HGCA

PROJECT REPORT No. 50

LATE-SEASON HUSBANDRY AND HAGBERG FALLING NUMBER OF WHEAT

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by

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Final report of a three year project at Harper-Adams Agricultural College, Newport, Shropshire TF10 8NB. The work commenced in June 1988 and was funded by a grant of £47,420 from the Home-Grown Cereals Authority (Project No. 0069/2/87).

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ABSTRACT

The aim of this study was to determine whether pre-harvest grain drying rate between 40 and 20% moisture content was related to Hagberg falling number in 88 commercial crops of Avalon and Mercia winter wheat located mainly in Shropshire. Eleven field experiments in total were undertaken at four different sites (Newport, Shropshire; York; Driffield and Cambridge) to see if pre-harvest desiccant (glyphosate) could speed up grain drying and combat the effect of fungicide in reducing falling number.

Five further field experiments were carried out to examine the effect on falling number of different timings (ear emergence to grain soft dough) of late-season foliar urea. Different rates of spring-applied nitrogen fertiliser were also evaluated in nine experiments, with and without late-season foliar urea, in eight of these experiments.

In 1988 the weather during grain ripening was generally cool and moist, but in both 1989 and 1990 above-average temperatures and below-average rainfall were recorded. In the commercial crops Hagberg falling number was high in all three years (mean 312, 340 and 412 in 1988, 1989 and 1990 respectively) and no sprouting was visible in any of the grain. Across all three seasons Hagberg falling number increased with faster grain drying rate, but within any season the relationship was poor.

In most of the fungicide experiments foliar disease was not severe; consequently there was little difference between fungicide-treated and untreated plots in crop senescence. Falling number was reduced by fungicide in only one of the eleven experiments and desiccant had no effect in any experiment.

Late-season foliar urea only increased falling number in two out of 13 experiments. Time of application had no clear effect. Hagberg increased linearly with amount of nitrogen applied in spring in five out of nine experiments. The responses of Hagberg to nitrogen at one site were associated with increases in alpha-amylase activity in 1988 and 1989, but not in 1990. Late-season foliar urea only interacted with spring-applied nitrogen in one out of eight experiments.

1. OBJECTIVES

1.1 To examine the relationship between pre-harvest grain drying and Hagberg falling number in commercial wheat crops grown under different conditions, and in glasshouse-grown wheat.

1.2 To evaluate late-season applications of pre-harvest desiccant for off-setting the detrimental effect of fungicide and maintaining Hagberg falling number in field experiments.

1.3 To evaluate the effects of time of application of late-season foliar urea on Hagberg falling number in field experiments.

1.4 To confirm the effect of spring-applied nitrogen fertiliser on Hagberg falling number, and in subsequent years to investigate the interaction with late urea in field experiments.

2. INTRODUCTION

Research at Harper Adams Agricultural College on the effects of late-season husbandry on grain quality of winter wheat has shown that Hagberg falling number can be reduced by late-season fungicide in some seasons (Kettlewell et al., 1987b). The mechanism of this effect is unknown, but drying rate between 40 and 20% moisture of the developing grain may affect the activity of the enzyme alpha-amylase which causes low falling number (Gale et al., 1983). Since fungicide has been found to retard pre-harvest drying of the grain (Gooding et al., 1987) then this may be the cause of the reduction in falling number by fungicide.

If this hypothesis is correct, then appropriate use of desiccants may limit the detrimental effect of fungicide by hastening pre-harvest drying of the grain. This project aimed to test the hypothesis that drying rate is important in determining Hagberg falling number in commercial crops, since this has never been proven (Objective 1.1). Pre-harvest desiccant was evaluated with and without fungicides in field experiments (Objective 1.2).

Late-season applications of foliar urea have also been found to increase falling number in a few field experiments (Kettlewell et al., 1987a; Rule, 1987), but not in others (Gooding et al., 1986a). There is no evidence for the mechanism of action of late-season foliar urea, but a greater knowledge of its effect on Hagberg falling number may enable the variability in response to be explained. Timing may be an important factor (Smith et al., 1987) and was investigated in this project (Objective 1.3).

The amount of nitrogen fertiliser applied in spring appears to influence Hagberg falling number (Gooding et al., 1986b), and in the first season this effect was investigated alone, but in the subsequent two years it was investigated in combination with the foliar urea (Objective 1.4).

Alpha-amylase activity was measured in the commercial crops and some of the field experiments to enable effects on Hagberg due to changes in the enzyme activity or in starch value to be differentiated (Ringlund, 1983).

3. MATERIALS AND METHODS

3.1 Pre-harvest grain drying in commercial crops

Winter wheat fields of either Avalon or Mercia were selected to achieve a wide spread of growing conditions likely to result in different grain drying rates during ripening.

Eighty eight fields were chosen in total over the seasons 1988, 1989 and 1990; most of these crops were in Shropshire, but a few were in other counties, including Staffordshire, Cambridgeshire, Yorkshire, North Humberside, Warwickshire and Powys.

In each field a single plot approximately 4 m by 10 m was marked out in the most uniform part of the crop, except that one field had two plots and another four plots. On several occasions during grain ripening 15 ears were randomly removed from each plot. The ears were sealed in PVC film and surrounded by ice packs in an insulated box. Normally within 24 hours, the grains from spikelet 15, floret 2 (counting from the base upwards) were removed, weighed, dried at $80^{o}C$ for 48 hours, allowed to cool in a desiccator and reweighed. All grains from each position were weighed together. Moisture content was calculated by difference.

$$\text{Moisture content (\%)} = \frac{\text{fresh weight - dry weight}}{\text{fresh weight}} \times 100$$

The dates of 40% and 20% moisture were calculated by assuming that the moisture content declined as a straight line between successive sampling dates and the grain drying rate was calculated as 20 divided by the number of days the grains took to dry from 40% moisture to 20% moisture. A pre-harvest hand-collected sample of about 200 ears was taken from each plot in case severe weather delayed harvest and induced low Hagberg through sprouting. A grain sample of about 2 kg from the combine harvester was collected by the cooperating farmers and farm managers after harvesting the plot. The grain samples were cleaned by removing impurities and grains above 4.5 mm and under 2 mm diameter using an aspirated sample cleaner fitted with a 2 mm slotted sieve (A/S Rationel Kornservice, Esbjerg, Denmark). Hagberg falling number was then measured on the milled sample using the International Cereals Committee method (Anon., 1968) within two months of sample collection. Alpha-amylase activity was determined using the method published by Barnes and Blakeney (1974) with Phadebas tablets. The extractant used was distilled water containing 5 g/l sodium chloride and 0.2 g/l calcium chloride, and for each sample, a sample blank (no tablet) was prepared, and for each batch of samples two reagent blanks (no extract) were prepared. Absorbance was converted to milli enzyme units per gram dry weight of sample using constants from Barnes and Blakeney (1974) and the moisture content of the sample.

A preliminary glasshouse experiment indicated that considerable variability existed in falling number compared with that of field-grown material and it was decided to restrict Objective 1 of the project to field crops only. The relationship between the measurements from the field crops was analysed statistically using linear regression.

3.2 General husbandry and assessments for outside trials

3.2.1 The location of the outside trials

The varieties Avalon and Mercia were used in field experiments in the three years 1988 to 1990 at four different sites in the U.K. In 1988 these sites were Harper Adams College, Newport, Shropshire; Arable Research Centre, Elsworth, Cambridge; Escrick Park, Escrick, Yorkshire. In 1989 and 1990 an additional northern site at Haywold Farms, Driffield, North Humberside was used, and in 1990 the Cambridge site was relocated to Little Dunmow, Essex.

3.2.2 Assessments for the outside trials

On several occasions during grain development, 10 ears were randomly removed from each plot, and sealed in PVC film. They were then placed in an insulated box and surrounded by ice packs. The grains from spikelet 15 floret 2 (counting from the base upwards) were removed, weighed, dried at 80^{o}C for 48 hours, allowed to cool in a desiccator and reweighed. Moisture content was then calculated as described for the commercial crops.

In the fungicide experiments flag, second leaf and ear green areas were assessed using the same categories as flag leaf and ear disease keys (Anon., 1976; Bennett, 1981).

