
P			0.02 (interaction)		0.9
All	6.60	6.56	6.46	6.12	
SED (57 df)			0.284		
P			0.3		

Table 4.74. *Summary of effects of cultivars on mean disease indices or incidences (%) and amounts of pathogen DNA*

	1997	1998	1999
Harper Adams			
Eyespot	L*M B S	L*S M*B	S L A M
Tapesia yallundae DNA	-	-	L*A M S
T. acuformis DNA	L*M B S	L S B*M	L A*S*M
Sharp eyespot (% in 1997)	S B M L	B S*L M	S L M A
Rhizoctonia cerealis DNA	-	B S M L	S M L A
Brown foot rot (% in 1997)	S M L B	S L B M	L*M S A
M. nivale var. *nivale* DNA	B L S M	M L*B S	S A L*M
M. nivale var. *majus* DNA	-	-	L A S M
Morley			
Eyespot	L*M*S B	L*M*S*B	M L*A*S
Tapesia yallundae DNA	-	-	L M A S
T. acuformis DNA	L*M*B=S	L*B M S	L M A*S
Sharp eyespot (%)	M L B S	L B S M	L M*A S
Rhizoctonia cerealis DNA	M L*B*S	B*S L M	M*L S A
Brown foot rot (%)	L S M B	B S L M	A*S L M
M. nivale var. *nivale* DNA	M L S B	L M S B	A M S L
M. nivale var. *majus* DNA	-	M L*B S	-
Rothamsted			
Eyespot	L M*B S	L*M B S	L*A M*S
Tapesia yallundae DNA	[L M S B]	L*B*M S	L*A*M S
T. acuformis DNA	[L M S B]	L B M S	A L S M
Sharp eyespot	S*L M B	S B*M*L	S L M A
Rhizoctonia cerealis DNA	[S B M L]	S B M L	S M L A
Brown foot rot	L B*S M	S B L*M	S*A*L M
M. nivale var. *nivale* DNA	[L=S B M]	M L S B	L S A*M
M. nivale var. *majus* DNA	[L B M S]	M L*S B	L A S M

Cultivars: A, Abbot; B, Brigadier; L, Lynx; M, Mercia; S, Soissons.
Cultivars are listed in order of increasing amounts of disease or pathogen DNA. These are based on averages over all fungicide treatments and therefore do not necessarily reflect relative susceptibilities to disease.
*indicates a significant ($P \leq 0.05$) difference between adjacent cultivars.
[ ], the data were not analysed statistically because of missing values.
-, amounts of DNA were insufficient to quantify.

Table 4.75. *Summary of effects of fungicides on mean disease indices or incidences (%), amounts of pathogen DNA and grain yields*

	1997	1998	1999
Harper Adams			
Eyespot	*C**F A P	*C P**H A	C H P A
Tapesia yallundae DNA	-	-	*C* H*P A
T. acuformis DNA	*C***P F* A	C P*H A	*C**P H A
Sharp eyespot (% in 1997)	*C**P A*F	*A**H C P	A P H C
Rhizoctonia cerealis DNA	-	A H*P C	*A**H P C
Brown foot rot (% in 1997)	*C**P A*F	A C P H	P A H C
M. nivale var. *nivale* DNA	A C P F	H A P C	A=H P C
M. nivale var. *majus* DNA	-	-	A P C H
Grain yield	A C P F	H C P A	*A**C*H P
Morley			
Eyespot	*C**F A P	*C**P H A	*C***P A**H
Tapesia yallundae DNA	-	-	*C P* H A
T. acuformis DNA	*C**A P F	*C***A**H P	*C**A P H
Sharp eyespot (%)	*A**F P C	*A**H C P	*A**H P C
Rhizoctonia cerealis DNA	A F P C	*A**H P C	*A**H P C
Brown foot rot (%)	A C P F	P C H A	H C A=P
M. nivale var. *nivale* DNA	A P F C	A H C P	*H A* C*P
M. nivale var. *majus* DNA	-	P A H C	-
Grain yield	*A C**F P	*A C* H P	A C P H
Rothamsted			
Eyespot	*C***F P**A	*P***C***H**A	*C**P H A
Tapesia yallundae DNA	[C F P A]	*P***C* H*A	*P C**H A
T. acuformis DNA	[C P A F]	*C P**H A	*C**P A H
Sharp eyespot	*A**P C F	*A* H C P	A*H C P
Rhizoctonia cerealis DNA	[A P C F]	*A* H P C	*A**H P C
Brown foot rot	*C A**P F	H C A P	*A H P C*
M. nivale var. *nivale* DNA	[A P C F]	*A* P C H	*C* A P H
M. nivale var. *majus* DNA	[A P C F]	C A H P	P A H C
Grain yield	*A**F C P	*A* H P C	A H C P

(Footnotes on next page)

Table 4.75 (continued)

Fungicides: A, azoxystrobin; C, cyprodinil; F, flusilazole; H, HGCA1; P, prochloraz; where italicised, there was a significant benefit over the untreated.
Fungicides are listed in decreasing order of effectiveness.
*indicates a significant ($P \leq 0.05$) difference between adjacent fungicide treatments.
[ ], the data were not analysed statistically because of missing values.
-, amounts of DNA were insufficient to quantify.
Italics indicate that the value was significantly less than (diseases and DNA) or more than (grain yields) that of the untreated control.

Table 4.76. *Summary of effects of fungicides on incidence or severity of stem-base diseases at GS69-85 and grain yield, 1997-99*

	No. significant decreases (disease) or increases (yield)[a]					
Cultivar...	Lynx	Brigadier	Abbot	Mercia	Soissons	All
Fungicide						
Eyespot (disease index, 0-100)						
Prochloraz	1 (9)	3 (6)	0 (3)	2 (9)	2 (9)	4 (9)
Cyprodinil	4 (9)	5 (6)	2 (3)	7 (9)	8 (9)	8 (9)
Azoxystr.	0 (9)	0 (6)	0 (3)	0 (9)	0 (9)	0 (9)
Flusilazole	0 (3)	0 (3)	0 (0)	1 (3)	1 (3)	1 (3)
HGCA1	0 (6)	0 (3)	0 (3)	0 (6)	1 (6)	0 (6)
Sharp eyespot (% plants)						
Prochloraz	0 (9)	0 (6)	0 (3)	0 (9)	0 (9)	0 (9)
Cyprodinil	0 (9)	0 (6)	0 (3)	0 (9)	0 (9)	0 (9)
Azoxystr.	3 (9)	1 (6)	2 (3)	1 (9)	2 (9)	6 (9)
Flusilazole	0 (3)	0 (3)	0 (0)	0 (3)	0 (3)	0 (3)
HGCA1	1 (6)	0 (3)	0 (3)	1 (6)	0 (6)	1 (6)
Brown foot rot (% plants)						
Prochloraz	0 (9)	0 (6)	0 (3)	0 (9)	1 (9)	1 (9)
Cyprodinil	1 (9)	1 (6)	0 (3)	1 (9)	2 (9)	2 (9)
Azoxystr.	0 (9)	0 (6)	0 (3)	1 (9)	2 (9)	2 (9)
Flusilazole	0 (3)	0 (3)	0 (0)	0 (3)	0 (3)	0 (3)
HGCA1	0 (6)	0 (3)	0 (3)	0 (6)	1 (6)	1 (6)
Grain yield (t ha^{-1})						
Prochloraz	0 (9)	0 (6)	0 (3)	0 (9)	0 (9)	0 (9)
Cyprodinil	0 (9)	0 (6)	0 (3)	2 (9)	3 (9)	3 (9)
Azoxystr.	2 (9)	3 (6)	1 (3)	3 (9)	3 (9)	5 (9)
Flusilazole	0 (3)	0 (3)	0 (0)	1 (3)	0 (3)	0 (3)
HGCA1	0 (6)	0 (3)	0 (3)	1 (6)	0 (6)	0 (6)

[a]The numbers of tests are shown in parentheses.
Effects are considered significant where the difference between untreated and treated exceeds 2 x SED and where there is a significant ($P \leq 0.05$) effect of fungicide over all cultivars.

Table 4.77. *Summary of effects of fungicides on amounts of pathogen DNA at GS69-85, 1997-99*

	No. significant decreases[a]					
Cultivar...	Lynx	Brigadier	Abbot	Mercia	Soissons	All
Fungicide						
Tapesia yallundae						
Prochloraz	1 (4)	0 (1)	0 (3)	3 (4)	2 (4)	3 (4)
Cyprodinil	0 (4)	0 (1)	3 (3)	2 (4)	2 (4)	4 (4)
Azoxystr.	0 (4)	0 (1)	0 (3)	0 (4)	0 (4)	0 (4)
Flusilazole	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
HGCA1	0 (4)	0 (1)	0 (3)	3 (4)	0 (4)	0 (4)
Tapesia acuformis						
Prochloraz	0 (8)	0 (5)	0 (3)	1 (8)	2 (8)	2 (8)
Cyprodinil	3 (8)	3 (5)	1 (3)	5 (8)	8 (8)	8 (8)
Azoxystr.	0 (8)	0 (5)	0 (3)	0 (8)	2 (8)	1 (8)
Flusilazole	0 (2)	0 (2)	0 (0)	0 (2)	1 (2)	1 (2)
HGCA1	0 (6)	0 (3)	0 (3)	0 (6)	0 (6)	0 (6)
Rhizoctonia cerealis						
Prochloraz	0 (7)	0 (4)	0 (3)	0 (7)	0 (7)	0 (7)
Cyprodinil	0 (7)	0 (4)	0 (3)	0 (7)	0 (7)	0 (7)
Azoxystr.	1 (7)	0 (4)	1 (3)	1 (7)	2 (7)	5 (7)
Flusilazole	0 (1)	0 (1)	0 (0)	0 (1)	0 (1)	0 (1)
HGCA1	0 (6)	0 (3)	0 (3)	0 (6)	0 (6)	0 (6)
Microdochium nivale var. *majus*						
Prochloraz	0 (4)	0 (2)	0 (2)	0 (4)	0 (4)	0 (4)
Cyprodinil	0 (4)	0 (2)	0 (2)	0 (4)	0 (4)	0 (4)
Azoxystr.	0 (4)	0 (2)	0 (2)	0 (4)	0 (4)	0 (4)
Flusilazole	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
HGCA1	0 (4)	0 (2)	0 (2)	0 (4)	0 (4)	0 (4)
Microdochium nivale var. *nivale*						
Prochloraz	0 (8)	0 (5)	0 (3)	0 (8)	0 (8)	0 (8)
Cyprodinil	0 (8)	0 (5)	0 (3)	1 (8)	0 (8)	1 (8)
Azoxystr.	0 (8)	0 (5)	0 (3)	1 (8)	1 (8)	2 (8)
Flusilazole	0 (2)	0 (2)	0 (0)	0 (2)	0 (2)	0 (2)
HGCA1	0 (6)	0 (3)	0 (3)	1 (6)	0 (6)	1 (6)

[a]The numbers of tests are shown in parentheses.
Effects are considered significant where the difference between untreated and treated exceeds 2 x SED and where there is a significant ($P \leq 0.05$) effect of fungicide over all cultivars.

