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by

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ABSTRACT

A rapid diagnostic test for resistance to phosphine, based on the mobility of adults during exposure, has been developed for a number of grain pest species. Field strains of *S. oryzae* were tested with the rapid test, alongside the laboratory susceptible strain, and the results agreed with those obtained with the standard F.A.O. resistance test for six of seven strains tested. The other strain was diagnosed as susceptible by the F.A.O. test but found to be resistant by the rapid test. The disagreement was attributed to the fact that the rapid test is able to detect heterozygotes whilst the F.A.O. test was never designed to do this, detecting only homozygous insects. Since the F.A.O. test relies upon the presence of homozygous insects to detect resistance, it cannot provide an early warning of an emerging resistance problem.

Efforts to select a homozygous resistant strain of *S. granarius* were unsuccessful but field strains diagnosed from the F.A.O. test as susceptible all gave responses in the rapid test which agreed with the diagnoses from the F.A.O. test.

A homozygous strain of *O. surinamensis* was produced from a strain collected from Palmital in Brazil and heterozygotes were then produced from this strain and the laboratory susceptible strain. Homozygous resistant, susceptible and heterozygote insects were tested with the rapid test and there was no overlap in the response lines of the homozygous resistant insects and either of the other two genotypes. The responses of the heterozygotes did overlap with the responses of the susceptible strain but a portion of the heterozygotes could still be distinguished from susceptible insects. When field strains of this species were tested, the rapid test agreed with the diagnoses of the F.A.O. test in 10 out of 13 strains tested. For the other three strains, the rapid test found evidence of resistance but the F.A.O. test did not. As with one strain of *S. oryzae*, this was attributed to the rapid test's ability to detect the major resistance gene in its heterozygous form.

The discriminating knockdown times for each species were as follows:
S. oryzae 141 min (2 hr, 21 min), *O. surinamensis* 225 min (3 hr, 45 min) and for *S. granarius* it is estimated to be at least 1065 min (17 hr, 45 min).

The immature stages of resistant strains of the above species were controlled by exposure to high concentrations of phosphine at 15°C. The most tolerant species was *S. oryzae* which required a 24-day exposure at a concentration of 2 g m^{-3}. At 10°C a single individual of this species survived a four week exposure at this concentration.

An automated dosing system for cylinder based phosphine was developed and tested by the Central Science Laboratory. The performance of the dosing system was compared with the Siroflo^{R} system that has been developed by CSIRO in Australia. Both systems were tested in a silo containing 700 tonnes of feed wheat and in a floor store containing 150 tonnes of feed wheat. Concentrations of 0.05 g m^{-3} or greater were achieved in all positions using the Siroflo^{R} system but the automated dosing system required gas re-circulation with a centrifugal pump to obtain the same result.

When re-circulation was used, higher concentrations and CTPs were achieved using the automated dosing system compared with the Siroflo^{R} system in both the grain silo and the floor store. In the case of the silo this was achieved using less gas. In the floor store the Siroflo^{R} used only 55 % of the amount of gas used by the automated dosing system with re-circulation but the average concentration was only 28 % of that obtained using the automated dosing system.

The automated dosing system was also used in an experimental fumigation of a part of a large bulk of infested grain . In the infested area concentrations of over 0.05 g m^{-3} were reached everywhere by 5 days and remained above this value until the system was switched off.

Methyl phosphine has been shown to be more effective against immature stages and adults of phosphine-resistant strains in comparison with susceptibles.

INTRODUCTION

The continuous usage of phosphine for the control of stored product insects and the inadequate sealing standards leading to low concentrations have led to the development of resistant strains in many countries. The FAO resistance survey carried out in 1972-73 detected resistance in 33 out of 82 countries sampled (Champ and Dyte, 1976). Since then the situation has worsened with resistance detected by several workers (Conway, 1981 (in Taylor, 1986); Mills, 1983; 1986a,b; Tyler *et al.*, 1983; Taylor, 1986; Srivastava, 1980; Taylor, 1989; Pacheco *et al.*, 1990; Zettler, 1990).

In spite of growing resistance problems, phosphine is still effective in achieving control of these pest species provided that an adequate gas concentration can be maintained so that the exposure period can be extended to control the naturally tolerant stages (Bell *et al.*, 1994) without residue problems. Methyl bromide, the only other major fumigant in general use, is being phased out under the terms of the Montreal Protocol On Substances Which Deplete the Ozone Layer. In the absence of methyl bromide, phosphine will remain as the only fumigant in use on grain and an increase in its use can be predicted. With this increase in phosphine usage we can expect an increase in the amount of sub-standard fumigations and a consequent increase in the resistance problem. The use of methyl bromide to combat phosphine resistant strains will not be a future option. There is a need for a pro-active strategy to prevent the development of the resistance. It is possible to use phosphine to combat the resistance by following the current best practices. These make use of new developments in continuous dosing using a cylinder-based supply of gas and phosphine generators to guarantee effective gas concentrations and exposure periods.