A pre-harvest hand-collected sample of about 200 ears was taken from each plot in case severe weather delayed harvest and induced low Hagberg through sprouting. All plots were combine harvested (with the exception of Little Dunmow in 1990 which was destroyed by fire during August) and a yield taken which was adjusted to 15% moisture. A small sample (approximately 3.5 kg) was kept from each plot and used for laboratory analysis. The samples were divided, cleaned (removing material above 4.5 mm and below 2.0 mm diameter) and milled before the Hagberg falling number was measured using the International Cereals Committee method number 107 (Anon., 1968). Protein content, at 14% moisture content, was also determined on ground wheat samples from the urea and nitrogen experiments. In 1988 and 1989 the Kjeldahl method with a Kjeltec automatic steam distillation and titration unit (Tecator, Bristol) was used, whilst in 1990 near infra-red reflectance analysis was used. (QN 1000, Oxford Instruments, Oxford). Alpha-amylase activity in the nitrogen experiment samples was determined as described for the commercial crops.

At the completion of each season, the values were analysed using a Genstat analysis of variance program. The values presented for Hagberg in the fungicide and urea sections are weighted means for all sites and all years, calculated by adding together the product of the treatment mean and replication from each site and then dividing by the sum of all the replicates.

For the spring nitrogen section the data is presented as functions of the linear relationship with applied nitrogen. This was due to the lack of consistency in the nitrogen rates from year to year and site to site.

It was not possible to complete a simple combined analysis of variance for Hagberg falling numbers from the fungicide and urea experiments due to heterogeneous variances between experiments.

3.3 Fungicide and desiccant interaction

This experiment was carried out at all sites in all years. At Harper Adams both Avalon and Mercia were used whilst at all other sites Mercia only was used.

Fungicide and desiccant treatments were factorial combinations of three levels of fungicide and two levels of desiccant (sprayed and unsprayed). Fungicide treatments consisted of three treatments of one, two and three applications: stem extension only, or stem extension plus flag leaf emergence or stem extension plus flag leaf emergence plus ear emergence. The fungicides used were prochloraz + carbendazim (Sportak-alpha, Schering Agriculture, Nottingham) and propiconazole + tridemorph (Tilt Turbo, Ciba Geigy Agrochemicals, Cambridge). The deciccant was glyphosate (Roundup, Monsanto Agricultural Company, Leicester), which was applied in a mixture with a surfactant when grain moisture was approximately 30%. In 1988 additional later desiccant treatments were included; two at Harper Adams (31 July, 36% moisture, and 3 August, 29%) and one at Elsworth (4 August, 32%). At Harper Adams and Arable Research Centres a fourth level of fungicide (unsprayed) was also included. The dates of treatment application over the three years are given in Table 1.

All these experiments were grown with rates of nitrogen fertiliser considered to be optimal for yield, and growth regulator when considered to be necessary.

Table 1. Application dates of fungicide and desiccant treatments

	Year and site	Fungicide sprays: Stem extension	Flag leaf emergence	Ear emergence	Desiccant (estimated % grain moisture at application)	Harvest
1988	Harper Adams	19 April	19 May	14 June	28 July (40)	17 August
1988	Elsworth	5 May	23 May	25 June	16 July (54)	26 August
1988	Escrick Park	25 April	2 June	29 June	22 August (21)	6 September
1989	Harper Adams	28 April	19 May	12 June	28 July (24)	8 August
1989	Elsworth	14 April	31 May	14 June	25 July (17)	8 August
1989	Escrick Park	8 April	24 May	16 June	31 July (21)	8 August
1989	Haywold	12 April	24 May	17 June	7 August (24)	18 August
1990	Harper Adams	26 March	17 May	11 June	24 July (26)	7 August
1990	Little Dunmow	9 April	17 May	7 June	16 July (41)	-
1990	Escrick Park	12 April	14 May	11 June	1 August(23)	10 August
1990	Haywold	30 March	17 May	17 June	7 August(16)	28 August

3.4 The timing of late foliar urea

In 1988 this experiment was located at three sites, with Avalon and Mercia used at both Harper Adams College and Elsworth, Mercia only at Escrick Park. In subsequent years the experiment continued only at Harper Adams using Mercia. The urea treatments and their date of application over the three years are given in Table 2. An unsprayed treatment was included in every experiment. The product used was undiluted NUFOL (Britag Industries Ltd., York). All these experiments received an amount of nitrogen considered optimal for yield, and fungicide and growth regulator when considered necessary.

For the calculation of the weighted means two values were excluded from the ear emergence mean - due to their late application. They were the Avalon sprayed at Harper Adams in 1988, and the Harper

Adams value in 1989, (see Table 2).

Table 2. Urea treatments and dates of application over the three years (1988 to 1990)

Year and site	Zadoks growth stage for the urea spray †59	69	75	83
1988 Harper Adams	13 June (65)*	17 June	15 July (77)	22 July (85)*
1988 Elsworth	17 June	25 June	6 July	16 July
1988 Escrick Park	13 June	29 June	15 July	11 August
1989 Harper Adams	12 June (61)	16 June	28 June (73)	18 July
1990 Harper Adams	30 May	11 June	28 June	10 July

Numbers in brackets indicate the growth stage of urea application, if different from the intended timing.

* for Avalon only

†59 ear emergence
61 beginning of anthesis
69 anthesis complete
73 grain early milk
77 grain late milk
83 grain early dough
85 grain soft dough

3.5 Spring-applied nitrogen and late foliar applied urea

This experiment was initiated at Harper Adams in 1988 where only the effect of application rate of nitrogen was investigated. In subsequent years all sites were used, and the experiment was enlarged to incorporate a late foliar urea application at GS 69 (anthesis) in factorial combination with a range of nitrogen rates. The application rates and dates for nitrogen and urea treatments are listed in Table 3. Two applications of the spring nitrogen were made, one during tillering and the treatment balance during stem extension. The products used were either NURAM (Britag Industries Ltd., York) or NITRAM (ICI Fertilisers plc, Billingham) in spring and undiluted NUFOL at GS 69. All experiments received fungicide and growth regulator when considered necessary.

Table 3 Application rates and dates for the spring-applied nitrogen and late foliar-applied urea treatments

Year	Site	Application range (kg N/ha)	Increment (number @ rate) (kg N/ha)	Form	Date of application: First 40 kg N/ha	Date of application: Treatment balance	Date of application: Urea spray† anthesis
1988	Harper Adams	0 - 351	6 @ 58.5	aqueous	2 March	27 April	-
1989	Harper Adams	0 - 300	3 @ 100	aqueous	17 March	12 April	15 June
	Elsworth	0 - 300	3 @ 100	solid	14 March	3 April	3 July
	Escrick Park	63 - 315	2 @ 63, 1 @ 126	solid	7 March*	14 April	23 June
	Haywold	63 - 315	2 @ 63, 1 @ 126	solid	7 March*	14 April	17 June
1990	Harper Adams	0 - 250	1 @ 50, 2 @ 100	aqueous	16 March	10 April	11 June
	Little Dunmow	0 - 300	3 @ 100	aqueous	26 March	9 April	7 June
	Escrick Park	63 - 315	2 @ 63, 1 @ 126	solid	20 March*	24 April	11 June
	Haywold	63 - 315	2 @ 63, 1 @ 126	solid	12 March*	23 April	17 June

Aqueous = urea-ammonium nitrate solution
Solid = solid ammonium nitrate

* 63kg N/ha

† 40kg N/ha

4. RESULTS

4.1 Pre-harvest grain drying in commercial crops

A comparison of the moisture content of grain from spikelet 15 floret 2 with the moisture content of all grain from the ear showed that grain from this particular ear position had a very similar moisture content to that of all the grain during drying from 40 to 20% moisture in each of two years (data not presented).

Sufficient data existed to calculate the drying rate between 40 and 20% moisture and compare with falling numbers for only 68 of the 92 plots. When the data from all three years was combined, there was a significant overall linear relationship between the Hagberg falling number and the grain drying rate between 40% and 20% moisture. There were, however, significant differences in the intercepts, but not in the slopes of the fitted lines when the regressions for the three separate years were compared (Figure 1). When regressions were fitted to the two varieties (ignoring years) there was no significant difference, although there were only 15 crops of Avalon in this comparison (Figure 2).