Table 4.78. *Daily rainfall (mm) in the 10 days after fungicidide applications*

Days after treatment...	0	1	2	3	4	5	6	7	8	9	10
Harper Adams											
1997	0	0	0	0	0	0	1.4	0	0	6.4	9.8
1998	0	3.0	9.4	2.0	2.2	6.6	0	4.0	5.3	4.8	4.0
1999	0.2	0	2.8	0	0	1.2	0	1.4	0.2	0	0
Morley											
1997	0.8	0.4	0	0	0	0	0	0	11.2	2.6	0
1998	1.0	5.4	11.0	0.8	0	4.0	4.4	5.6	0.2	0.2	1.0
1999	0.2	1.0	2.6	6.0	0.2	8.6	0.8	0.2	1.4	2.4	0
Rothamsted											
1997	0	0	0	0	0	0	0	10.4	0	0.4	0.4
1998	3.8	16.6	3.8	6.0	2.1	0	0.6	9.0	11.9	0.5	0.1
1999	0	0	7.5	7.1	3.2	0	1.2	0.5	4.4	0	1.7

Table 4.79. *Performance of prochloraz applied at GS31 on eyespot severity assessed at GS 71-85 in relation to the presence of quantifiable* Tapesia yallundae *DNA and rainfall events within 7 days of application*

		Significant eyespot control	Quantifiable *T. yallundae* DNA	Rainfall events (>5 mm)
Harper Adams	1997	N	N	N
	1998	Y	N	Y
	1999	N	Y	N
Morley	1997	N	N	N
	1998	N	N	Y
	1999	Y	Y	Y
Rothamsted	1997	Y	Y	N
	1998	Y	Y	Y
	1999	N	Y	Y

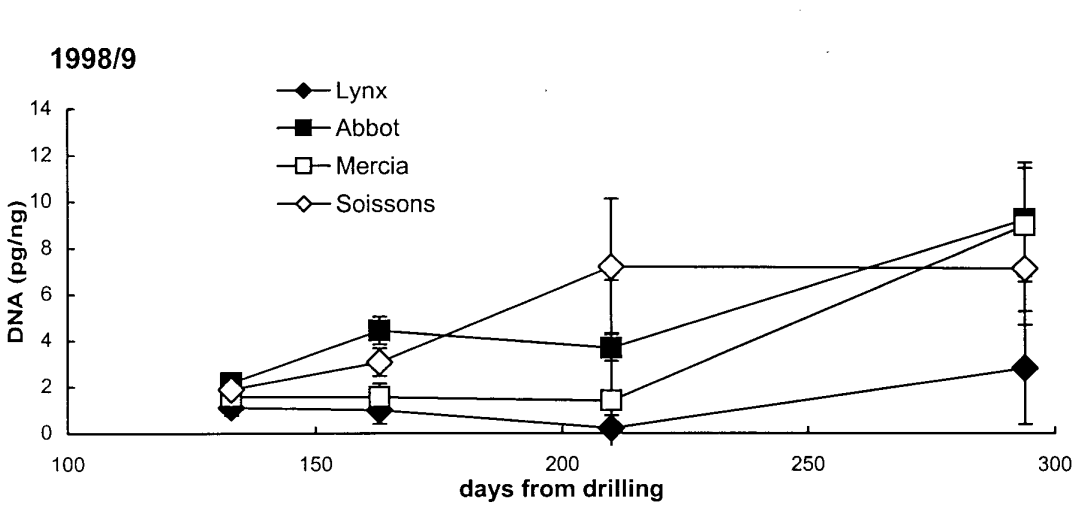

Figure 5.1. Development of *Tapesia yallundae* in untreated plots at Harper Adams. Vertical bars show SED (df = 57) calculated from full factorial ANOVA with cultivar and fungicide as factors.

Tapesia acuformis at Harper Adams

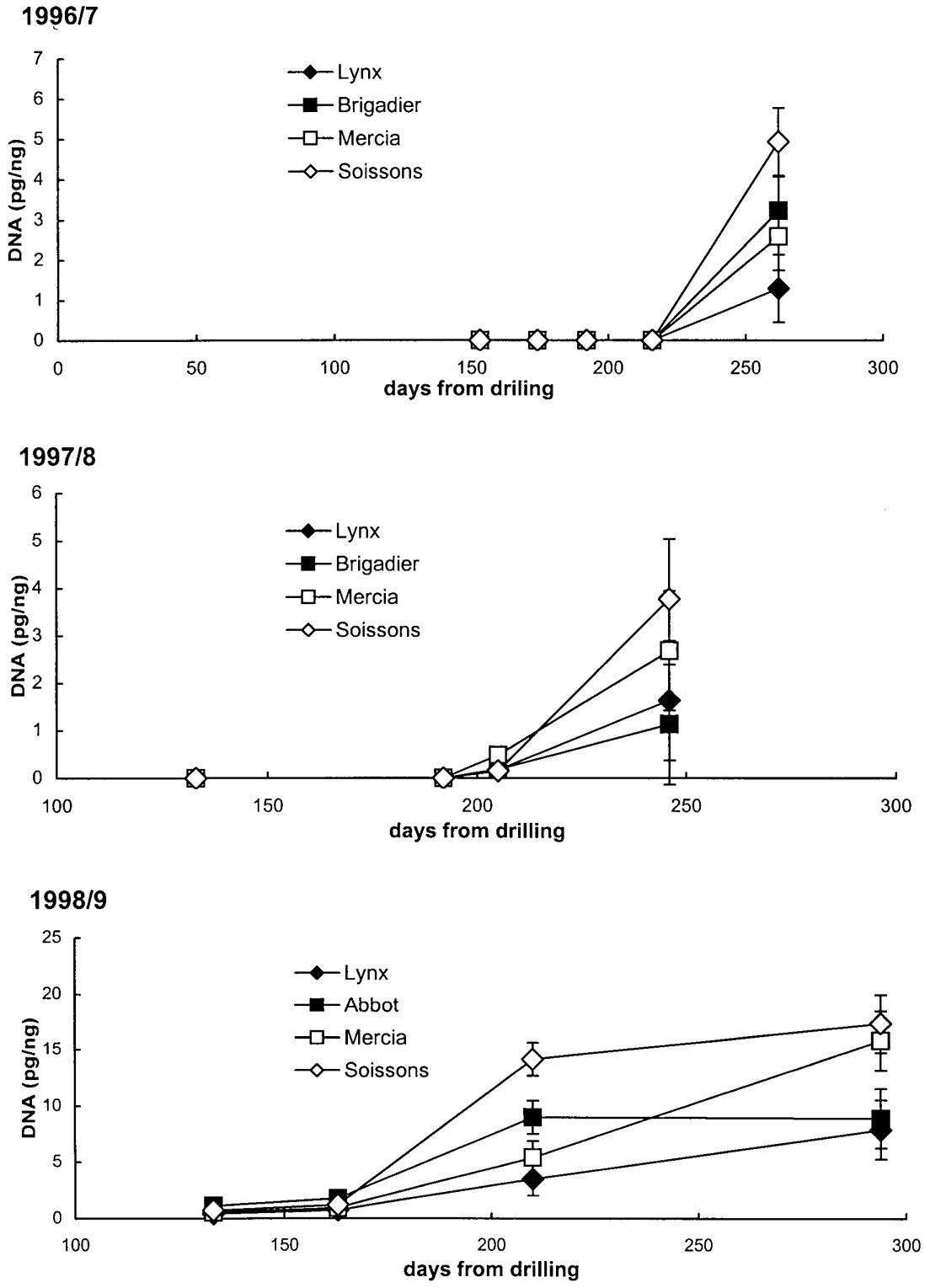

Figure 5.2. Development of *Tapesia acuformis* in untreated plots at Harper Adams. Vertical bars show SED (df = 57) calculated from full factorial ANOVA with cultivar and fungicide as factors.

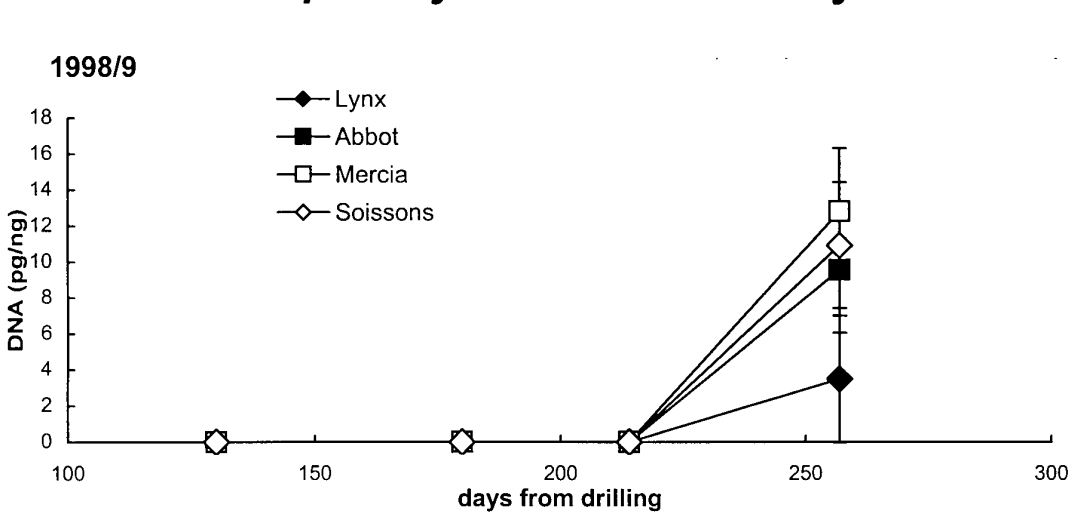

Figure 5.3. Development of *Tapesia yallundae* in untreated plots at Morley. Vertical bars show SED (df = 57) calculated from full factorial ANOVA with cultivar and fungicide as factors.