The key to an effective strategy is the detection of resistant insects so that an appropriate dosage schedule can be applied to control them. The current discriminating dose test, FAO Method No. 16 (Anon., 1975) is based on mortality and requires 14 days to produce results. This is frequently too long when fumigations are required to be carried out rapidly. A new methodology for detecting resistance in a few hours has been developed at the Central Science Laboratory (CSL) for *Tribolium castaneum* (Herbst) and *Cryptolestes ferrugineus* (Stephens) and was partially developed for *Sitophilus oryzae* (L.) (Savvidou *et al.*, 1994).

The first objective of the research in the current project is to complete the development of the rapid test for *S. oryzae* and to develop the test for *Oryzaephilus surinamensis* (L.). At the early stages in the development of the resistance the resistance gene(s) are mainly in the heterozygous condition with a small, probably undetectable, proportion of homozygous resistants present. Doses to control all life stages of resistants carefully selected to be homozygous for all genes and for control of their corresponding heterozygotes need to be established. The emergence of resistance in the first place can be prevented by a small increment to existing dosage schedules to control heterozygotes. Another more rigorous dosage schedule for the control of all stages of homozygotes should be applied where heterozygotes are found. It follows that fumigations designed to prevent the development of resistance and to eliminate it where it has developed will demand the highest attention to sealing and the use of modern dosing technologies with the necessary training.

The second objective is to determine the tolerance of resistant strains of *Sitophilus oryzae, Sitophilus granarius, Cryptolestes ferrugineus* and *Oryzaephilus surinamensis* at 10 and 15°C in order to provide target concentrations and exposure periods for practical control as part of an ongoing examination of problem areas with phosphine fumigation. Research on the toxicity of phosphine at low temperatures (5, 7.5 and 10°C) to mainly susceptible strains is completed (Clifton, *et al.*, 1995)

The third objective is to develop the use of the automated dosing system invented at CSL for the fumigation of bulk grain. Previous research centred on the economical dosing of methyl bromide in flour mills and grain storage structures (Wontner-Smith, *et al.*, 1994, 1998). The equipment was modified to enable it to dose the cylinder-based phosphine supply described by Bell *et al.* (1991). The dosing system achieves a pre-programmed concentration where and when necessary in a bulk grain fumigation. This will, therefore, guarantee a minimum concentration over the required exposure period for insect control. It is a considerable improvement over the conventional dosing technique which employs solid metal phosphide formulations. These give off phosphine over a period of a few days, depending on temperature and the moisture content of the grain. Once they are spent, the unknown leakage in a silo or floor store will allow the concentration level to drop and, in some cases, this precludes the attainment of the necessary exposure period. Where insects having resistance

genes are present, the resulting survival can lead to the selection of resistant insects. This may cause further difficulties in obtaining disinfestation in the future.

The fourth objective is to assess the effect of a potential new fumigant, methyl phosphine, against the immature stages of some resistant strains. This gas is a potential novel solution to the resistance problem since it kills phosphine-resistant insects more easily than it does susceptibles (Chaudhry *et. al.,* 1997). It could be dosed like phosphine from cylinders. Thus it could be applied either in a mixture with phosphine or alternated with phosphine to counter-select the resistant individuals.

FURTHER DEVELOPMENT OF A RAPID TEST FOR DETECTING RESISTANCE TO PHOSPHINE.

A rapid resistance test for phosphine, based on the knockdown responses of unaged adult, insects was designed by Bell *et al.* (1994) and developed by Savvidou *et al.* (1994). The published work involved the testing of susceptible, homozygous resistant and heterozygous adults of *Cryptolestes ferrugineus* (Stephens), *Tribolium castaneum* (Herbst) and *Sitophilus oryzae* (L.). In addition, some comparative tests were done with field strains of *C. ferrugineus* and *T. castaneum,* whose resistance status had already been diagnosed using the resistance test of the Food and Agricultural Organisation (F.A.O.) (Method no. 16, Anon. 1975).

The aim of the current work was to carry out comparative tests with field strains of *Sitophilus oryzae* and develop the test further, to allow testing of two other important pests of stored products, *Oryzaephilus surinamensis* and *Sitophilus granarius*, including comparative tests with field strains. The extension of the test to include the additional species, required that homozygous resistant strains be bred and heterozygous insects produced, by crossing the homozygotes with the laboratory susceptible strain of each species. After tests had been completed with susceptible field strains of *S. granarius*, it subsequently proved impossible to produce a viable, homozygous resistant strain of this species. In the absence of comparative tests with homozygous resistant and heterozygous insects, it would not have been possible to set a reliable discriminating time for *S. granarius* and therefore it was omitted from further testing.