Alpha-amylase activity of the grain showed a curvilinear relationship with drying rate, but because alpha-amylase activity is proportional to the reciprocal of Hagberg falling number (Perten, 1964) the reciprocal of the alpha-amylase activity showed a linear relationship with drying rate. Similar regression relationships to those for Hagberg when comparing years and varieties were found with alpha-amylase activity (Figures 3 and 4). For the overall regression there was little difference between the proportion of the variation which was accounted for by variation in the grain drying rate for Hagberg falling number (32%) and for the reciprocal of alpha-amylase activity (27%).

Information on several husbandry factors (eg. nitrogen fertiliser applied) was used in a multiple regression analysis, but no factor was

Figure 1. Grain drying rate and Hagberg falling number

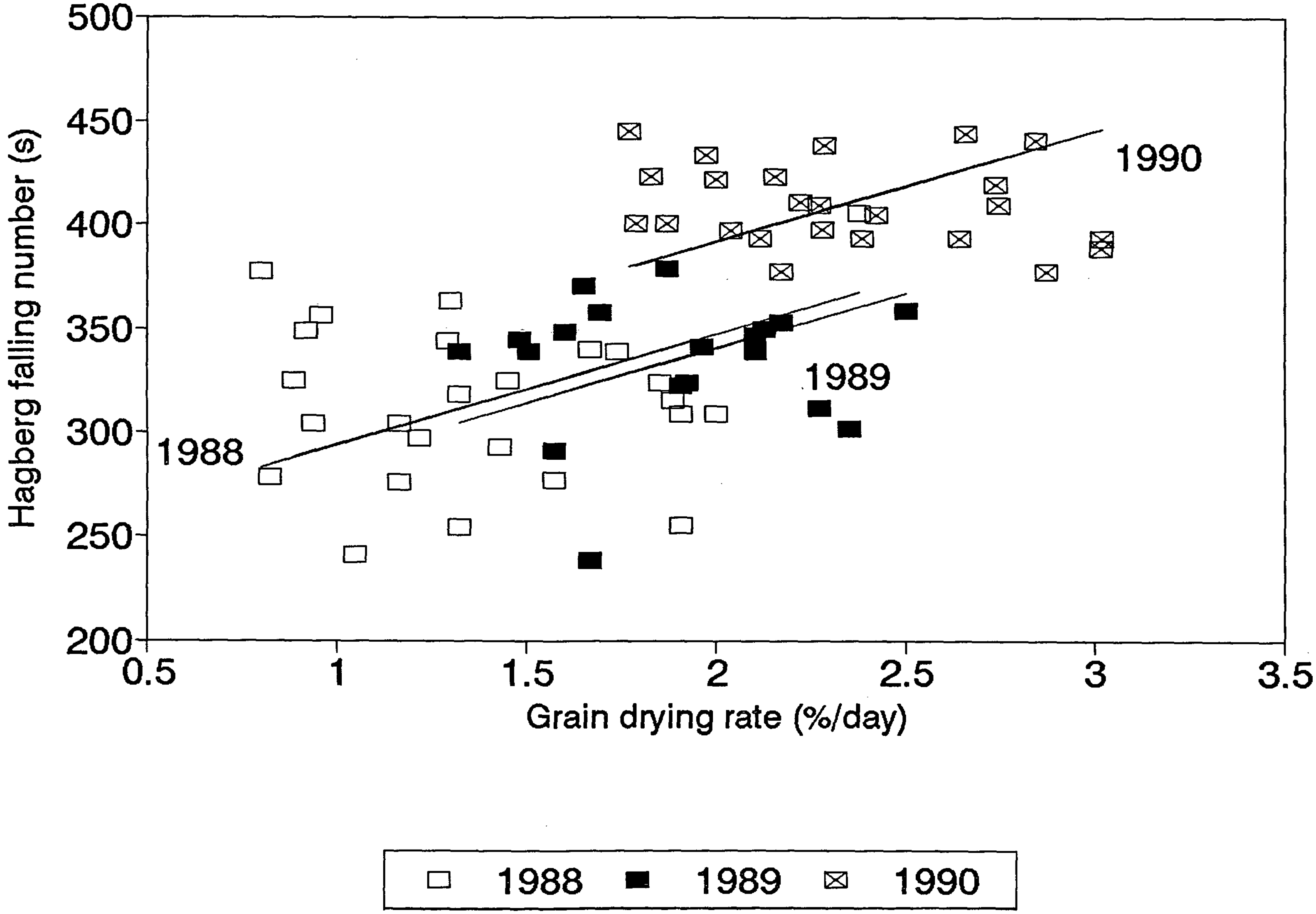


Figure 2. Grain drying rate and Hagberg falling number