Tapesia acuformis at Morley

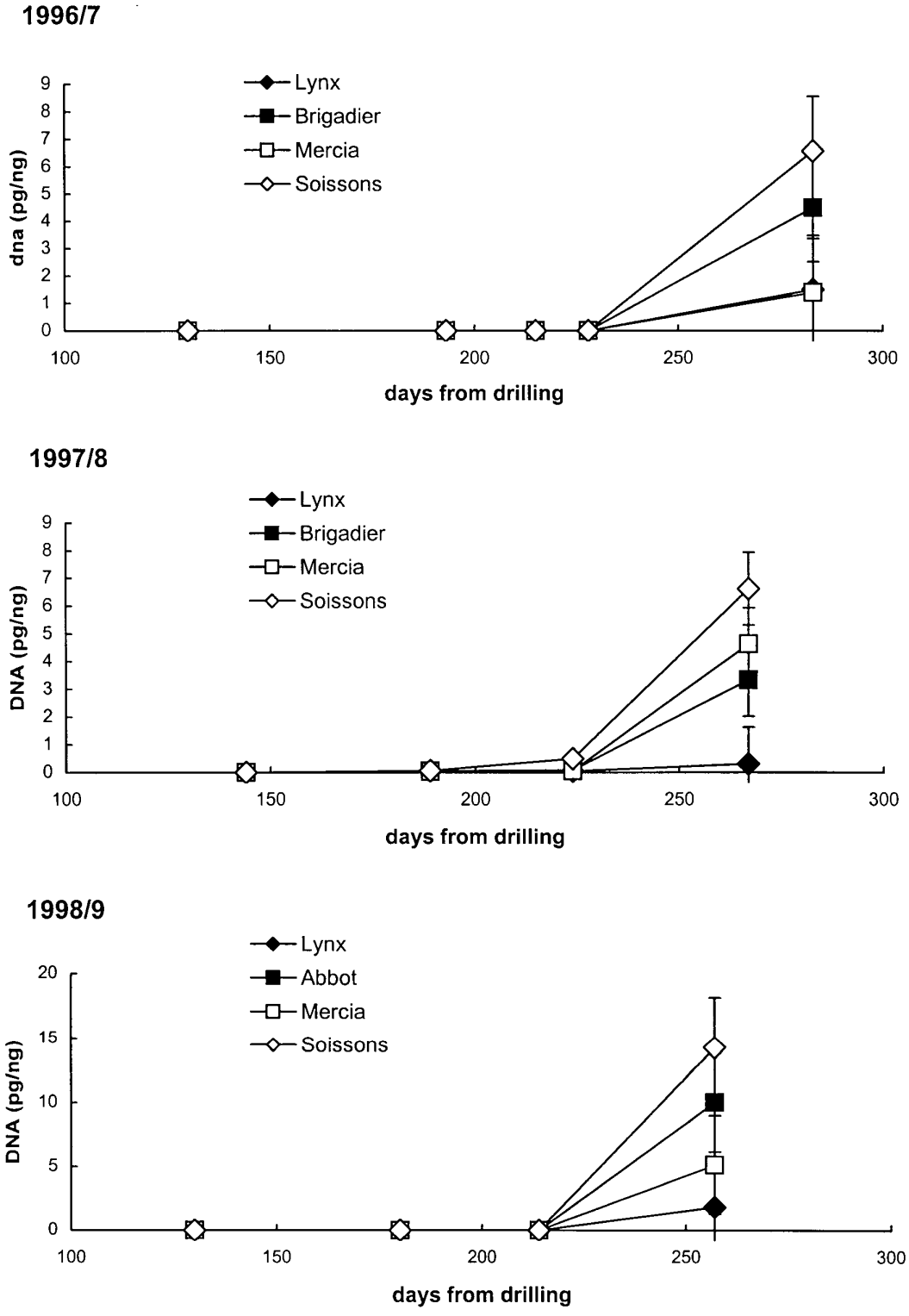

Figure 5.4. Development of *Tepesia acuformis* in untreated plots at Morley. Vertical bars show SED (df = 57) calculated from full factorial ANOVA with cultivar and fungicide as factors.

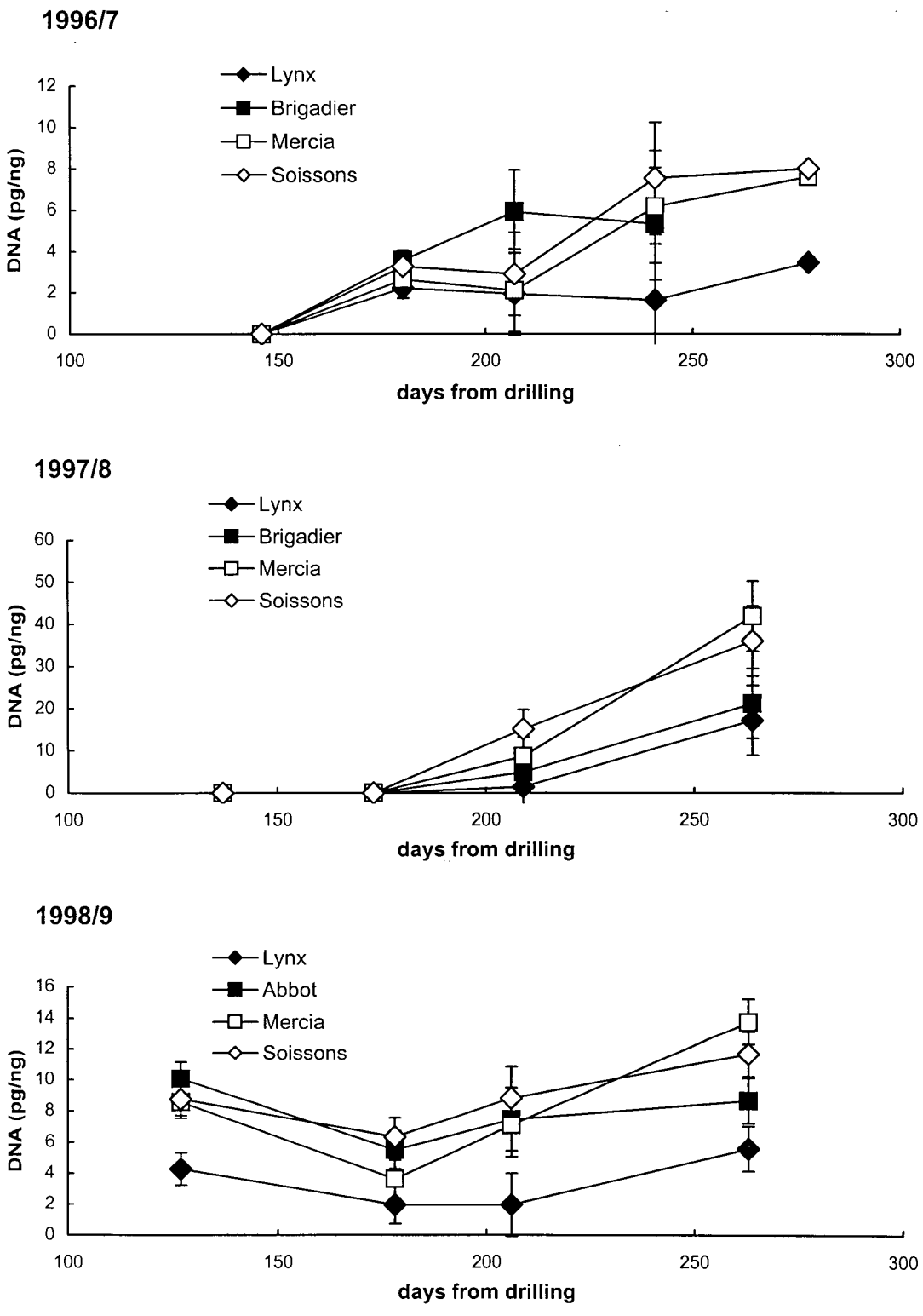

Figure 5.5. Development of *Tapesia yallundae* in untreated plots at Rothamsted. Vertical bars show SED (df = 57) calculated from full factorial ANOVA with cultivar and fungicide as factors.

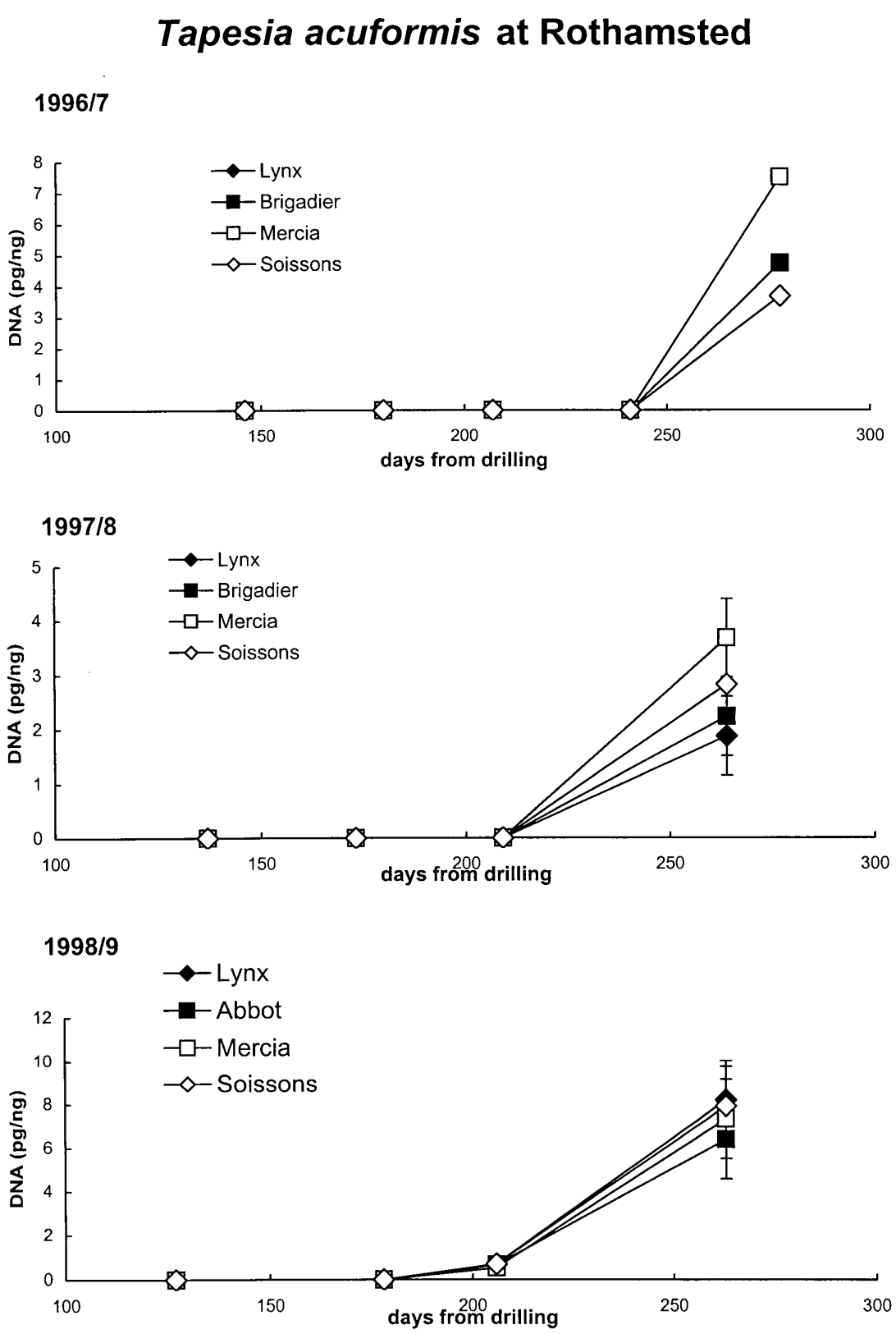

Figure 5.6. Development of *Tapesia acuformis* in untreated plots at Rothamsted. Vertical bars show SED (df = 57) calculated from full factorial ANOVA with cultivar and fungicide as factors.