METHODS

The F.A.O. Resistance Tests

The resistance tests were done according to F.A.O. method no. 16, based on a 20-hour exposure to gas followed by a 14-day mortality assessment. The F.A.O. tests for all the species were done together, over the period 1993-1994, prior to the start of this work. although some re-testing was done during this project. To improve the accuracy of concentration measurements, tests were done in 1700 litre, steel fumigation chambers instead of the standard 6-litre desiccators, with two replicates of 100 adults treated and two

replicates of 100 adults as controls for each strain. The insects were treated at 3-5 weeks old, without food and then placed on food for 14 days before being assessed for mortality. Each strain was tested using the F.A.O. discriminating dose, for 20 hours; 0.04 g m^{-3} for *S. oryzae*, 0.05 g m^{-3} for *O. surinamensis* and 0.07 g m^{-3} for *S. granarius*.

Where it was necessary to modify any details of the original method during re-testing, the modifications are outlined in the appropriate section.

The Rapid Test

All the tests were done in 6 litre, glass desiccators at 25°C, 60% relative humidity (r.h.). The doses were based on a nominal concentration of 0.4 g m^{-3} but the concentrations ranged as follows: *S. oryzae* and *O. surinamensis* 0.385 $\pm$ 0.055 g m^{-3}, *S. granarius* 0.41 $\pm$ 0.01 g m^{-3}.

The tests with the field strains of *S. oryzae* were done according to the method outlined in Bell *et al.* (1994) and Savvidou *et al.* (1994). Three replicates of 30 insects were observed and each field strain was tested alongside the laboratory, susceptible strain, in the same desiccator.

For the other species, the method was modified slightly. The method in the original version of the test, used paper cones to make the assessment of knockdown easier. It was found however, that the tarsi of the adult *O. surinamensis* and *S. granarius* were gripping the paper cones and consequently were not falling off the cone, even after they were overcome by the fumigant. Therefore the paper cones were replaced with cones made from acetate sheet (overhead projection grade) which gave a much smoother surface to the cone. As with *S. oryzae*, three replicates of 30 insects were used for each strain and the laboratory, susceptible strain, was tested in the same desiccator.

Phosphine was generated from a pellet of aluminium phosphide. A 500 ml glass measuring cylinder was placed in a 15 cm glass crystallising dish. A pellet of aluminium phosphide was placed in the cylinder and a small glass funnel inverted over the pellet. The cylinder was then filled with 5% sulphuric acid and a burette inverted and lowered into the cylinder, above the funnel so as to displace all the air with acid. Whilst submerged, the top of the burette was

closed with a screw top, fitted with a rubber septum and the neck of the burette clamped to hold it in place.

The desiccators were sealed with flat, glass, observation tops which had a central dosing port, fitted with a rubber septum. A gas-tight syringe was used to dose the desiccators, whilst mixing with a magnetic stirrer for approximately 5 min. Timing was started from the introduction of the fumigant and observations were made at intervals of 2-5 min.

Knockdown was recognised as being the point at which the insects fell off the cone, to the bottom of the slope and were unable to stand again.

At the end of the test, the phosphine concentration in the desiccator was analysed by gas chromatography, using a flame photometric detector, calibrated with a cylinder formulation of phosphine in nitrogen, of known concentration. The data from the completed tests were then subjected to probit analysis (Finney, 1971).

Attempts to Produce a Homozygous Resistant Strain of *S. granarius*.

Six field strains, previously diagnosed as resistant by the F.A.O. test, were re-tested in large numbers at the discriminating concentration of 0.07 g m^{-3} in order to confirm that the strains were resistant. Approximately 1500-2000 unaged adults of each field strain and of the laboratory susceptible strain were placed in 1 litre glass jars, on pleated filter papers and the jars covered with nylon mesh tops. The tests were conducted in a 1700 litre, steel fumigation chamber for 20 hours. After removal from the gas, the insects were incubated on food at 25°C, 60% r.h. for 14 days, before being assessed for mortality.

After the confirmation tests, all the strains were combined to interbreed and the progeny were tested further at four phosphine concentrations, 0.05, 0.08, 0.1, 0.18 g m^{-3}, with an untreated control batch. The numbers of insects tested as unaged adults were 665, 1350, 3880, 5230 and 750, respectively and the survivors from the top dose were then bred to build up large numbers of insects. The immature stages of their progeny were included in toxicity tests, the results of which led to the decision to discontinue further tests with this strain after the susceptible field strains had been tested (see section on immature tests).

Production of Homozygous Resistant *O. surinamensis*

It appears, from previous data from this and other stored product species, that there is more than one gene which controls resistance to phosphine. There appears to be a major gene, involved in an active exclusion mechanism and a minor gene, involved in a de-toxification process. It is extremely difficult to select for both genes, as one often masks the effect of the other. The selection carried out for this project was designed to select for the major gene and the term 'homozygous resistant' refers to insects homozygous for the major gene.

1) Finding a resistant strain to begin selecting for resistance.