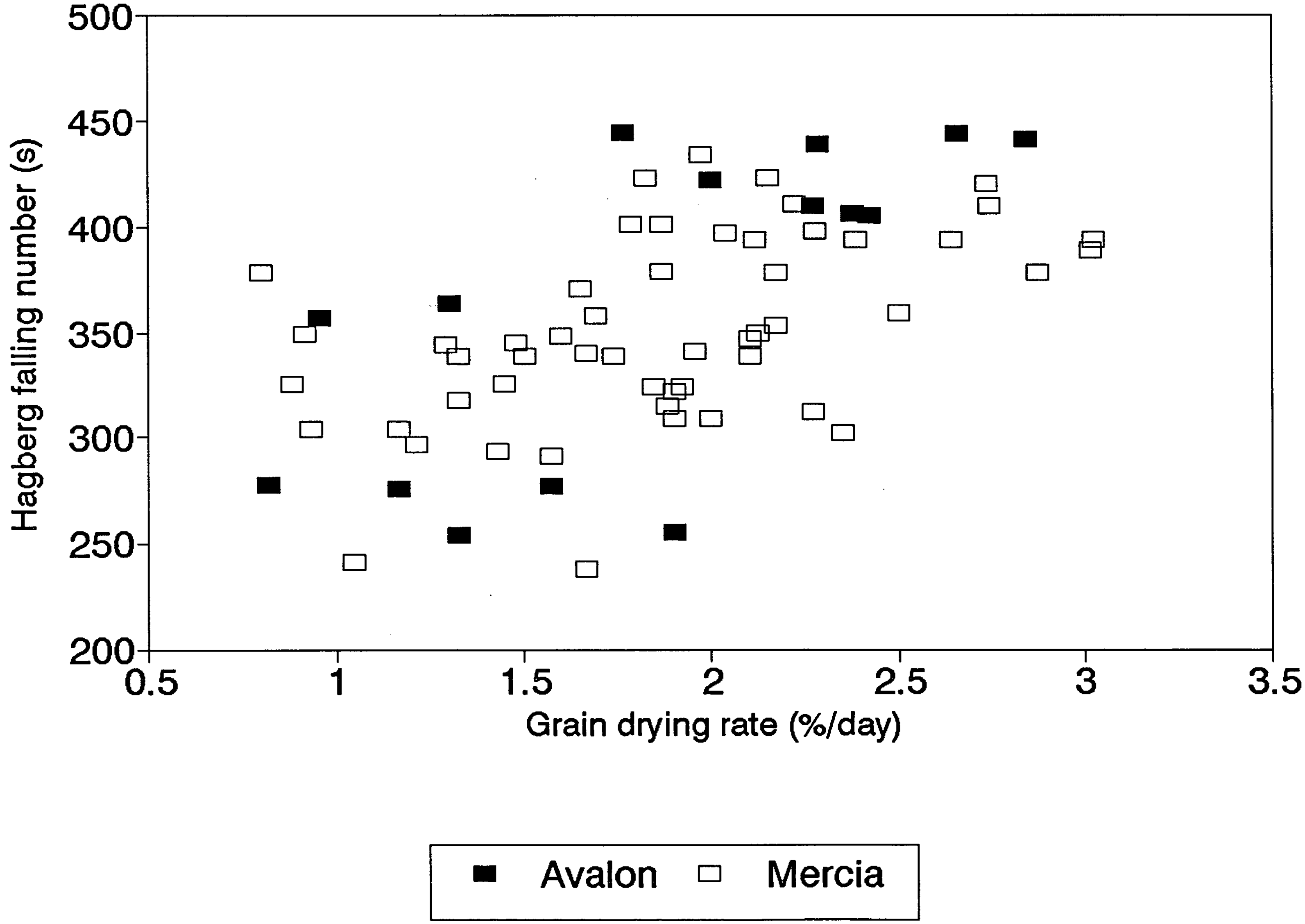


Figure 3. Grain drying rate and alpha-amylase activity

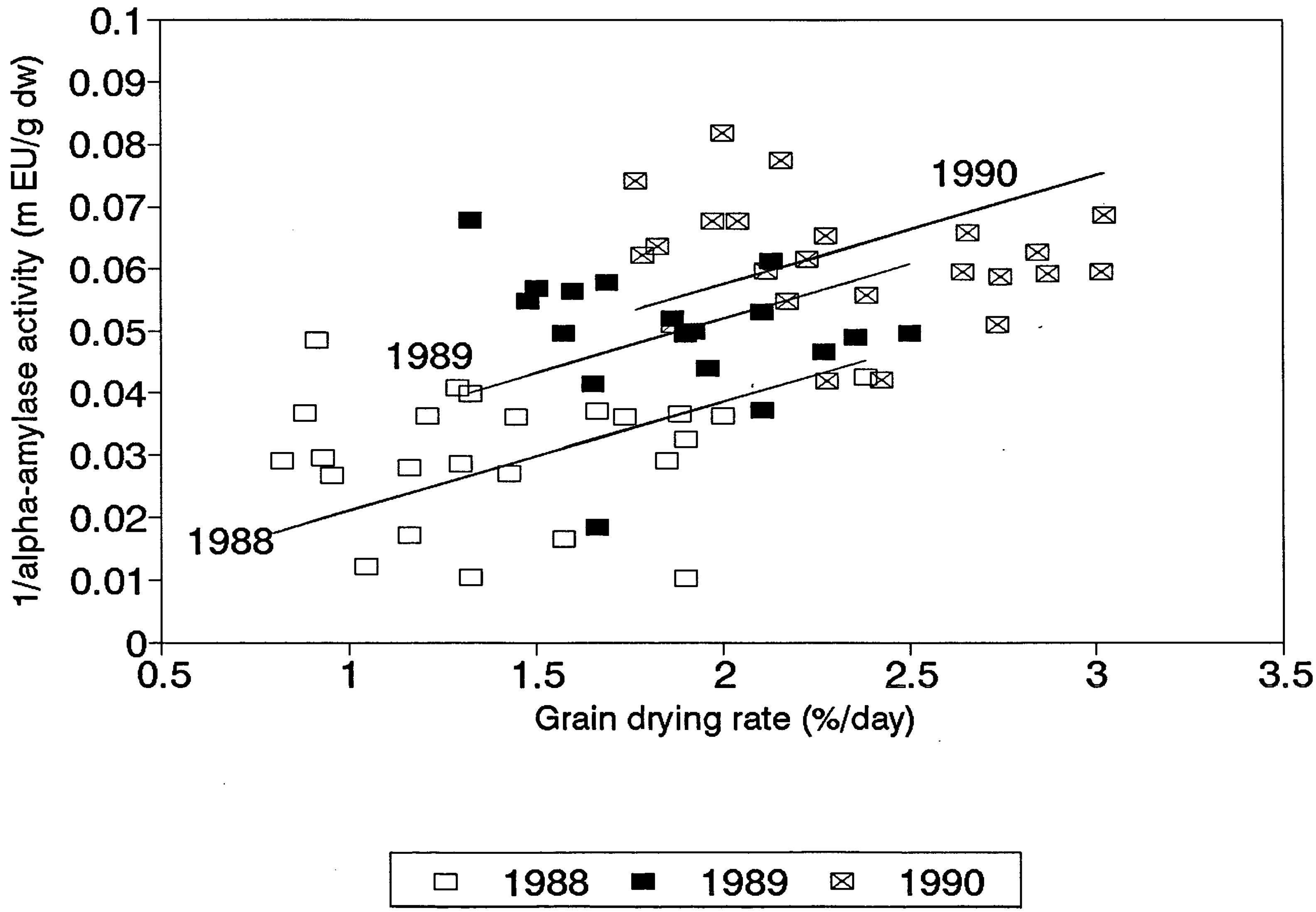
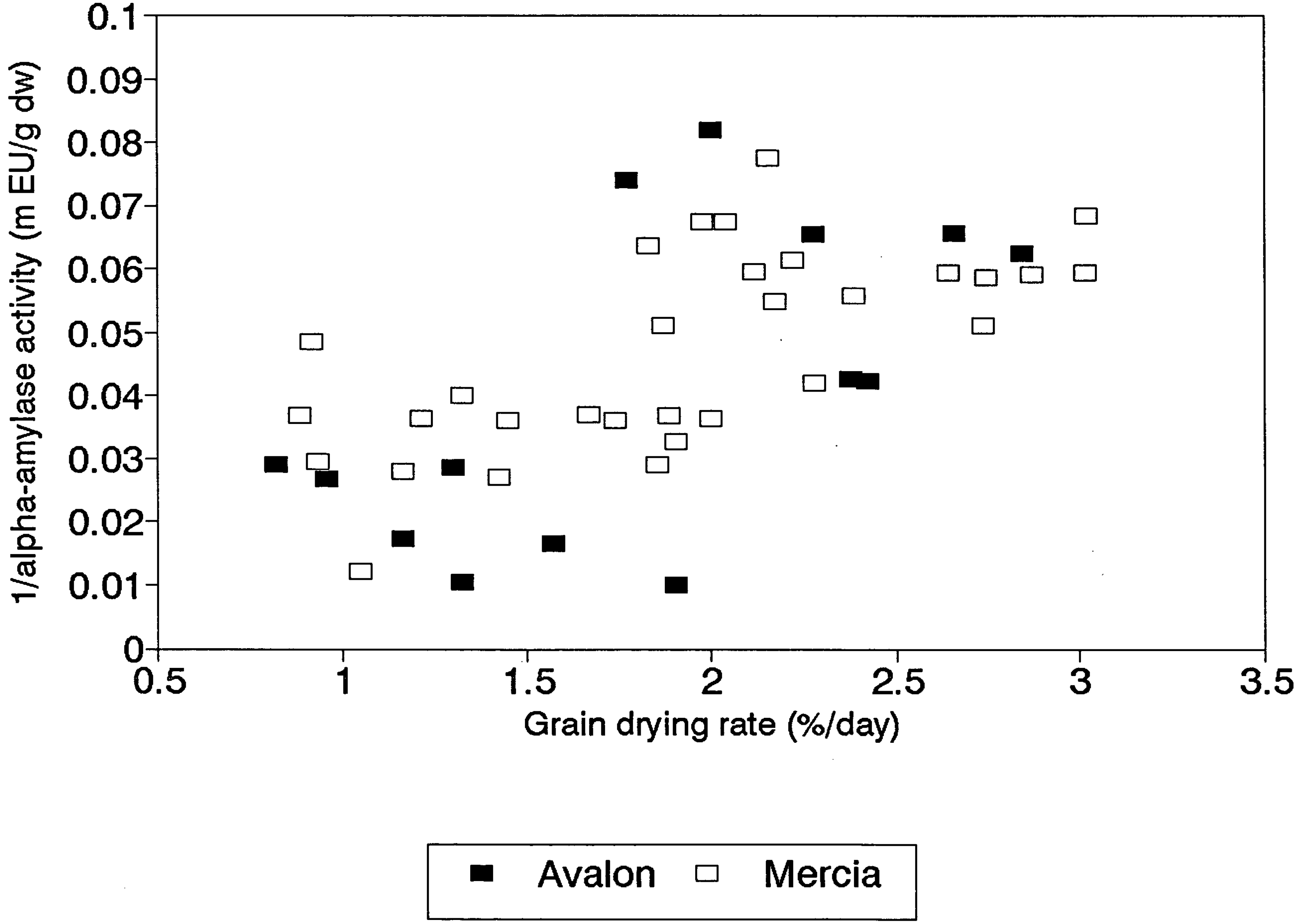


Figure 4. Grain drying rate and alpha-amylase activity



clearly associated with either Hagberg falling number or the reciprocal of alpha-amylase activity. There was an indication that lodging led to lower Hagberg falling number in 1988, but insufficient data was available to examine this relationship for all crops in 1988, and virtually no lodging occurred in the crops in the two subsequent years.

4.2 Fungicide and desiccant

4.2.1 Hagberg falling number

Owing to the difficulty of assessing grain moisture in the field for timing the desiccant application the later treatments in 1988 were applied when the crops were completely senescent. Data from these treatments is not presented and later treatments were omitted in subsequent years.