Rhizoctonia cerealis at Harper Adams

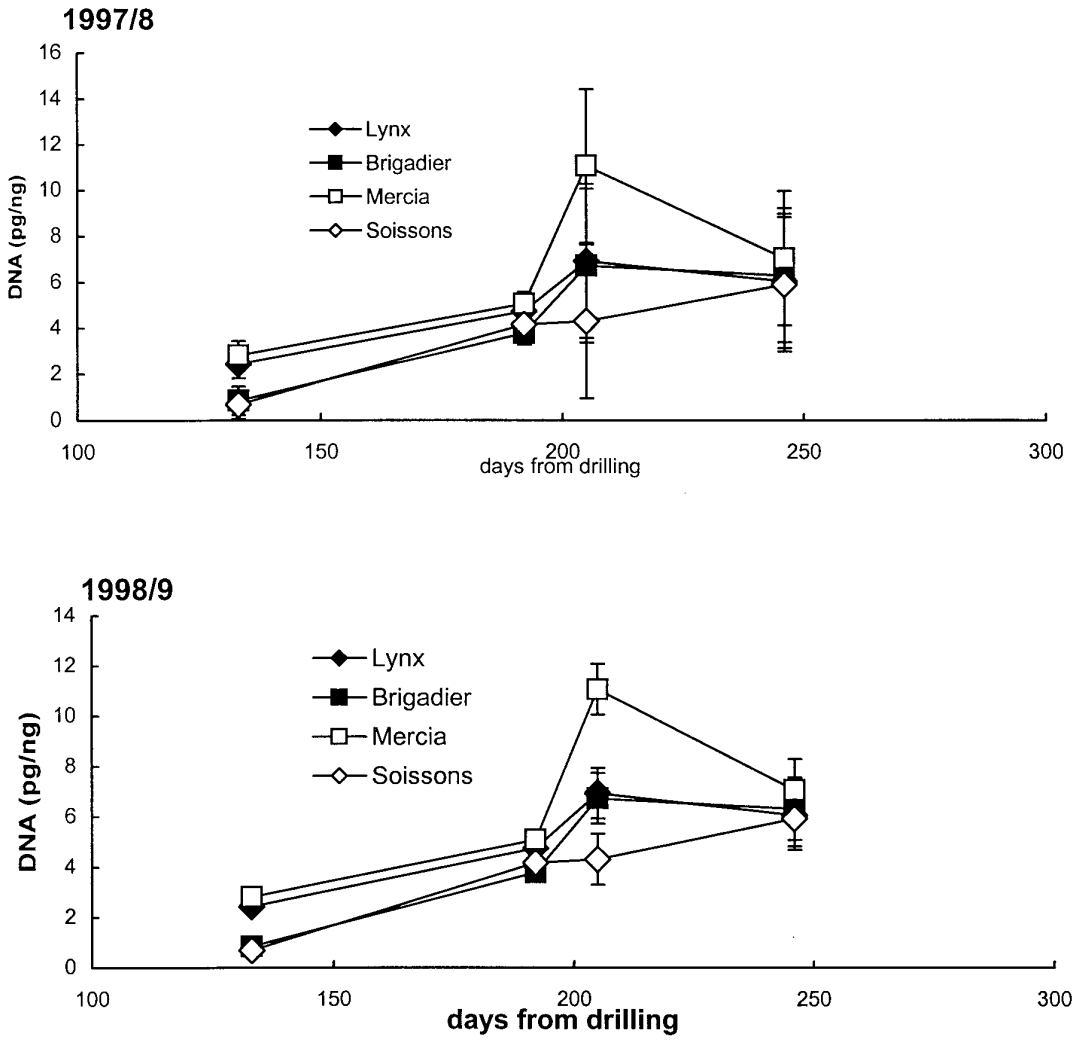

Figure 5.7. Development of *Rhizoctonia cerealis* in untreated plots at Harper Adams. Vertical bars show SED (df = 57) calculated from full factorial ANOVA with cultivar and fungicide as factors.

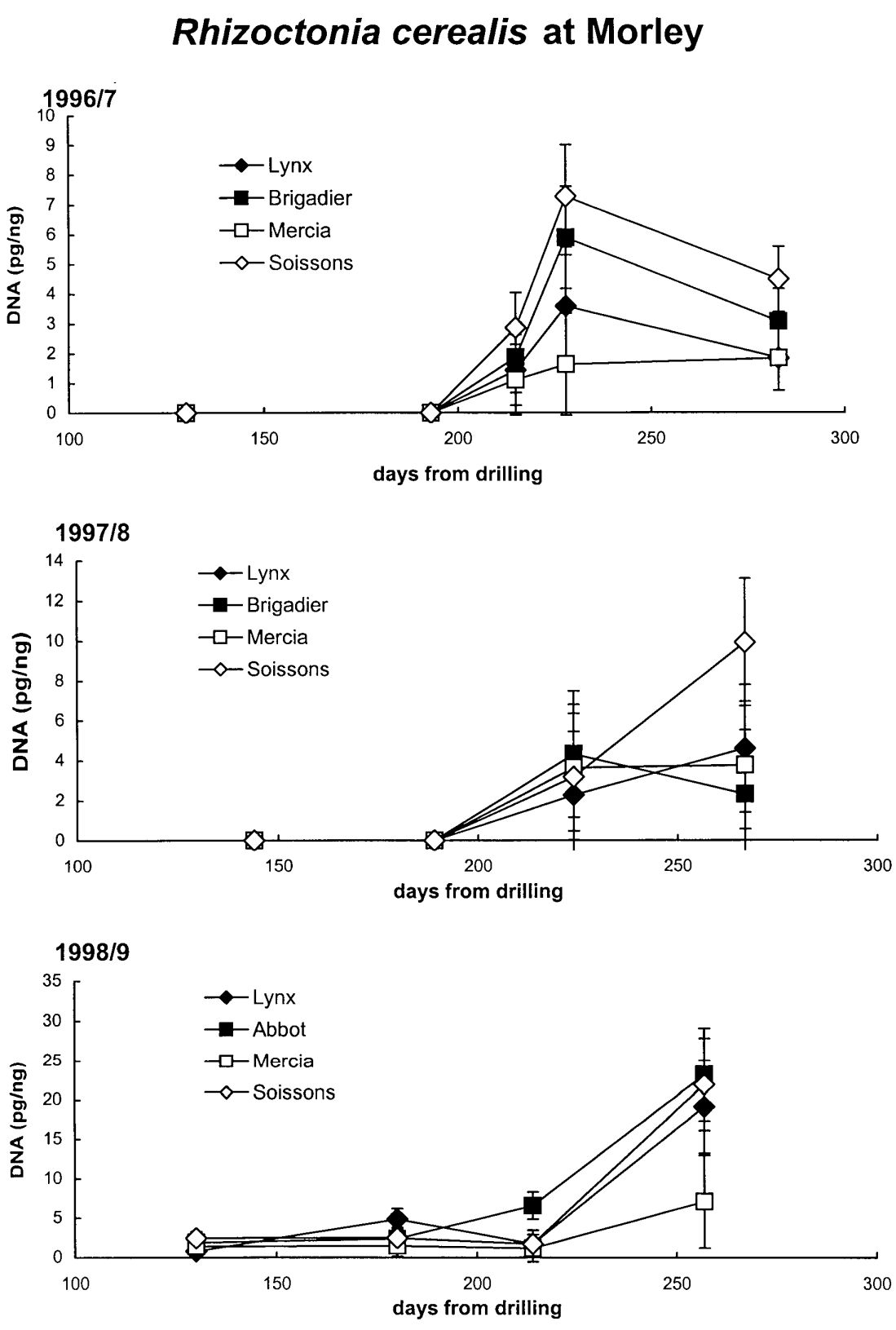

Figure 5.8. Development of *Rhizoctonia cerealis* in untreated plots at Morley. Vertical bars show SED (df = 57) calculated from full factorial ANOVA with cultivar and fungicide as factors.

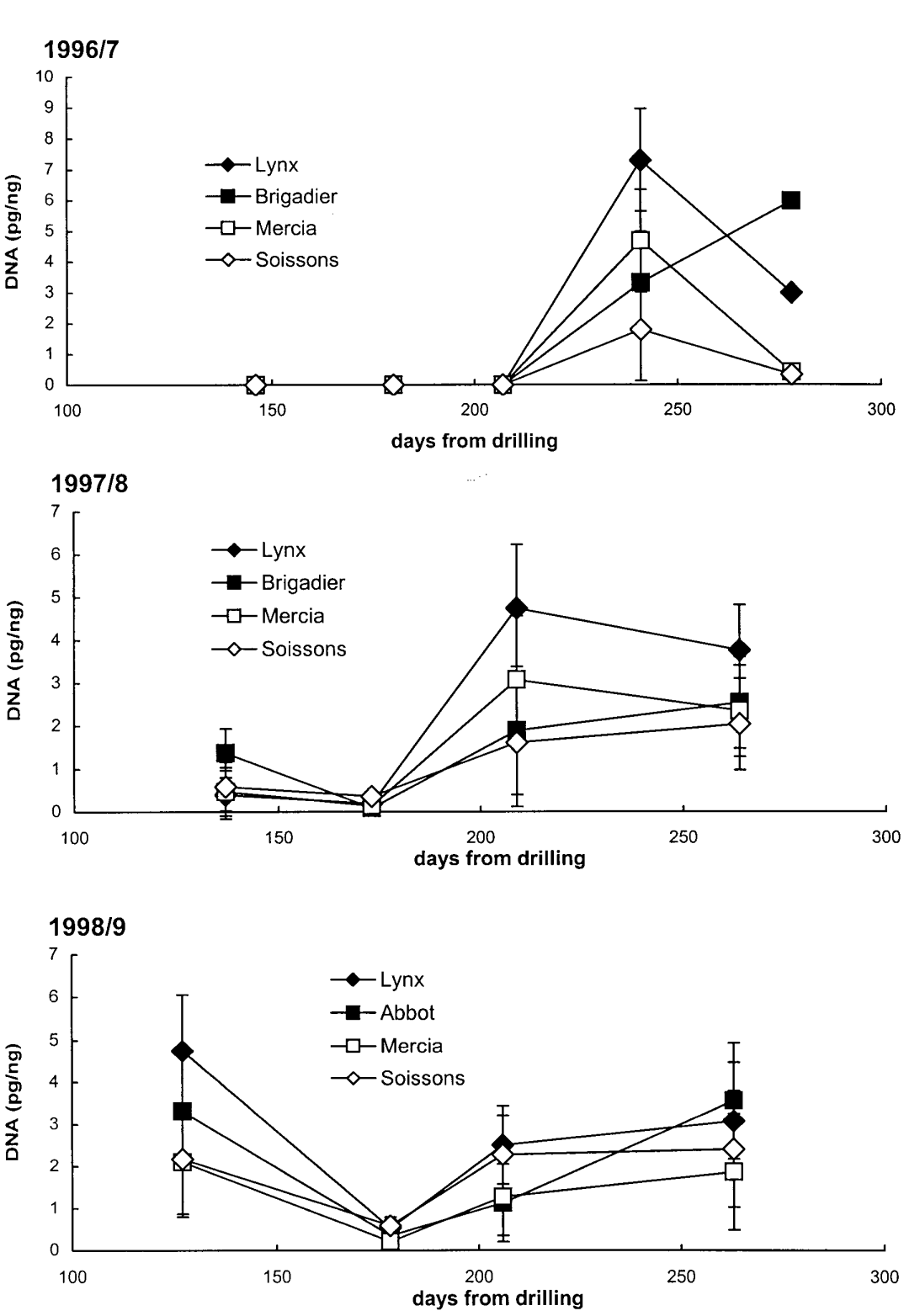

Figure 5.9. Development of *Rhizoctonia cerealis* in untreated plots at Rothamsted. Vertical bars show SED (df = 57) calculated from full factorial ANOVA with cultivar and fungicide as factors.