Beetles were available from three stores in Brazil which had previously been fumigated with phosphine. They were collected from corn stores in Palmital, Sao Paulo (S.P.) and Dourados in 1991, and a rice store in Presidente Prudente, S.P. in 1988. These, along with a strain collected from a provender mill in Bridgewater, England and the laboratory susceptible strain, were tested with the F.A.O. resistance test. All, except the laboratory strain were found to be resistant.

Steps were then taken to ascertain which strain was the most resistant, using F.A.O. mortality tests. Two replicates of 30 insects of each of the five strains, were then treated with approximately 3x, 5x and 10x the F.A.O. discriminating concentration, for the standard 20 hour exposure, with the same replication in untreated controls. Two replicates of 50 insects for each strain were subsequently tested with approximately 5x, 8x and 10x the discriminating concentration for 72 hours, along with two replicates of untreated controls. After both tests, the insects were placed on food and kept at 25°C, 60% r.h. for 14 days, before being assessed for mortality. The Palmital strain proved to be the most resistant and was further selected.

2) Selecting the strain to produce a homozygous resistant population.

In the first instance, 985 unaged adults were treated with 0.393 g m^{-3} and 700 unaged adults were treated with 0.622 g m^{-3} for 20 hours, concentrations near the LC_{90} and LC_{95} figures respectively, obtained from the earlier tests with this strain.

After 14 days, survivors from the higher of the two concentrations were placed on fresh food and allowed to breed and lay eggs at 25°C, 60% r.h.. First generation larvae were then placed individually into 4 cm x 1 cm glass tubes, containing approximately 1 cm depth of food.

Once the virgin adults (F1) emerged, the tubes were divided into three batches of 90, 127 and 177 tubes and treated with 0.67, 0.86 and 1.16 g m^{-3} respectively. After 14 days, the survivors from each concentration were sexed, paired on fresh food in 7 cm x 2.5 cm glass tubes and each pair given an identifying number. Every two weeks, each pair was moved onto new tubes, containing fresh food and labelled with the pair's identifying number. This resulted in four sets of progeny (a family) from each pair. After emergence, these F2 adults were moved onto fresh food every 3 weeks, to prevent their own progeny (F3) from contaminating the test batch.. For the first batch of tests, the F2 families of each pair were tested with the F.A.O. test, 0.05 g m^{-3} for 20 hours, to detect susceptible insects which may be present. A second batch was also tested in the same manner but consisted of a mixture of F2 and F3 adults.

Families where mortality occurred, along with their original pairs, were discarded. Those with no mortality, along with their original pairs, were kept and considered to be homozygous families. These homozygotes were tested with the rapid test, alongside the laboratory strain.

Producing Heterozygotes of *O. surinamensis.*

Larvae from families 6, 16 and 20 were available and therefore were used as the homozygous resistant parents. Single larvae from these families were placed in 5 cm x 1 cm glass tubes, with approximately 1 cm depth of rolled oats. After incubation at 32°C and 60% r.h. virgin adults emerged which were then sexed and paired with virgin adults of the laboratory susceptible strain, which had undergone the same procedure. The pairs were placed on fresh food in 120 ml, wide mouthed, glass jars. After emergence, the progeny were pooled in 1 litre glass jars and moved to fresh food every two weeks, to prevent contamination by the next generation.

The heterozygotes were then tested with the rapid test, alongside the laboratory strain.

RESULTS

S. oryzae

The rapid test agreed with the diagnosis of resistance from the F.A.O. tests in six of the seven strains (Table 1). Of the six however, two, Downham and Kinross were re-tested after initial disagreement between the two tests. The rapid test consistently diagnosed them as susceptible while the F.A.O. test had initially found resistance but then subsequently did not. The results for the 7th strain (Pickering) were reversed, it was diagnosed as susceptible by the F.A.O. test but the rapid test indicated that the resistance gene was present in the population. The response data generated by the rapid test had a distinct plateau in the probit line which indicated that there was more than one genotype present (Fig. 1).

Table 1 Probit parameters from the rapid test for field strains of *S. oryzae* and their resistance status.