The weighted means calculated for all sites during the three year investigation indicated that fungicide applications had only a small effect on the Hagberg falling number of winter wheat. There did, however, appear to be a reduction in falling number with fungicide applications both in the presence and absence of the desiccant spray. This comparison is, however, confounded with the number of experiments, only six in the unsprayed mean but eleven in the sprayed means. The trend was, however, observed as a significant effect only once during the three years where the Hagberg of the three spray fungicide programme at Elsworth in 1989 was significantly reduced by 10 seconds against the unsprayed control. In all other experiments there was no significant effect of fungicide or desiccant application on Hagberg falling number.

Table 4. Weighted means calculated for the eleven fungicide and desiccant interaction experiments 1988 to 1990

Fungicide treatment	Hagberg falling number (seconds)	Yield (t/ha)
*None	378	5.17
Stem	357	6.23
Stem + flag leaf	356	6.53
Stem + flag leaf + ear	356	6.74
*None + desiccant	377	5.25
Stem + desiccant	362	6.29
Stem + flag leaf + desiccant	360	6.63
Stem + flag leaf + ear + desiccant	357	6.64

* Means from six experiments only

4.2.2 Yield

The weighted means calculated for the yield showed a positive relationship with fungicide application, with the greatest gain apparently resulting from the application of the single fungicide spray. This comparison is, however, confounded with the number of experiments, only six in the unsprayed mean but eleven in the sprayed means. During the three years of investigation there were only four instances out of 10 where the fungicide applications resulted in a significant yield response, three of which were in 1989.

4.2.3 Disease incidence and green area

Disease incidence was low at all sites in all years, and as a result there were only 9 occasions out of a possible 44 where fungicide significantly controlled the spread of disease. The values shown in Tables 5 and 6 are the maximum disease levels recorded for *Septoria nodorum* and powdery mildew (*Erysiphe graminis*) at each site.

In the three years and four sites, there were only two instances when there was no significant green area response to fungicide application (Harper Adams 1988, Haywold 1990). All other sites showed a significant increase in the green area duration of either the second leaf, flag leaf, ear, or all three on at least one date during the first three weeks in July (data not presented). Figure 5 shows the increase in green area resulting from the fungicide application at Haywold in 1989.

Table 5. Maximum infection levels (%) of Septoria nodorum at the four sites, 1988 to 1990

Site and year		Flag leaf disease	Zadoks growth stage and date	Ear disease	Zadoks growth stage and date
Harper Adams	1988	1.27	77 on July 12	0	-
Elsworth	1988	5.20	83 on July 27	0	-
Escrick Park	1988	4.80	83 on August 3	8.13	83 on August 3
Harper Adams	1989	6.83	83 on July 14	1.40	83 on July 14
Elsworth	1989	7.33	83 on July 13	0.20	83 on July 13
Escrick Park	1989	2.20	83 on July 18	4.17	83 on July 18
Haywold	1989	0.97	77 on July 17	3.50	85 on July 31
Harper Adams	1990	1.83	77 on July 2	0.60	83 on July 9
Little Dunmow	1990	0.80	75 on July 12	0.53	75 on July 12
Escrick Park	1990	0.83	85 on July 19	1.07	85 on July 19
Haywold	1990	2.70	83 on July 18	0.73	83 on July 18

Figure 5. The effect of fungicide on green area at Haywold on 17th July 1989.

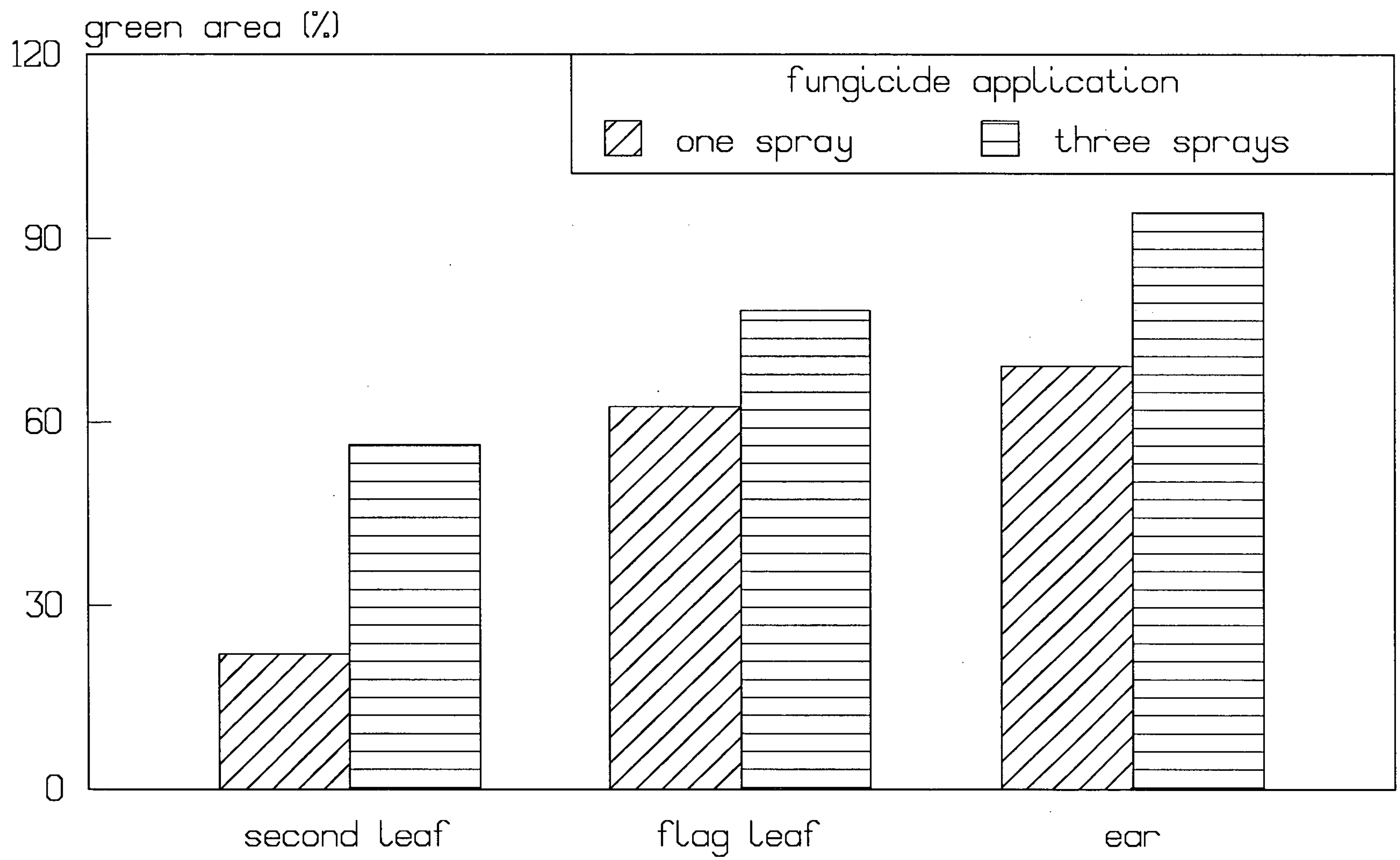


Table 6. Maximum infection levels (%) of *Erysiphe graminis* at the four sites, 1988 to 1990

Site and year		Flag leaf disease	Zadoks growth stage and date	Ear disease	Zadoks growth stage and date
Harper Adams	1988	4.00	77 on July 12	6.13	77 on July 12
Elsworth	1988	0	-	0	-
Escrick Park	1988	2.17	83 on August 3	6.43	83 on August 3
Harper Adams	1989	4.47	83 on July 14	22.73	83 on July 14
Elsworth	1989	0.43	83 on July 13	3.27	83 on July 13
Escrick Park	1989	4.50	83 on July 18	8.40	83 on July 18
Haywold	1989	3.33	77 on July 17	10.26	77 on July 17
Harper Adams	1990	2.37	77 on July 2	2.57	77 on July 2
Little Dunmow	1990	0.06	75 on July 12	0.77	75 on July 12
Escrick Park	1990	0.37	85 on July 19	1.03	85 on July 19
Haywold	1990	1.07	83 on July 18	1.97	83 on July 18