M. nivale var. nivale at Harper Adams

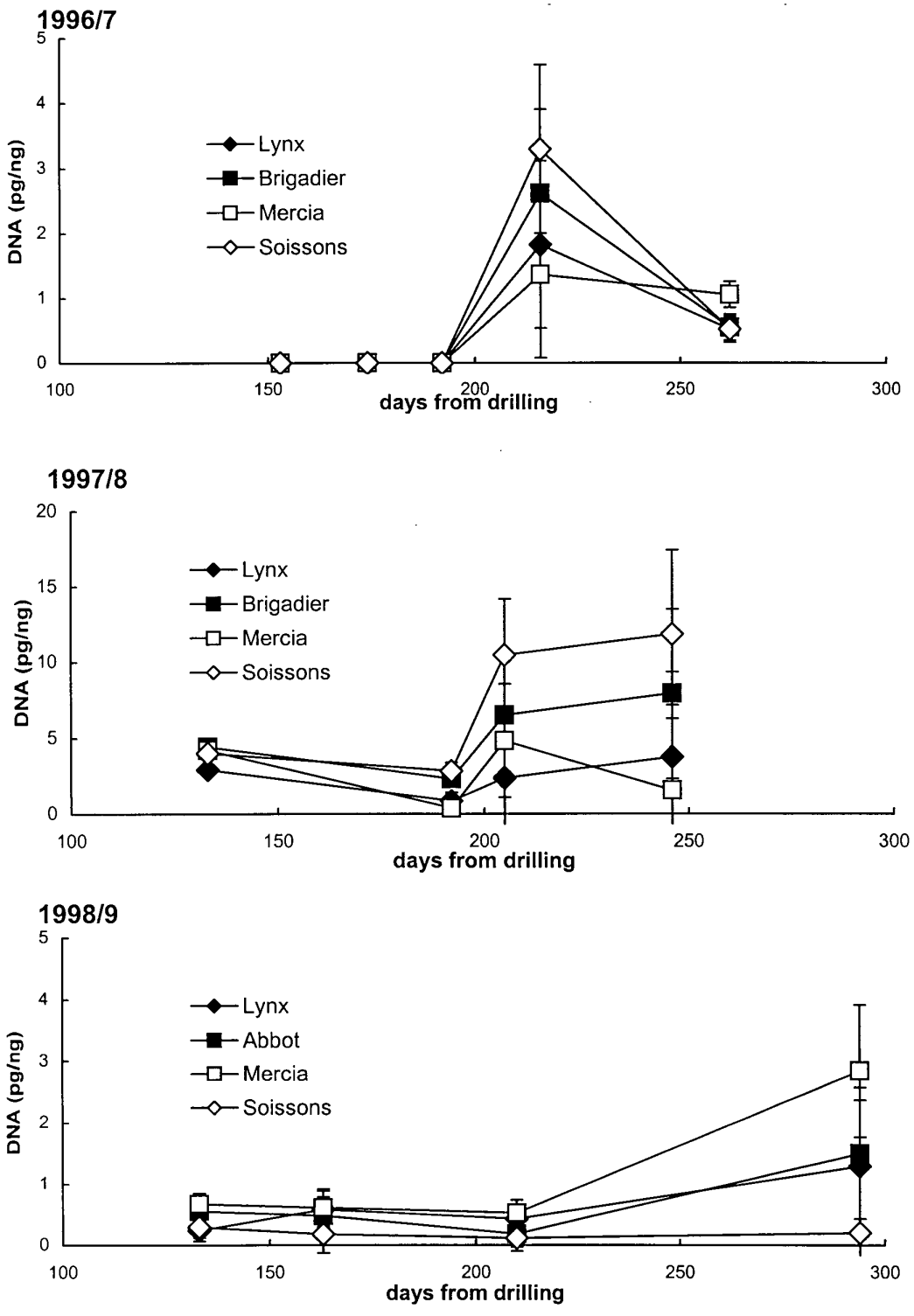

Figure 5.10. Development of *M. nivale var. nivale* in untreated plots at Harper Adams. Vertical bars show SED (df = 57) calculated from full factorial ANOVA with cultivar and fungicide as factors.

M. nivale var. majus at Harper Adams

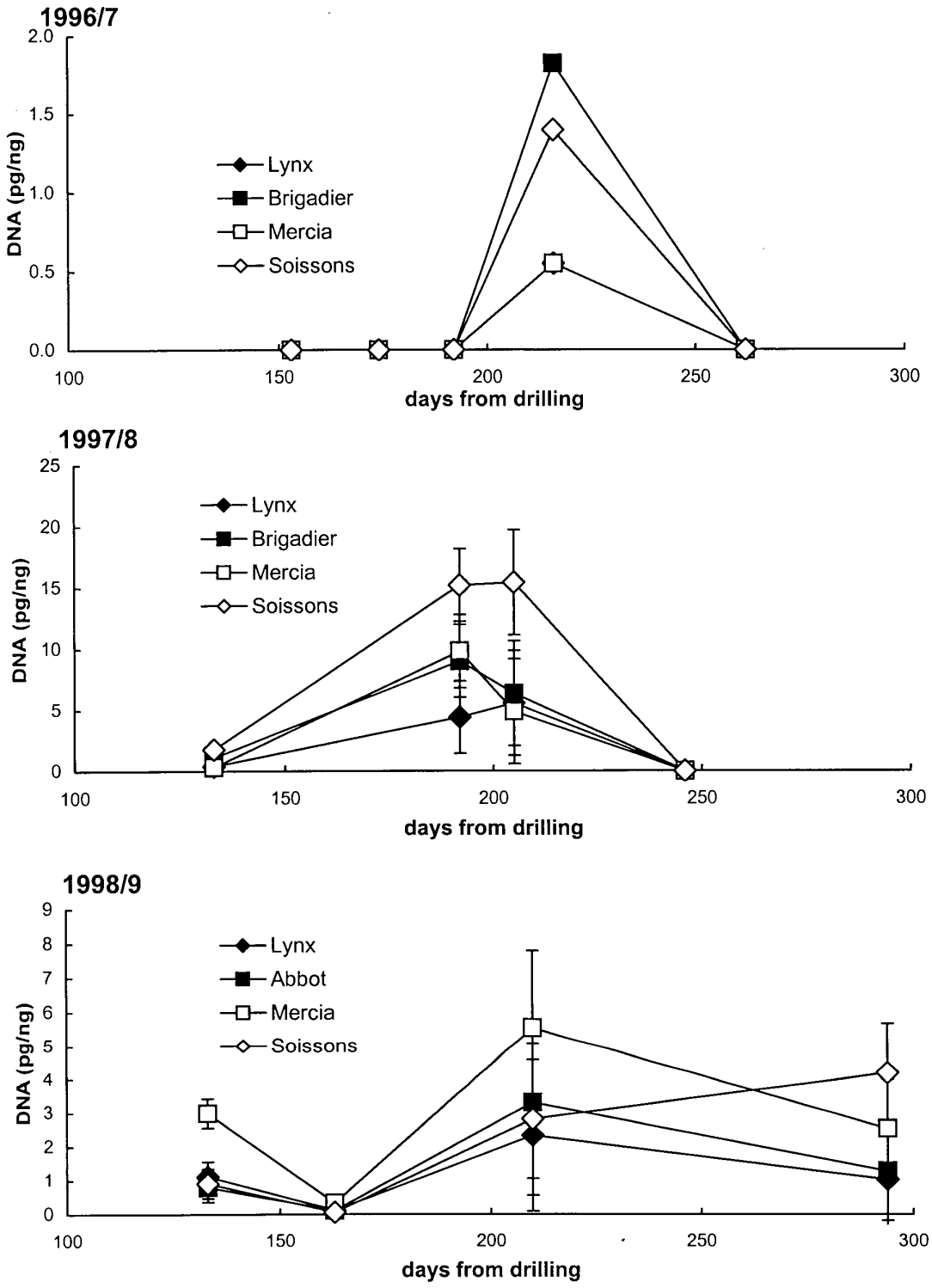

Figure 5.11. Development of *M. nivale var. majus* in untreated plots at Harper Adams. Vertical bars show SED (df = 57) calculated from full factorial ANOVA with cultivar and fungicide as factors.