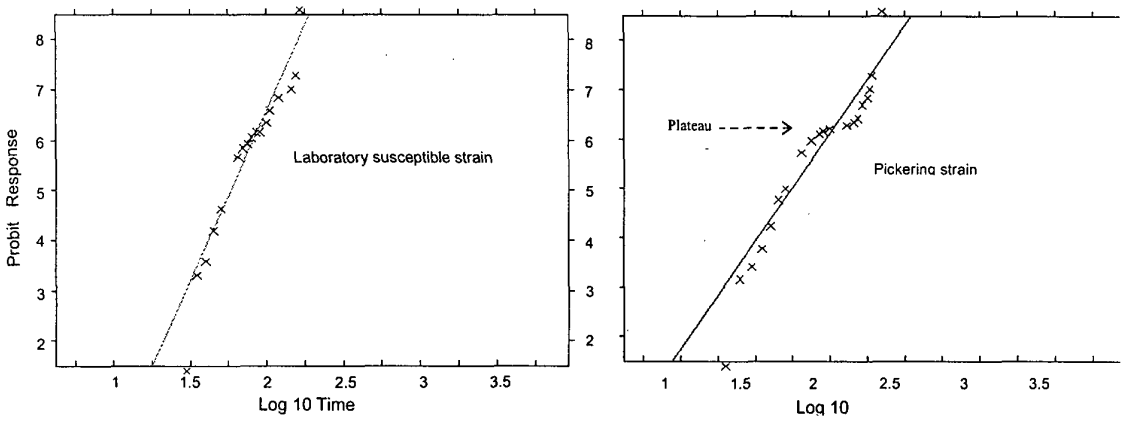
Strain	**$KD_{99.99}$ (fiducial limits)**	**SLOPE (S.E.)**	**RESISTANCE STATUS**	
			F.A.O	Rapid test
Laboratory	196.09 (*)	7.7 (*)	S	S
Westbury	140.60 (117.42, 185.00)	8.6 (0.8)	S	S
Downham	73.73 (61.20, 99.55)	8.9 (0.8)	S[a]	S
Kinross	94.69 (84.12, 110.05)	7.5 (0.5)	S[a]	S
Pickering	397.02 (300.44, 583.39)	4.4 (0.3)	S	R
Chard	682.69 (503.35, 1019.35)	3.5 (0.2)	R	R
Maringa	7457.32 (5287.29, 11692.92)	3.2 (0.2)	R	R

R= Resistant, S= Susceptible.

* These figures are the means of all the tests with the laboratory strain and therefore fiducial limits and standard errors from the probit analysis cannot be given.

[a] In tests done in 1993, these strains were diagnosed as resistant by the F.A.O. test and 8 months later the rapid test diagnosed them as susceptible. Re-tests were done in 1998, a week apart and these are the re-test results

Figure 1. Distribution of probit points of the Laboratory Susceptible and Pickering strains of *S. oryzae* from the rapid test with 0.441 g m^{-3}.



S. granarius

Re-testing of the resistant field strains from the F.A.O. tests confirmed that all six were resistant (Table 2). Unfortunately, efforts to select a homozygous resistant strain were unsuccessful. The toxicity tests, described separately in this report, proved that the survivors at 0.18 g m^{-3} (Table 3) had produced progeny whose pupae were no more tolerant to phosphine than the pupae of the laboratory susceptible strain (see section on immature stages).

The field strains, diagnosed as susceptible by the F.A.O. test and the laboratory susceptible strain, were all confirmed as susceptible by the rapid test (Table 4). All the field strains were more susceptible than the laboratory strain.

Table 2 Re-testing of field strains of *S. granarius*, with the F.A.O. test at the discriminating dose, 0.07 g m^{-3} for 20 hours.

Strain	Number of Insects Tested	% Survival
Laboratory susceptible	>1000	0
Driffield	2311	1.32
Glusburn	2465	2.03
Helena	1722	0.58
Preston	2319	14.75
Woodbridge	2966	2.83

Table 3 Selection of combined strain of *S. granarius*.

Concentration (g m^{-3})	Number tested	% survival
Control	750	98.93
0.0543	665	13.8
0.0755	1352	8.58
0.1096	3884	3.81
0.1831	5234	1.39

Table 4 Probit parameters from the rapid test for susceptible field strains of *S. granarius* and their resistance status.

Strain	$KD_{99.99}$ (fiducial limits)	SLOPE (S.E.)	RESISTANCE STATUS	
			F.A.O	Rapid test
Laboratory	1064.88 (*)	5.4 (*)	S	S
Windsor	449.96 (388.75, 534.75)	4.3 (0.2)	S	S
Forstal	395.77 (219.20, 1538.67)	4.1 (0.7)	S	S
Peppers	247.75 (160.49, 577.73)	4.7 (0.6)	S	S

* These figures are the means of all the tests with the laboratory strain and therefore fiducial limits and standard errors cannot be given.

O. surinamensis

Of the four strains tested, the British strain, from Bridgewater, proved to be the most susceptible, with 100% mortality at 0.1 g m^{-3}. The Palmital strain was the most tolerant (Table 5). It was the only strain to survive 20 hours at 0.37 g m^{-3} and over 10% survived.

A further selection, using a larger number of insects, resulted in nearly 19% survival at 0.39 g m^{-3} and over 10% survival at 0.62 g m^{-3} (Table 6). When the virgin progeny of these survivors were tested, a greater proportion survived 0.67, 0.86 and 1.16 g m^{-3}, although there was little difference in survival at the three concentrations, with 23.3%, 25.2% and 25.4% survival respectively (Table 6). After these survivors were sexed and paired, 10 of the 29 families tested had some mortality when they were tested with the F.A.O. discriminating dose, 0.05 g m^{-3} (Table 7).