4.2.4 Grain moisture content

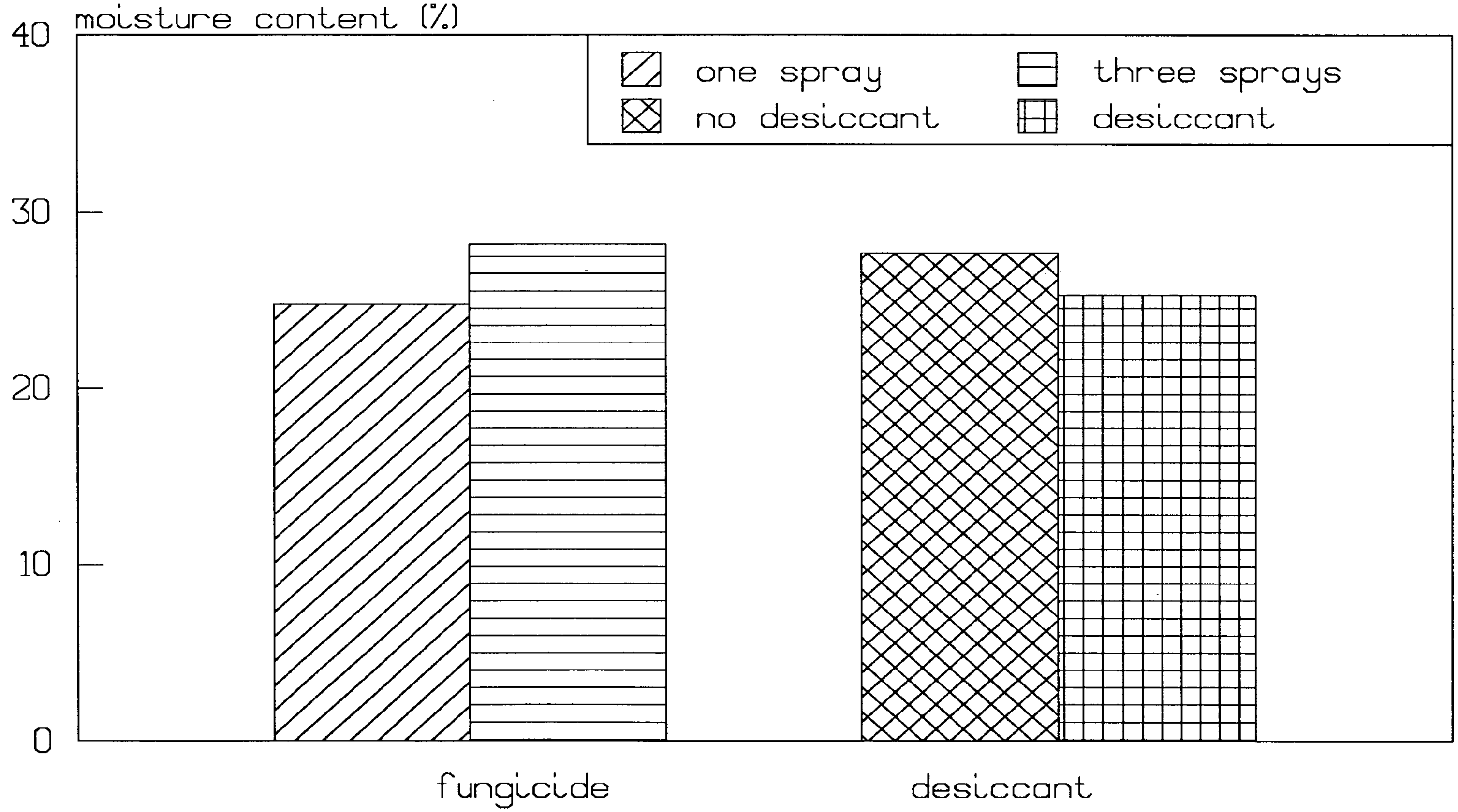
Desiccant averaged over all fungicide treatments had a drying effect on the grain in only one experiment (Figure 6), although the fungicide application did significantly increase the moisture content of the grain in two other experiments (data not presented).

4.3 Foliar urea timing

4.3.1 Hagberg falling number

The three year weighted means for the urea applications (Table 7) indicate that benefits to Hagberg may only occur if the urea is applied during ear emergence or anthesis. Hagberg was, however, only significantly improved by urea at Escrick Park in 1988 when the two

Figure 6. The effect of fungicide and desiccant on grain moisture content at Little Dunmow 25th July 1990



early sprays resulted in the largest Hagberg increase (48 seconds at ear emergence and 23 seconds at anthesis over the unsprayed control).

Table 7. Weighted means calculated for the late foliar urea timing experiment, 1988 to 1990

Timing of urea spray (40 kg N/ha)	Hagberg falling number (seconds)
unsprayed	334
ear emergence	347
anthesis	352
milk development	338
dough development	333

4.3.2 Protein content and yield

The protein content of the grain was improved significantly at Harper Adams only in 1988 and 1989. In both cases the greatest improvement resulted from urea sprays applied at ear emergence and anthesis (data not presented). The yield was only significantly improved by the urea application at ear emergence at Harper Adams in 1988 (data not presented). The Harper Adams site lodged badly in 1989 and although soil-applied nitrogen appeared to have a significant effect on whether a plot lodged or not, there was no relationship between urea application and lodging. Neither was there any yield loss from urea scorching the green leaf area, with scorch only evident at Harper Adams College in 1988 after the ear emergence application.

4.4 Spring-applied nitrogen and late foliar urea interaction

4.4.1 Hagberg falling number

The foliar urea in these experiments only had a significant effect on the Hagberg falling number at Harper Adams in 1990 (when a greater response to nitrogen occurred where urea was not applied) therefore all the nitrogen values shown in this section are averaged over the urea treatment.

In each year the Hagberg falling number was significantly increased by the nitrogen applications at Harper Adams College and the Arable Research Centre sites in a linear relationship, except in the 1990 Little Dunmow experiment where only pre-harvest hand-collected samples were available (Table 8). At Harper Adams the two varieties showed a different magnitude of response to the nitrogen rates (Figure 7); the Hagberg falling number of Avalon was increased to a greater extent than that of Mercia over the same nitrogen range (145 compared to 39 seconds in 1988; 64 and 11 seconds in 1989 and 31 and 7 seconds in 1990). There was no significant falling number response to the nitrogen rates at Escrick Park and Haywold in either 1989 or 1990. At Harper Adams in 1989 the Hagberg increased despite increased lodging with higher nitrogen rates from the time of ear emergence.

Figure 7. Spring-applied nitrogen fertiliser and Hagberg falling number at Harper Adams Agricultural College 1988 to 1990.