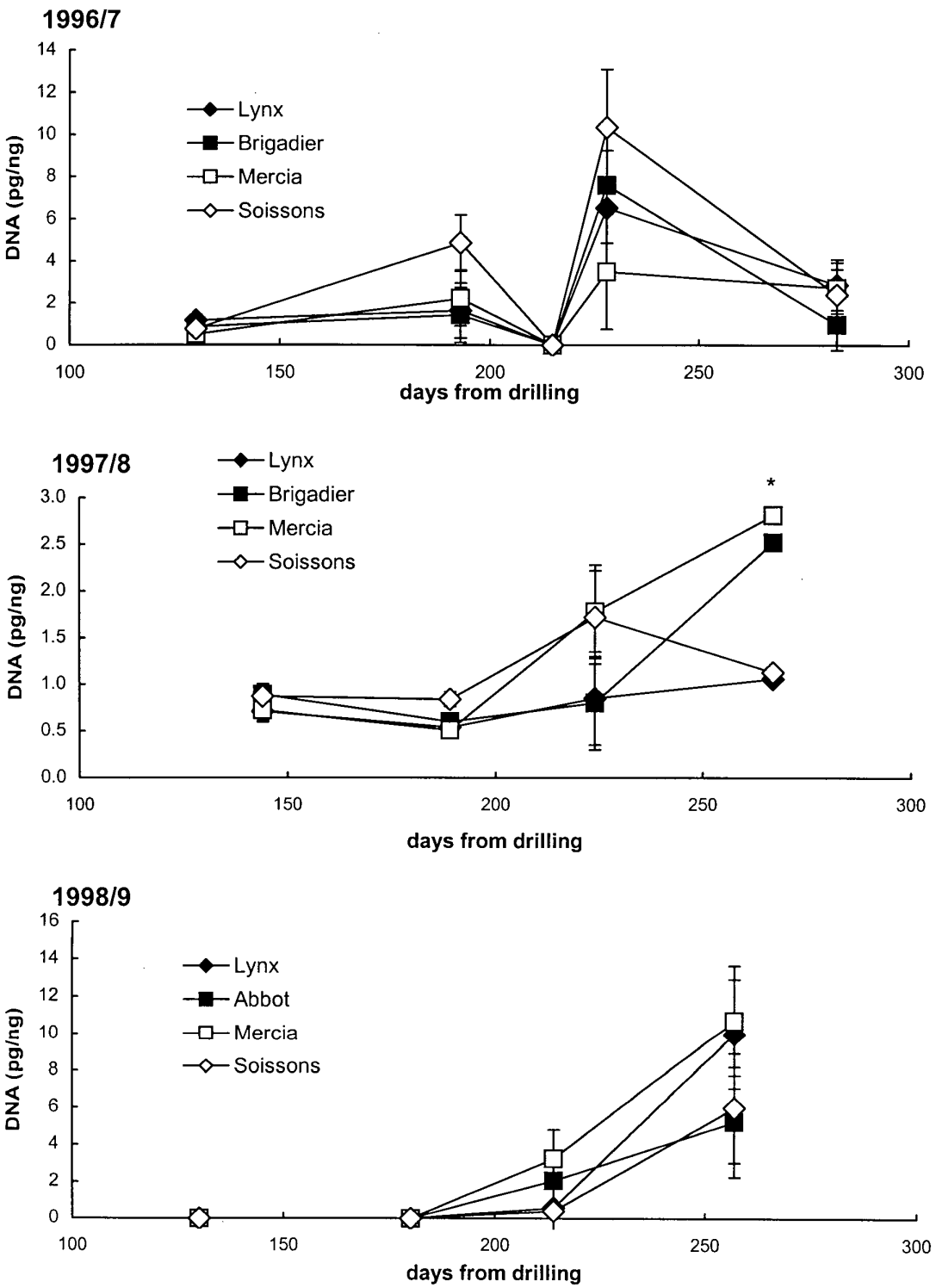

Figure 5.12. Development of *M. nivale var. nivale* in untreated plots at Morley. Vertical bars show SED (df = 57) calculated from full factorial ANOVA with cultivar and fungicide as factors. *SED = 4.58 at 267 days, 1997/8.

M. nivale var. majus at Morley

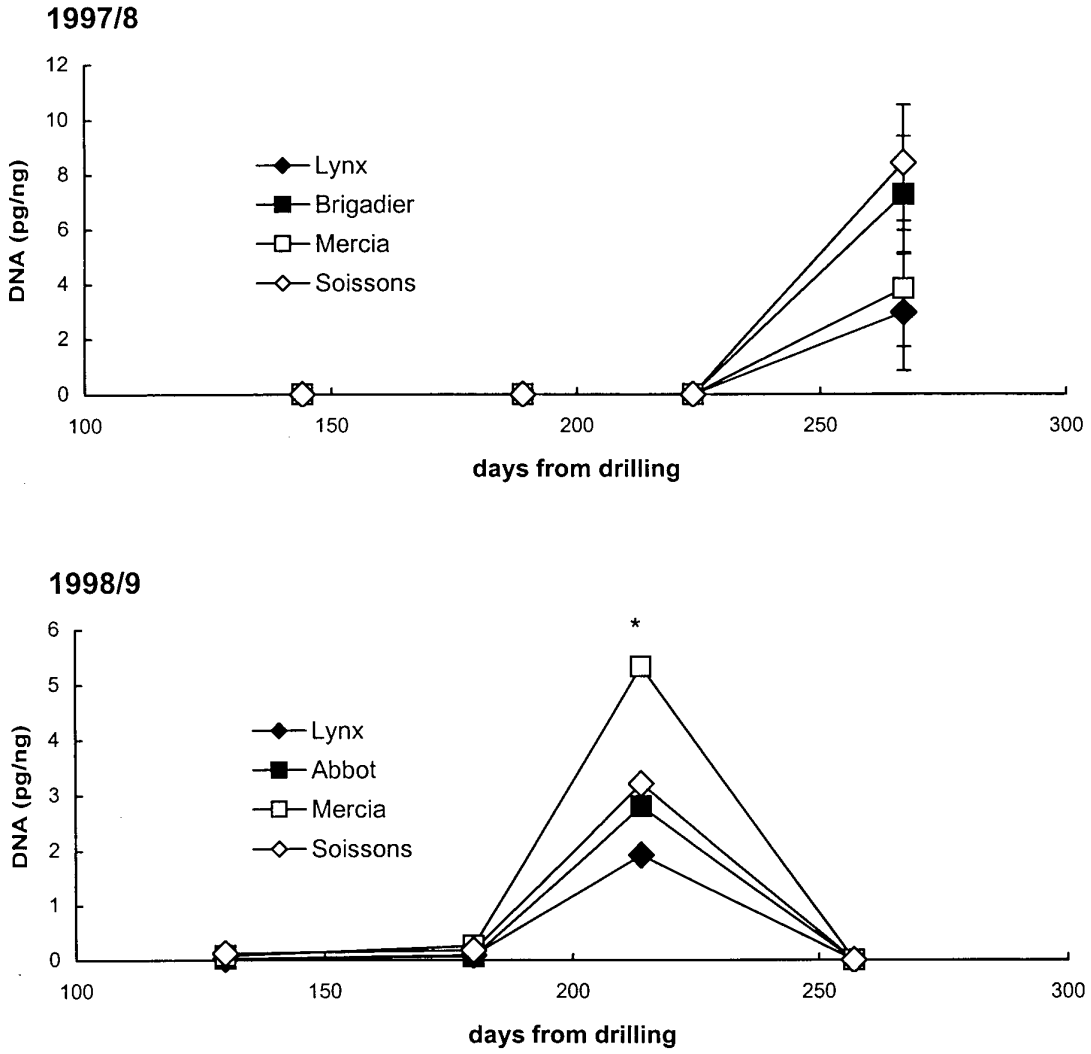

Figure 5.13. Development of *M. nivale var. majus* in untreated plots at Morley. Vertical bars show SED (df = 57) calculated from full factorial ANOVA with cultivar and fungicide as factors. *SED = 4.84 at 214 days, 1998/99.

M. nivale var. nivale at Rothamsted

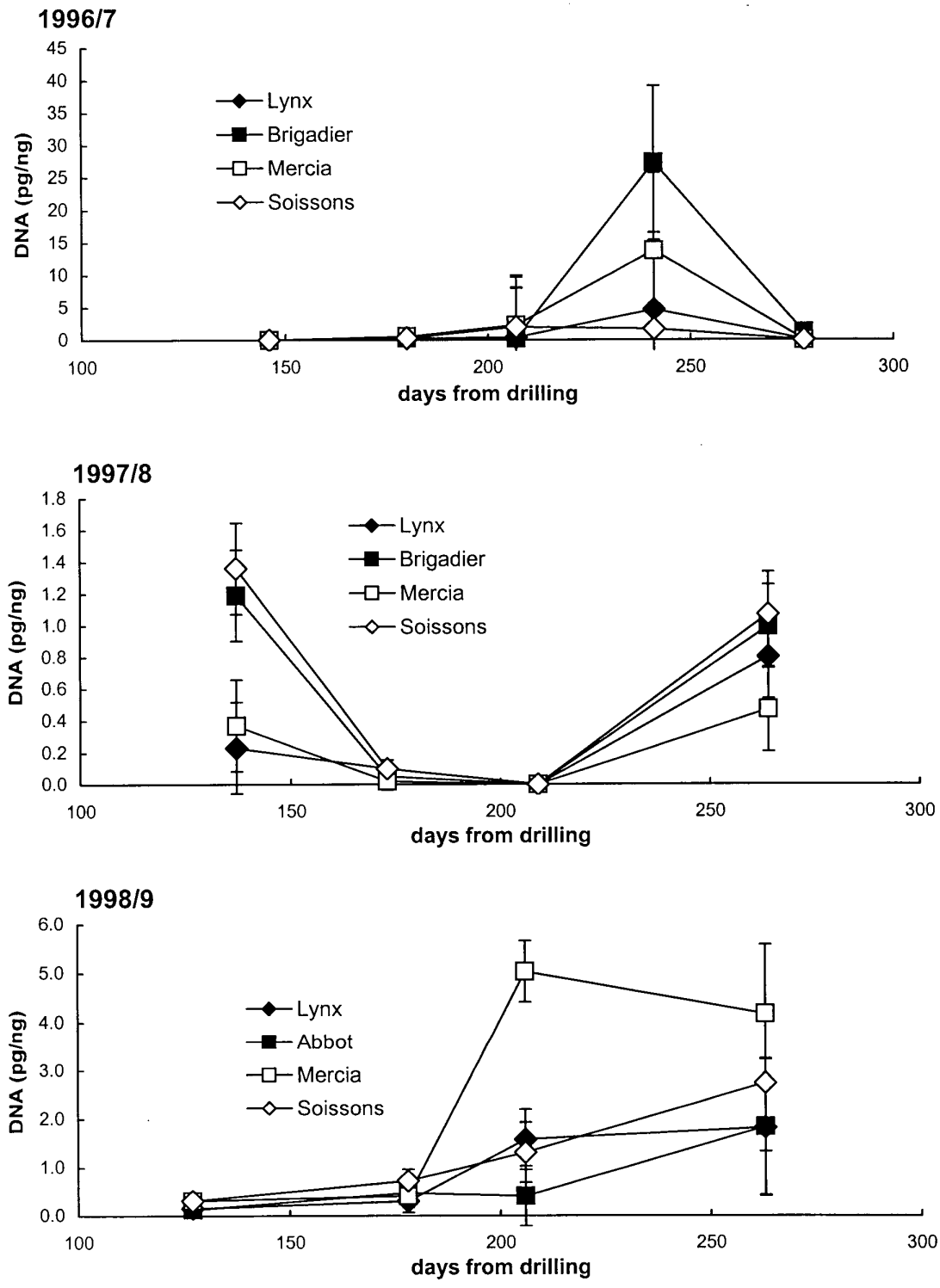

Figure 5.14. Development of *M. nivale var. nivale* in untreated plots at Rothamsted. Vertical bars show SED (df = 57) calculated from full factorial ANOVA with cultivar and fungicide as factors.