In the rapid test, there was an increase in $KD_{99.99}$ values for the heterozygotes from those of the laboratory strain (Table 8), although there was overlap between the response lines from the two populations (Fig. 2). However, no such overlap was seen between the response lines of the homozygous resistant strain and those of either the laboratory strain or the heterozygotes (Fig. 2).

In the comparative rapid tests involving field strains, 10 of the 13 diagnoses agreed with those of the F.A.O. test (Table 9). For the other three strains, Bridgewater, Melksham and Platt, the F.A.O. test diagnosed them as resistant but, whilst the rapid tests done in 1993/94 suggested that resistance may be present, they were marginal (Fig. 3) and therefore re-tests with both methods were done in 1998. The results from the rapid test were conclusive and diagnosed all three strains as resistant but the diagnoses of the F.A.O. test were reversed from the earlier findings and diagnosed them as susceptible. Therefore the two tests disagreed in their most recent diagnoses of these strains.

Table 5 Corrected mortalities (%) for four field strains of *O. surinamensis* tested with the F.A.O. mortality test and figures from the probit analysis.

STRAIN	PHOSPHINE CONCENTRATION ($g\ m^{-3}$)				PROBIT PARAMETERS		
	0.031	**0.100**	**0.168**	**0.370**	**LC_{90}**	**LC_{95}**	**SLOPE (S.E)**
Palmital	27.5	57.9	68.9	89.6	0.44	0.73	1.66 (0.25)
Presidente Prudente	51.4	87.0	88.8	100	0.13	0.20	1.98 (0.38)
Dourados	60.2	100	98.2	100	0.06	0.08	3.25 (0.64)
Bridgewater	96.5	100	100	100	-	-	-

Table 6 Selection of *O. surinamensis* Palmital with phosphine, for 20 hours.

Concentration ($g\ m^{-3}$)	Number Tested	Number Survived	% Survival	No. of pairs resulting
	Mixed adults			
0.39	985	185	18.78	-
0.62	710	72	10.56	-
	F1 Virgin adults			
0.67	90	21	23.3	8
0.86	127	32	25.2	10
1.16	177	45	25.42	20

Table 7 Response of *O. surinamensis* families to F.A.O. discriminating dose (0.05 g m^{-3}) for 20 hours .

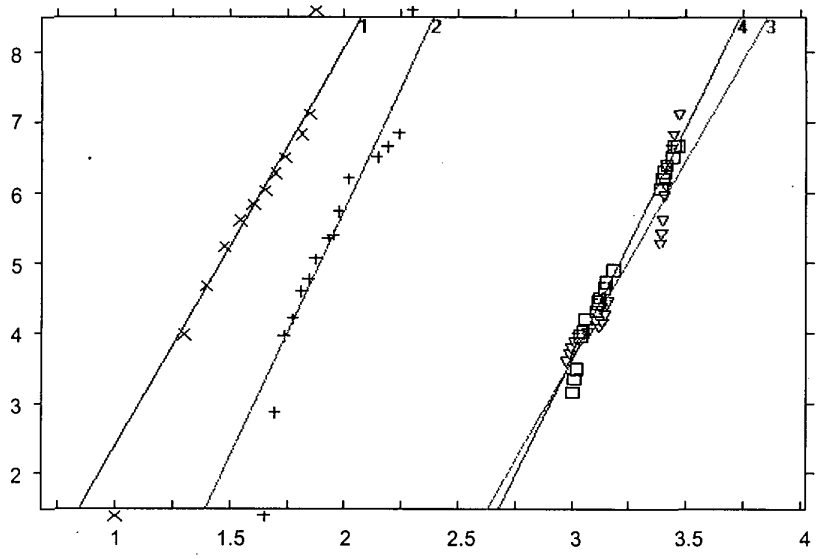
Conc. which F1 parents survived. (g m^{-3})	Family No.	Number of F2 adults tested. (Batch 1)	Number dead	Number of F2+F3 adults tested. (Batch 2)	Number dead
1.16	1	13	0	7	0
	2	7	0	20	0
	3	16	0	-	-
	4	6	1	64	1
	5	6	0	-	-
	6	18	0	50	0
	7	24	0	46	0
	8	-	-	10	2
	9	33	1	-	-
	10	32	0	-	-
	11	8	0	44	0
	14	28	0	3	0
	15	7	1	59	0
	16	8	-	23	0
	19	8	-	21	2
	20	13	-	70	0
0.86	21	33	1	-	-
	22	19	0	57	0
	23	38	0	37	1
	25	30	0	54	1
	26	47	0	49	0
	28	14	0	-	-
	29	36	0	-	-
	30	33	0	58	1
0.67	32	15	0	25	0
	33	34	2	41	2
	34	-	-	26	0
	35	12	0	41	0
	36	3	0	27	0

Families discarded.

Table 8 Probit parameters of *O. surinamensis* laboratory strain, homozygous resistant strain and heterozygotes.