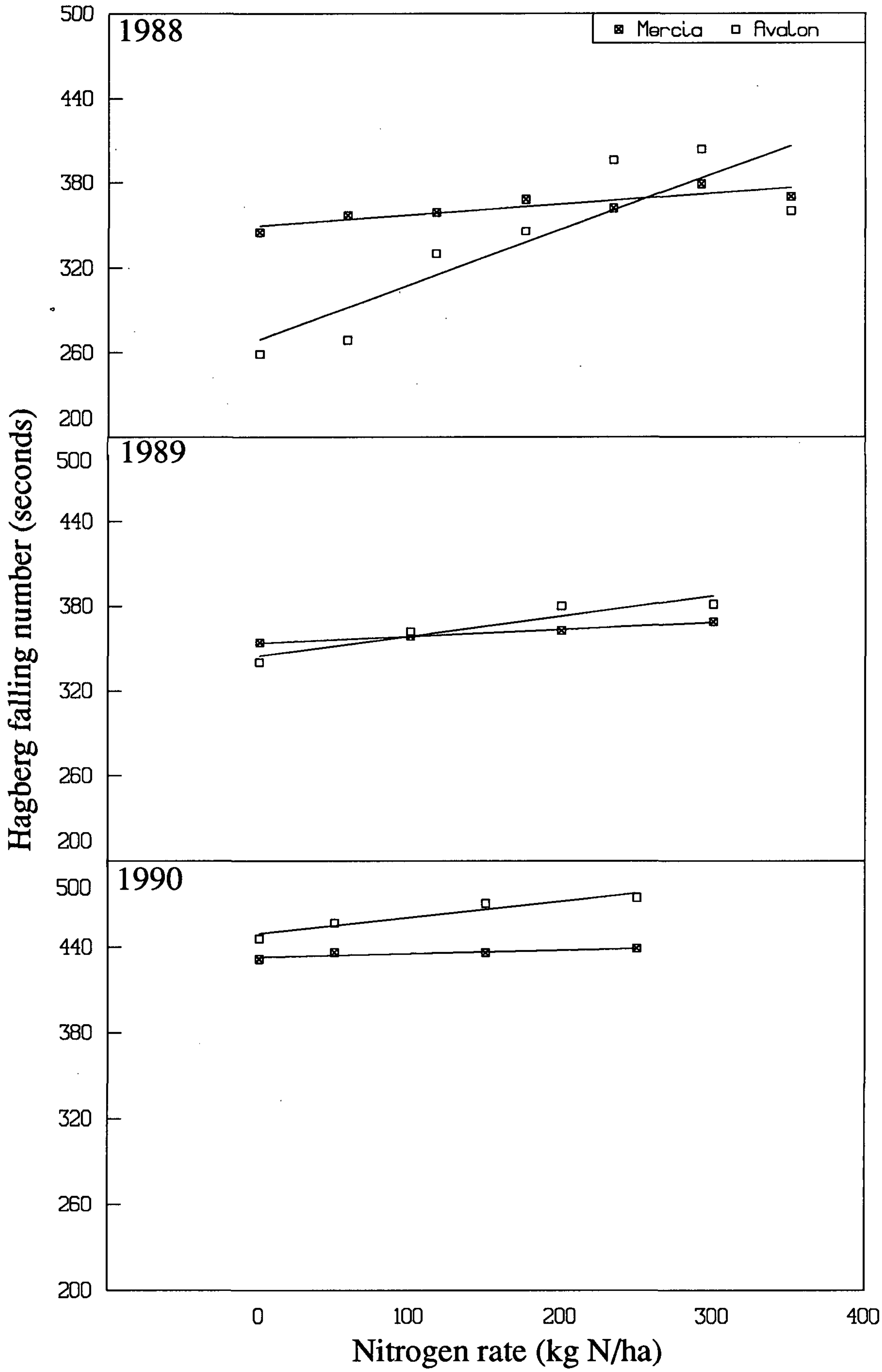


Table 8. The relationship between spring nitrogen application rate and Hagberg falling number at four sites, 1988 to 1990

Site and variety	Year	Slope	Intercept	S.E. slope	R^2 (%)	Significance from analysis of variance
Harper Adams College:						
Avalon	1988	0.390	269.3	0.100	75.4	nitrogen:linear, and variety x nitrogen:linear
Mercia	1988	0.074	349.8	0.019	75.1	
Avalon	1989	0.141	344.6	0.034	89.3	nitrogen:linear and variety x nitrogen:linear
Mercia	1989	0.049	353.9	0.003	99.4	
Elsworth Mercia	1989	0.088	297.3	0.016	93.8	nitrogen:linear
Escrick Park Mercia	1989	- 0.075	319.7	0.048	54.8	NS
Haywold Mercia	1989	0.023	308.7	0.062	6.5	NS
Harper Adams College:						
Avalon	1990	0.054	461.2	0.032	59.3	nitrogen:linear, and urea, and variety x nitrogen: linear, and nitrogen x urea: linear and quadratic
Mercia	1990	0.023	433.1	0.008	81.5	
Little Dunmow Mercia	1990	0.106	318.1	0.034	82.9	nitrogen:linear and quadratic
Escrick Park Mercia	1990	0.006	382.4	0.031	2.0	NS
Haywold Mercia	1990	0.110	315.6	0.042	77.7	NS

4.4.2 Protein content and yield

The protein content of the grain increased with increasing nitrogen rate in all experiments, and the urea spray applied at complete anthesis improved the protein content at all sites in all years with the exception of Escrick Park in 1990 (data not presented).

The yield at harvest showed a significant linear relationship with nitrogen application at all but two sites (Harper Adams College and Escrick Park in 1989), and urea increased yield at all sites in 1990 and at Haywold in 1989 (data not presented).

4.4.3 Alpha amylase activity

Alpha-amylase activity was significantly reduced by spring-applied nitrogen rate in 1988 and 1989, but not in 1990 (Figure 8). The response in 1988 was not simple. The two varieties exhibited significantly different magnitudes of response, with Mercia showing only small differences in activity (36.4 to 26.9 milli enzyme units/g D.W.) compared to Avalon (123.6 to 33.0 milli enzyme units/g D.W.) within the range of nitrogen application.

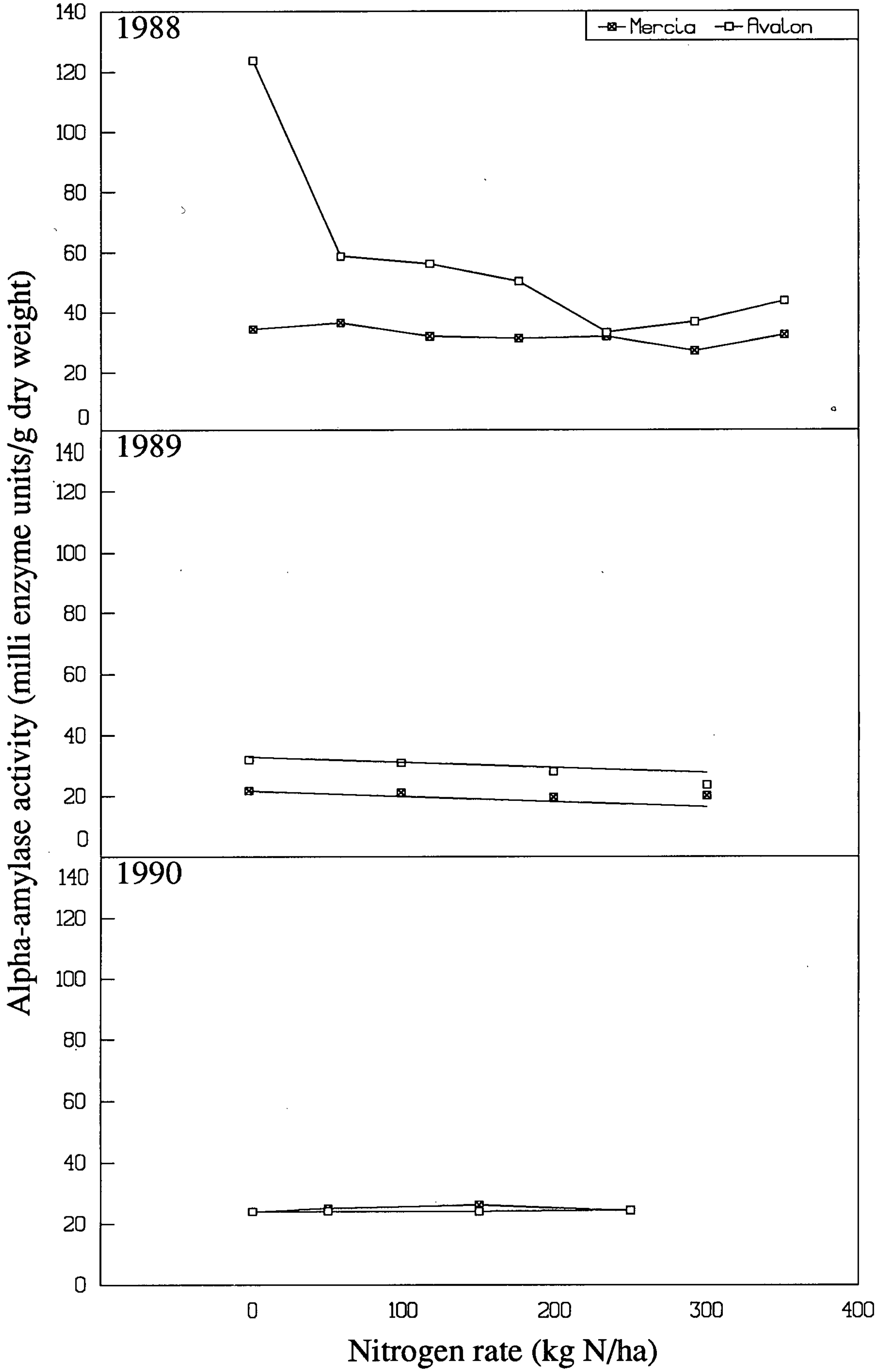
In 1989 the grain alpha-amylase activity was significantly reduced by the increased nitrogen rates, but no varietal difference in response was exhibited. In 1990 there was no significant relationship between spring-applied nitrogen rates and alpha-amylase activity.