M. nivale var. majus at Rothamsted

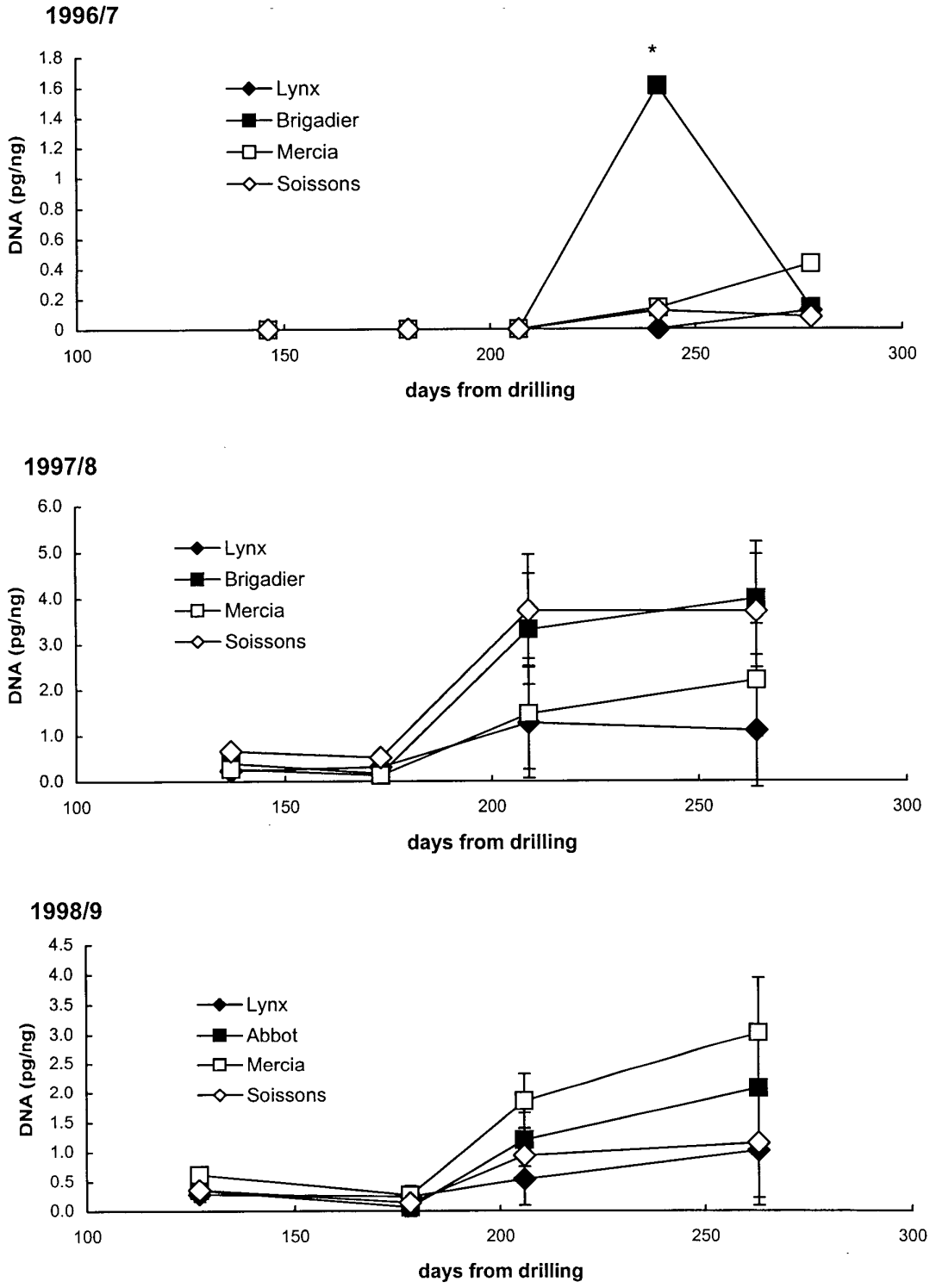

Figure 5.15. Development of *M. nivale var. majus* in untreated plots at Rothamsted. Vertical bars show SED (df = 57) calculated from full factorial ANOVA with cultivar and fungicide as factors. *SED = 1.94 at 209 days, 1996/7.

Table 6.1. *Regressions of grain yield on disease incidence or severity during anthesis or grain ripening (all cultivars and treatments)*

Independent variables (x)	Mean[a]	Regression equation	Variance acc'ted for (%)	Variance ratio (78 df)	*P*
Harper Adams 1997					
Eyespot	10.9	y=9.03-0.0004x	-	0.00	1.0
Sharp eyespot	1.9%	y=8.91+0.061x	1.4	2.14	0.1
Brown foot rot	52.4%	y=9.02+0.00004x	-	0.00	1.0
Harper Adams 1998					
Eyespot	23.3	y=10.29-0.010x	0.7	1.60	0.2
Sharp eyespot	7.1	y=10.15-0.015x	0.2	1.19	0.3
Brown foot rot	23.2	y=9.66+0.017x	2.4	2.98	0.09
Harper Adams 1999					
Eyespot	27.8	y=2.44+0.490x	8.4	8.21	0.005
Sharp eyespot	1.2	y=2.83+0.410x	-	0.09	0.8
Brown foot rot	10.0	y=2.95-0.336x	-	0.85	0.4
Morley 1997					
Eyespot	18.7	y=8.02-0.006x	-	0.49	0.5
Sharp eyespot	11.6%	y=7.73+0.016x	1.8	2.42	0.1
Brown foot rot	71.8%	y=7.74-0.004x	-	0.01	0.9
Morley 1998					
Eyespot	28.5	y=8.47-0.002x	-	0.15	0.7
Sharp eyespot	15.4%	y=8.42-0.0001x	-	0.00	1.0
Brown foot rot	23.2%	y=8.49-0.003x	-	0.22	0.6
Morley 1999					
Eyespot	18.7	y=7.77-0.008x	0.5	1.36	0.2
Sharp eyespot	11.9%	y=7.70-0.007x	-	0.54	0.5
Brown foot rot	35.7%	y=7.11+0.014x	7.1	7.07	0.01
Rothamsted 1997					
Eyespot	16.5	y=8.94-0.008x	-	0.58	0.5
Sharp eyespot	8.3	y=8.85-0.005x	-	0.07	0.8
Brown foot rot	6.0	y=9.27-0.078x	27.0	22.95	<0.001
Rothamsted 1998					
Eyespot	37.8	y=9.38-0.001x	-	0.03	0.9
Sharp eyespot	9.7	y=9.70-0.038x	14.5	11.88	<0.001
Brown foot rot	8.3	y=9.29+0.006x	-	0.08	0.8
Rothamsted 1999					
Eyespot	45.7	y=6.93-0.011x	1.5	2.24	0.1
Sharp eyespot	6.5	y=6.42+0.003x	-	0.01	0.9
Brown foot rot	12.4	y=6.10+0.027x	1.7	2.39	0.1

[a]Shown as disease index (0-100) except where only % stems available.
-, residual variance exceeds the variance of the response variate.

Table 6.2. *Regressions for individual cultivars of grain yield on disease incidence or severity during anthesis or grain ripening*

Independent variables (x)	Cultivar[a]	Mean[b]	Regression equation	Variance acc'ted for (%)	Variance ratio[c]	*P*
Harper Adams 1998						
Eyespot	L	17.4	y=10.65-0.041x	19.3	5.53	0.03
	B	29.9	y=10.59-0.015x	-	0.57	0.5
	M	24.9	y=9.45+0.018x	2.7	1.52	0.2
	S	20.9	y=11.05-0.039x	15.7	4.54	0.05
	No significant comparison					
Harper Adams 1999						
Eyespot	L	26.0	y=2.57+0.643x	8.6	2.79	0.1
	A	32.5	y=2.21+0.531x	5.1	2.02	0.2
	M	33.2	y=2.88+0.330x	7.0	2.42	0.1
	S	19.4	y=2.50-0.219x	-	0.25	0.6
	Parallel lines					
Rothamsted 1997						
Eyespot	L	9.6	y=9.81-0.005x	-	0.06 (15)	0.8
	B	20.8	y=8.46+0.037x	13.1	3.87	0.07
	M	13.9	y=8.38-0.026	17.2	4.74	0.04
	S	21.6	y=8.49-0.015x	7.9	2.63	0.1
	All lines different					
Morley 1999						
Sharp eyespot	L	8.5%	y=6.96+0.005x	-	0.10	0.8
	A	15.3%	y=8.42-0.029x	19.3	5.54	0.03
	M	10.1%	y=8.34-0.012	3.6	1.71	0.2
	S	13.8%	y=7.59-0.025x	1.7	1.32	0.3
	Overall regression not significant					
Rothamsted 1997						
Sharp eyespot	L	8.4	y=9.95-0.023x	-	0.61	0.4
	B	11.3	y=10.13-0.078x	16.9	4.87	0.04
	M	10.1	y=7.89+0.012x	-	0.51	0.5
	S	3.5	y=8.25-0.025x	-	0.48	0.5
	Parallel lines					
Rothamsted 1998						
Sharp eyespot	L	15.6	y=10.28-0.046x	27.0	8.04	0.01
	B	6.2	y= 9.90-0.030x	5.9	2.07 (16)	0.2
	M	11.6	y=9.30-0.039x	9.4	2.88 (17)	0.1
	S	5.6	y=9.65 -0.081x	22.0	6.37	0.02
	Parallel lines					
Morley 1999						
Brown foot rot	L	36.7%	y=6.23+0.021x	11.11	3.38	0.08
	A	23.1%	y=7.76+0.010x	-	0.66	0.4
	M	52.7%	y=8.04+0.003x	-	0.24	0.6
	S	30.2%	y=6.61+0.021x	3.4	1.68	0.2
	Parallel lines					

(Continued on next page)

(Table 6.2 - continued)

Rothamsted 1999						
Brown foot	L	8.4	y=9.25+0.038x	-	0.75	0.4
Rot	A	7.2	y=9.18+0.080x	21.9	5.77	0.03
	M	12.1	y=8.02+0.030x	18.8	5.18	0.04
	S	5.4	y=9.64-0.080x	4.5	1.90	0.2
	Overall regression not significant					

[a].L, Lynx,; B. Brigadier; A, Abbot; M, Mercia; S, Soissons.
[b]Shown as disease index (0-100)
[c]18 d.f. unless shown otherwise in parenthesis.
[-] residual variance exceeds the variance of the response variate.

Table 6.3. *Relationships between amounts of* Tapesia *DNA (pg ng^{-1}) in shoot bases between tillering and pseudostem erection stages and subsequent effects of fungicides on eyespot and grain yield*[a]

a)	Plants with visible eyespot (%)[b]		Amount of DNA at GS30-31		Untreated plots at GS69-85	
Location/year	GS12-26	GS30-31	TY	TA	Eyespot index (0-100)	Grain yield (t ha^{-1})
Harper Adams/97	4.1	6.0	0	0	15.6	8.84
Harper Adams/98	0.2	0	0	0	25.8	10.12
Harper Adams/99	0 (50.5[c])	28.3	2.53	1.15	28.2	2.64
Morley/97	1.5	0.9	0	0	23.1	7.72
Morley/98	3.7	7.1	0	0.06	30.5	8.21
Morley/99	0.7	1.4	0	0	23.8	7.48
Rothamsted/97	5.8	12.3	2.94	0	23.8	8.60
Rothamsted/98	20.8[d]	11.4	0	0	48.6	8.96
Rothamsted/99	53.7	55.6	4.34	0	46.5	6.31

(Continued on next page)

Table 6.3. (continued)

b)

	Decrease in eyespot index (%)				Increase in grain yield (%)			
	P	C	A	F/H	P	C	A	F/H
Harper Adams/97	18.0	84.6*	19.2	30.8	2.04	2.83	4.52	1.13
Harper Adams/98	28.3*	46.9*	-22.5	-4.3	-1.09	0	-3.56	1.19
Harper Adams/99	-10.6	30.1	-13.8	2.1	-5.68	15.53	30.30	-1.14
Morley/97	9.3	52.3*	13.7	19.8	0.80	4.94*	5.52*	1.22
Morley/98	-0.9	57.6*	-12.9	-10.5	-1.34	5.24*	5.85*	3.05
Morley/99	19.1*	76.6*	17.8	-9.9	1.60	2.41	3.88	0.80
Rothamsted/97	39.1*	66.0*	9.2	39.5*	-0.81	2.44	8.26*	1.86
Rothamsted/98	55.6*	45.6*	0.02	9.7*	4.13	1.45	7.60*	2.79
Rothamsted/99	1.0	53.0*	-37.5	-8.0	0.16	2.69	4.60	2.38

[a]All cultivars combined.
[b]Includes possible or suspected eyespot.
[c]Indeterminate brown lesions.
[d]Includes only a few clear, penetrating eyespot lesions.
TA, *Tapesia acuformis*; TY, *T. yallundae*.
P, prochloraz; C, cyprodinil; A, azoxystrobin; F, flusilazole (1997); H, HGCA1 (1998, 1999).
*Significant effect.