Strain	$KD_{99.99}$ (fiducial limits)	SLOPE (S.E.)
Laboratory	109.18 (98.12, 124.40)	7.3 (0.4)
Laboratory	100.86 (86.81, 124.48)	7.7 (0.6)
Laboratory	186.52 (154.32, 237.81)	5.0 (0.3)
Heterozygotes	185.27 (171.55, 202.61)	7.7 (0.3)
Heterozygotes	183.30 (158.53, 221.25)	7.5 (0.5)
Homozygous Resistant	13743.57 (9290.34, 22123.02)	2.2 (0.1)

Figure 2 Probit response lines for *O. surinamensis* laboratory susceptible strain, homozygous resistant strain and heterozygotes.



Line 1 = Laboratory susceptible strain.
Line 2 = Heterozygotes.
Lines 3 & 4 = Homozygous resistant strain.

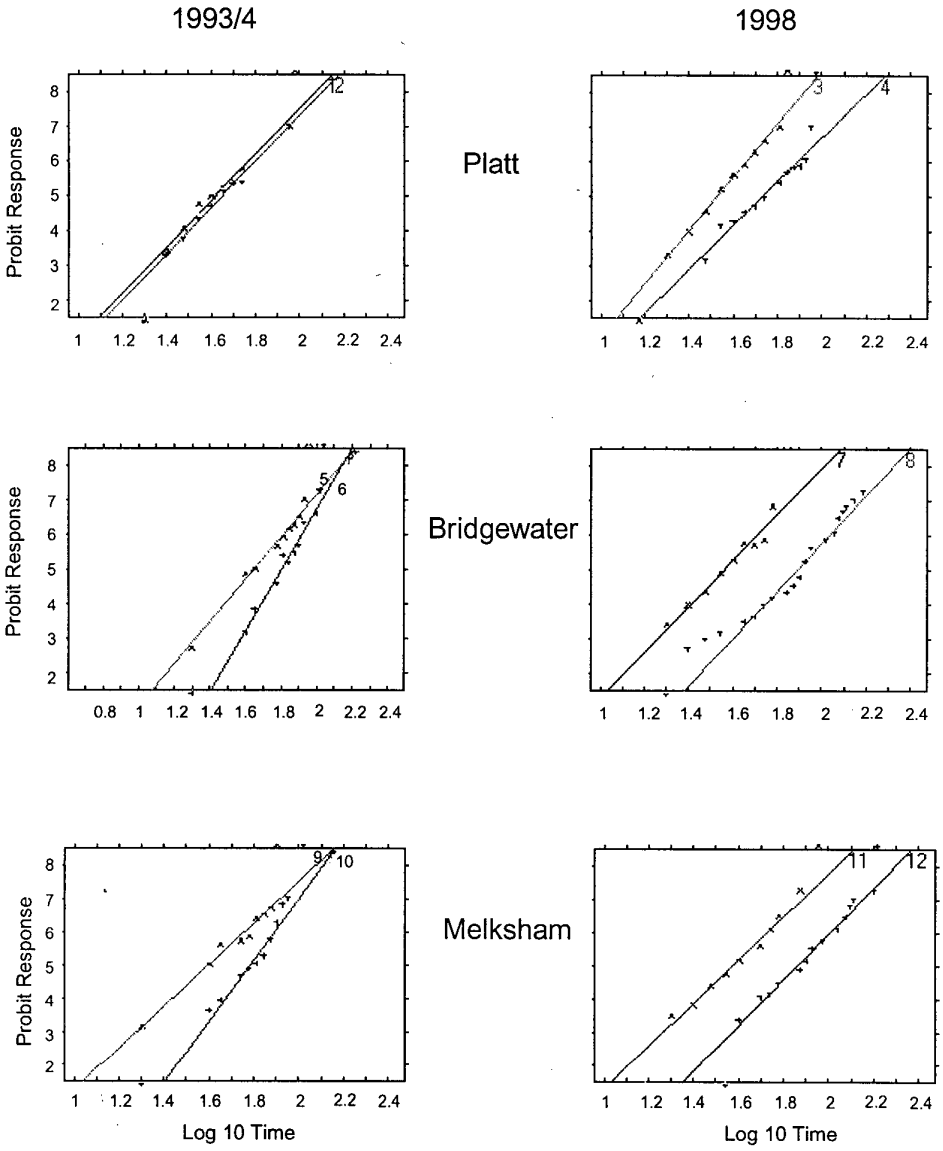
Table 9 Probit parameters from the rapid test for field strains of *O. surinamensis* and their resistance status.