5. DISCUSSION

5.1 Pre-harvest grain drying in commercial crops

The existence of an overall linear relationship for both Hagberg falling number and alpha-amylase activity with the grain drying rate from 40% to 20% moisture content supports the hypothesis of Gale *et al*. (1983) that slow drying rate triggers pre-maturity alpha-amylase

Figure 8. Spring-applied nitrogen fertiliser and alpha-amylase activity at Harper Adams Agricultural College 1988 to 1990.



formation. No sprouting was visible in any of the grain samples indicating that alpha-amylase probably was only produced before grain maturity. It can be inferred from the similarity in the proportion of the variation accounted for by the grain drying rate in both falling number and alpha-amylase activity that the effect of drying rate on falling number was mediated largely through changes in alpha-amylase activity rather than through changes in starch properties in this grain.

Since drying rate appears to be a determinant of the falling number, then, in theory, desiccant may have the potential for reversing the harmful effects of fungicide in delaying grain drying. Desiccant may even be of potential value irrespective of fungicide applications if the weather leads to slow grain drying.

Since a relationship exists between falling number and drying rate it may be possible to predict falling number in advance of maturity from assessment of drying rate. The overall relationship was, however, poor in that only one third of the variation in falling number could be accounted for. Indeed, the relationship appeared largely to depend on differences between years with considerable variation in any one year. Predictions using this data may only be of use in detecting gross year-to-year differences. A further problem with prediction is that the test of parallelism indicated that the slope of the relationship differed in each year. The implication from this is that another seasonal factor may have been involved in triggering pre-maturity alpha-amylase formation in addition to drying rate. Alternatively, these differences may represent post-dormancy alpha-amylase formation from incipient sprouting not visible in harvested grain. Mean falling numbers of pre-harvest hand-collected samples were not, however, higher than mean falling numbers of harvested grain indicating that post-dormancy alpha-amylase formation had not occurred.

It is possible that the drying rate over a different range of moisture contents (other than 40% to 20%) may be more closely related to falling number. Further analysis of the data collected in this project may help to clarify this. The lack of effect of amount of applied nitrogen fertiliser on falling number in the commercial crops does not necessarily contradict the results from the field experiments since considerably greater variability exists in the commercial crop falling numbers which will tend to mask relationships.

5.2 Fungicide and desiccant

Desiccant was applied after fungicide in an attempt to offset any detrimental effect that the fungicide may have had on the Hagberg falling number. Fungicide has been suggested to cause a fall in Hagberg by retarding the rate of grain drying (Gooding et al., 1987). An application of desiccant could possibly accelerate the drying of grain by killing the existing green area. In the years 1988 to 1990 there were only three occasions (out of a possible 11) where there was a significant effect of fungicide or desiccant on moisture content. This lack of effect probably partly reflected the high temperatures (Appendix 1) and consequent rapid natural desiccation of the crops that was evident in these years such that very little, if any, green area remained at the time of desiccant application, and differences in senescence induced by fungicide were minimised. Disease incidence was low during the three years and may also explain the paucity of fungicide effects on moisture content. It is thus not surprising that the Hagberg generally remained unaffected by the fungicide and desiccant applications. A further complication was the failure to apply the desiccant at the intended moisture content in several experiments. It is not valid, therefore, to conclude that desiccant cannot improve falling number, since the conditions in which these experiments were performed were not conducive to a clear evaluation. Further experiments in cooler, wetter environments are needed before any conclusion can be drawn.

The only significant effect of fungicide in reducing falling number occurred in conjunction with a large increase in yield. This supports previous work (Kettlewell et al., 1987b; West, 1990) which has shown that a detrimental effect on Hagberg only occurs when there are considerable beneficial effects on yield.

5.3 Timing of foliar urea

The effects of foliar urea on Hagberg were as inconsistent as those found previously (Kettlewell, 1989), with a significant effect in only one out of five experiments. The data indicated that timing may be important, and that the best timing may coincide with the optimum timing for increasing protein content.

5.4 Spring-applied nitrogen and late foliar urea interaction

Hagberg falling number was increased by increasing the rate of nitrogen application in five out of nine experiments, and these results thus confirm those in previous reports (Gooding *et al*., 1986b; McDonald and Vaidyanathan, 1987). It has been suggested that the difference in falling number between low and high nitrogen plots may reflect a difference in maturity of the plots, that is plants in low nitrogen plots may reach maturity earlier than plants in high nitrogen plots (Anon., 1985). The low nitrogen plots could then be more at risk from falling number deterioration through post-dormancy alpha-amylase formation than the high nitrogen plots on the same date. A pre-harvest sample taken from Harper Adams College in 1988 exhibited a higher falling number than the subsequent harvest sample collected 5 days later, which suggested that some deterioration in the grain quality had occurred. This trend was not recorded again during the study as the summers of 1989 and 1990 were hot and dry (Appendix 1); conditions not conducive to sprouting and falling number deterioration. Values of mean grain dry weight recorded only in 1990 indicated that there was no clear time difference between high and low nitrogen plots in reaching grain maturity (maximum grain weight). Thus the data from these experiments does not clearly support the hypothesis that maturity differences are responsible for the Hagberg response to nitrogen.

The differences in Hagberg falling number observed in the spring-applied nitrogen trial may have been due to differences in alpha-amylase activity or in the starch value, or a combination of the two factors (Ringlund, 1983). Alpha-amylase activities of grain from the 1988 and 1989 harvests showed an approximate inverse relationship to the corresponding falling number, and it would appear that in 1988 and 1989 nitrogen influenced the falling number by reducing the alpha-amylase activity. In 1990 no relationship between the falling number and alpha-amylase activity was evident. This may have been a consequence of the very low alpha-amylase activity where differences between values would be more difficult to detect, or it may have been that the changes in falling number were not related to differences in alpha amylase activity, but were related to changes in the starch value.

The difference in response between varieties to nitrogen has been reported previously (Gooding et al., 1986b). The existence of this nitrogen x variety interaction may have consequences for variety testing. If large amounts of fertiliser nitrogen are applied then the variety ranking for Hagberg may be different from that where smaller amounts of nitrogen are used. From our study it appears that this difference will be greater in some years (eg. 1988) than in others (eg. 1989).

The response of falling number to nitrogen was consistent whether or not urea was also applied, except in 1990 at Harper Adams when a greater response to nitrogen occurred where urea was not applied. Thus, generally, no interaction was found.

6. Conclusions and further research

1. Drying rate of the grain does appear to influence Hagberg falling number in the field, but clarification of the exact period over which it acts is needed to determine whether prediction of Hagberg from drying rate is feasible.

2. No conclusion can be reached on the effectiveness of desiccant in

off-setting detrimental effects of fungicide and maintaining falling number since the field experiments did not experience weather conducive to low falling number. Further work is necessary in cooler, moister environments (eg. Northern Ireland) before a valid conclusion can be drawn. Artificial wetting/irrigation treatments in field experiments may simulate appropriate weather adequately if experiments were located in mainland wheat-growing areas. A faster-acting desiccant than glyphosate may be worth using in future experiments (glufosinate-ammonium is reputedly slightly faster-acting and is the only other chemical currently approved for use on wheat).

3. Late-season foliar urea has been confirmed as giving only a small chance of an increase in falling number. Further research is unlikely to produce practically worthwhile results.

4. It has been confirmed that spring-applied nitrogen fertiliser increases falling number. Late-season foliar urea does not consistently affect this increase, but varieties differ in their responsiveness. Further work should be done to examine differences in responsiveness of a wider range of varieties so that an assessment can be made of the consequences of such differences for routine variety testing.

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Appendix 1. Weather data for Harper Adams Agricultural College 1988 to 1991

1.1 Mean monthly rainfall (in mm).

Month	1988	1989	1990	Mean 1961-1990
June	40.0	45.7	56.6	54.2
July	103.0	35.6	30.5	49.1
August	72.4	27.9	36.6	60.4

1.2 Mean monthly temperature (^{o}C)

Month	1988	1989	1990	Mean 1961-1990
June	14.3	14.2	13.5	13.8
July	14.6	17.8	16.8	15.6
August	14.9	16.2	18.8	15.4

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