Table 6.4. *Relationships between* Tapesia *DNA (pg ng^{-1}) in shoot bases between tillering and pseudostem erection stages and susequent effects of fungicides on eyespot and grain yield in individual cultivars*

a)

Location /year	Cultivar	Plants with visible eyespot (%)[a]		Amount of DNA at GS30-31		Untreated plots at GS69-85	
		GS22-26	GS30-31	TY	TA	Eyespot index (0-100)	Grain yield (t ha^{-1})
Harper Adams/98	Lynx	-	-	0	0	17.5	10.25
	Brigadier	-	-	0	0	33.6	10.98
	Mercia	-	-	0	0	21.1	9.92
	Soissons	-	-	0	0	30.8	10.24
Rothamsted/97	Lynx	-1.95 (1.5)	-2.00 (1.3)	2.23	0	16.1	9.83
	Brigadier	-1.39 (5.4)	-0.71 (19.0)	3.58	0	28.2	8.53
	Mercia	-1.36 (5.7)	-1.25 (7.1)	2.65	0	20.4	8.07
	Soissons	-1.32 (6.2)	-0.94 (12.9)	3.29	0	30.7	7.97
	SED (57 d.f.)	0.133	0.134	0.483			
	P	<0.001	<0.001	0.03			

(Continued on next page)

Table 6.4. (continued)

b)

		Decrease in eyespot index (%)				Increase in grain yield (%)			
		P	C	A	F/H	P	C	A	F/H
Harper Adams/98	Lynx	33.1	32.0	-33.1	-58.9	-3.8	-1.9	-7.0	-3.0
	Brigadier	33.1	27.4	-13.4	8.3	-0.5	4.7	-0.4	-0.6
	Mercia	6.6	54.0	-73.9	-79.1	4.4	-7.3	-3.2	4.3
	Soissons	35.1	72.1*	8.1	45.8*	-4.4	4.5	-3.6	3.4
Rothamsted/97	Lynx	49.7	77.6	18.6	55.9	-6.4	0.6	4.7	-2.6
	Brigadier	49.3*	63.1*	-9.6	27.7	6.8	1.4	24.0*	-2.6
	Mercia	17.6	62.7*	29.4	48.5	-1.6	3.7	-2.6	-1.5
	Soissons	38.1*	64.5*	9.4	35.8*	-1.5	4.4	7.0	2.5

[a]Logit % plants (back-transformed mean in parenthesis).
TA, *Tapesia acuformis*; TY, *T. yallundae.*
-, no symptoms identified.
P, prochloraz; C, cyprodinil; A, azoxystrobin; F, flusilazole (1997); H, HGCA1 (1998, 1999).
*Significant effect.

Table 6.5. *relationships between between amounts of DNA (pg ng^{-1}) of* Rhizoctonia cerealis *in shoot bases between tillering and pseudostem erection stages and subsequent effects of fungicides on sharp eyespot and grain yield*[a]

a)	Plants with visible sharp eyespot (%)		Amount of DNA		Untreated plots at GS69-87	
Location/year	GS12-26	GS30-31	GS22-26	GS30-31	Sharp eyespot index (0-100) or % stems	Grain yield (t ha^{-1})
Harper Adams/97	1.0	1.0	0	0	2.7%	8.84
Harper Adams/98	14.2	15.0	0.61	0.51	6.2	10.12
Harper Adams/99	-	9.2	0.78	1.68	0.4	2.64
Morley/97	-	-	0	0	11.6%	7.72
Morley/98	-	-	0	0	19.5%	8.21
Morley/99	-	-	1.64	2.80	11.8%	7.48
Rothamsted/97	3.9	5.6	0	0	10.4	8.60
Rothamsted/98	19.9	12.9	6.57	0.09	11.0	8.96
Rothamsted/99	5.8	14.0	3.09	0.42	4.7	6.31

(Continued on next page)

Table 6.5. (continued)

b)

	Decrease (%) in sharp eyespot index or % stems				Increase in grain yield (%)			
	P	C	A	F/H	P	C	A	F/H
Morley/97	-18.2	-14.6	36.1	-7.2	0.80	4.94*	5.52*	1.72
Morley/98	0.5	27.2	49.7*	26.7	-1.34	5.24*	5.85*	3.05
Morley/99	-18.2	-33.3	48.8*	-2.0	1.60	2.41	3.88	0.80
Rothamsted/97	18.3	6.7	81.7*	-6.7	-0.81	2.44	8.26*	1.86
Rothamsted/98	-40.9	-4.5	70.0*	32.7	4.13	1.45	7.60*	2.79
Rothamsted/99	-108.5*	-104.3*	53.2	-34.0	0.16	2.69	4.60	2.38

[a]All cultivars combined.
-, no symptoms identified.
P, prochloraz; C, cyprodinil; A, azoxystrobin; F, flusilazole (1997); H, HGCA1 (1998, 1999).
*Significant effect.

Table 6.6. *Relationships between DNA (pg ng^{-1}) of* Rhizoctonia cerealis *in shoot bases between tillering and pseudostem erection stages and subsequent effects of fungicides on sharp eyespot and grain yield in individual cultivars*

a)

Location /year	Cultivar	Plants with visible sharp eyespot (%)[a]		Amount of DNA at GS		Untreated plots at GS69-87	
		GS22-26	GS30-31	12-26	30-31	Sharp eyespot index (0-100) or % stems	Grain yield (t ha^{-1})
Morley/99	Lynx	-	-	0.79	4.85	5.8%	6.67
	Abbot	-	-	1.90	2.38	17.5%	7.76
	Mercia	-	-	1.41	1.49	10.0%	8.29
	Soissons	-	-	2.46	2.46	14.0%	7.12
	SED (57 df)			0.836	1.336		
	P			0.2	0.09		
Rothamsted/97	Lynx	-1.77 (2.3)	-1.53 (4.0)	0	0	9.8	9.83
	Brigadier	-1.56 (3.7)	-1.28 (6.7)	0	0	16.0	8.53
	Mercia	-1.62 (3.3)	-1.66 (3.0)	0	0	14.7	8.07
	Soissons	-1.67 (2.9)	-1.43 (4.9)	0	0	0.9	7.07
	SED (79 d.f.)	0.134	0.134				
	P	0.5	0.04				
Rothamsted/98	Lynx	-0.79 (17.2)	-0.86 (15.2)	0.40	0.19	21.6	9.13
	Brigadier	-0.52 (26.2)	-1.26 (7.4)	1.37	0.09	4.0	9.61
	Mercia	-0.95 (13.0)	-1.18 (8.7)	0.47	0.14	12.0	8.68
	Soissons	-0.88 (14.7)	-1.26 (7.4)	0.59	0.36	6.3	8.44
	SED (73 d.f.)	0.131	0.165	0.567	0.094		
	P	0.02	0.07	0.3	0.03		

(Continued on next page)

Table 6.6 (continued)

b)

		Decrease in sharp eyespot index (%)				Increase in grain yield (%)			
		P	C	A	F/H	P	C	A	F/H
Morley/99	Lynx	-114*	-157*	71.4	-27.9	4.2	6.3	9.9	3.0
	Abbot	-10.6	10.3	70.4*	-8.1	0.4	6.1	7.9	0.3
	Mercia	8.8	-99.2*	18.1	58.2*	-1.9	-2.8	0.0	0.7
	Soissons	-7.0	5.7	34.4*	-26.5	5.8	1.8	-0.1	0.8
Rothamsted/97	Lynx	18.4	7.1	78.6*	-30.6	-6.4	0.6	4.7	-7.6
	Brigadier	26.9	6.3	87.5*	26.3	6.8	1.4	24.5*	9.6
	Mercia	31.1	39.5	78.9*	8.2	-1.6	3.7	-2.6	-1.5
	Soissons	-366.7	-552.2	66.7	-588.9	-1.5	4.4	7.0	2.5
Rothamsted/98	Lynx	-10.2	19.0	74.5*	55.1*	6.6*	3.4	17.1*	-3.2
	Brigadier	-242.5	-6.5	47.5	-12.5	2.3	-0.9	2.1	2.0
	Mercia	-45.8	5.0	55.8	2.5	3.3	-7.0	8.6*	2.1
	Soissons	-11.1	-68.3	96 8	42.9	4.0	10.4*	20.4*	10.7*

[a]Logit % plants (back-transformed mean in parenthesis).
P, prochloraz; C, cyprodinil; A, azoxystrobin; F, flusilazole (1997); H, HGCA1 (1998, 1999).
*Significant effect.
-, no symptoms identified.

Table 7.1. *Estimated variance components for sampling units using REML analysis, samples 1 (GS 22) and 2 (GS 30), Rothamsted, 1998*

Variate	Sampling unit	Variate as %		Variate as logit %	
		Variance	SE	Variance	SE
Sample 1					
Plants with symptoms	Block	0.7	5.1	0.0006	0.0024
	Plot	30.1	19.6	0.0127	0.0085
	Sample	827.5	44.5	0.3638	0.0196
Plants with probable eyespot or brown foot rot	Block	17.3	18.1	0.0063	0.0071
	Plot	25.3	15.3	0.0142	0.0074
	Sample	828.2	33.8	0.2883	0.0155
Plants with possible eyespot	Block	11.0	14.0	0.0043	0.0060
	Plot	61.8	19.8	0.0323	0.0098
	Sample	538.3	28.9	0.2526	0.0136
Plants with sharp eyespot	Block	15.6	18.3	0.0111	0.0117
	Plot	66.7	21.7	0.0310	0.0103
	Sample	602.4	32.4	0.2952	0.0159
Sample 2					
Plants with symptoms	Block	13.8	17.1	0.0057	0.0072
	Plot	70.1	24.8	0.0303	0.0111
	Sample	748.4	40.2	0.3457	0.0186
Plants with brown lesions	Block	20.6	22.1	0.0079	0.0089
	Plot	34.6	20.8	0.0169	0.0097
	Sample	853.8	45.9	0.3922	0.0211
Plants with possible eyespot	Block	40.9	40.5	0.0183	0.0089
	Plot	72.9	27.1	0.0326	0.0097
	Sample	854.3	45.9	0.3922	0.0211
Plants with penetrating eyespot	Block	9.9	11.7	0.0055	0.0065
	Plot	46.0	14.3	0.0275	0.0082
	Sample	376.9	20.2	0.2043	0.0110
Plants with sharp eyespot	Block	37.1	33.3	0.0251	0.0221
	Plot	4.6	12.0	0.0055	0.0065
	Sample	636.5	34.2	0.3185	0.0171