Strain	$KD_{99.99}$ (fiducial limits)	SLOPE (S.E.)	RESISTANCE STATUS	
			F.A.O	Rapid test
Laboratory	126.00 (*)	6.9 (*)	S	S
Barlby	224.41 (196.98, 261.92)	5.5 (0.3)	S	S
Bishopstone	210.02 (186.28, 242.86)	6.3 (0.3)	S	S
Gillwilly	129.95 (115.38, 150.79)	7.0 (0.4)	S	S
Horncastle	124.33 (110.46, 143.77)	6.6 (0.4)	S	S
Lutterworth	113.32 (99.48, 134.17)	9.1 (0.6)	S	S
Staxton	131.25 (105.81, 182.04)	7.0 (0.6)	S	S
Avonmouth	171.42 (149.15, 204.28)	7.3 (0.4)	R	R
Bridgewater	167.76 (146.07, 204.08)	6.9 (0.4)	R/S[a]	R/R[a]
Melksham	153.12 (132.90, 187.99)	6.9 (0.3)	R/S[a]	R/R[a]
Platt	163.32 (138.87, 201.53)	6.4 (0.4)	R/S[a]	R/R[a]
Ryhall	112.52 (102.95, 125.03)	8.0 (0.4)	R	R
Wigston	358.17 (309.94, 425.34)	5.2 (0.2)	R	R

* These figures are the means of all the tests with the laboratory strain and therefore fiducial limits and standard errors from the probit analysis cannot be given..

[a] In tests done in 1993, these strains were diagnosed as resistant by the F.A.O. test and 8 months later diagnosed as marginally resistant by the rapid test. Re-tests were done in 1998 with both tests, a week apart and these are the re-test results.

Figure 3 Probit lines from rapid tests on three field strains of *O. surinamensis* which were re- tested.



Lines with odd numbers = Laboratory susceptible strain

DISCUSSION

S. oryzae

Including the laboratory susceptible strain, seven field strains, already tested with the F.A.O. test, were tested with the rapid test. When first tested, approximately eight months elapsed between the F.A.O. test and the rapid test and the tests agreed for four strains and disagreed for three. For one of these three strains, Pickering, the rapid test detected resistance where the F.A.O. test had not. When the frequency of the resistant gene in a population is low, there will inevitably be problems with sampling those few insects which carry the gene. This could be a potential problem for either of the tests and in both cases and could explain why the F.A.O. test failed to detect the presence of the gene in the Pickering population.

The tests also disagreed in two other cases, Downham and Kinross. When first tested, the F.A.O. test found resistance and the rapid test did not, with both strains knocked down before the laboratory susceptible strain. There was a possibility that in the time that elapsed between doing the two tests and in the absence of any selection pressure, the genetic make-up of the population may have changed. To give a more accurate comparison between the two methods, Downham and Kinross were re-tested with both methods, only a week apart. The results from the rapid test were the same as before with no resistance detected. The F.A.O. test result was reversed and showed no resistance present in the population. The re-test results from the two methods therefore, were in agreement. In the eight months between the first F.A.O. test and the first rapid test, the strain appears to have changed. It is possible that the resistance gene was lost during laboratory culture or, in the absence of any selection pressure, was present in such low proportions that it was not sampled in either test.

From the probit analysis, the most tolerant susceptible strain was the field strain, Westbury. The discriminating knockdown time is therefore based on the $KD_{99.99}$ figure for this strain, 141 min (2 hr, 21 min).

S. granarius

Efforts to select a homozygous resistant strain for this species proved to be fruitless. Six field strains tested with the F.A.O. test in 1993 were diagnosed as resistant. Unfortunately, after initial selection efforts, testing of the pupae of the selected strain showed no increase in resistance to phosphine and gave results similar to those of pupae of the laboratory susceptible strain. There are a number of possible reasons why this may have happened.

It is possible that the major resistance gene also conferred some disadvantage to the insects carrying it which would result in those insects being less able to compete and therefore less likely to breed. Eventually, this would result in the loss of the gene from the population and therefore when the pupae were tested, they were in fact not resistant. Alternatively, those strains diagnosed by the F.A.O. test as resistant may have been tolerant susceptible strains.

Testing of the susceptible field strains with the rapid test confirmed the results from the F.A.O. tests and although a reliable discriminating time can not be set without first comparing the responses of heterozygotes and homozygous resistant insects, indications are that the susceptible insects of this strain are much more tolerant than those of other species. The results suggest a discriminating time of at least 1065 min (17 hr, 45 min), from the $KD_{99.99}$ of the laboratory susceptible strain.

O. surinamensis

A homozygous resistant strain of this species was successfully produced from the Brazilian Palmital strain, making it possible to produce heterozygotes and go on to develop a rapid test. The relative response lines from the rapid tests of the laboratory susceptible, homozygous resistant and heterozygote insects showed a similar pattern to those of the species previously tested, with some overlap in response between laboratory susceptibles and heterozygotes, but no overlap with the homozygous resistant strain. As with *T. castaneum* and *C. ferrugineus*, it is possible to distinguish easily between homozygotes and other genotypes. With the overlap in responses of the susceptible and heterozygote insects however, it is likely that a large sample size would be necessary in order to maximise detection of heterozygotes. The positive side to this is that if their relative mortality responses mirror their knockdown responses, then it should be possible to kill heterozygous insects with only small changes in the current dosing or exposure recommendations.

The rapid tests involving field strains previously tested with the F.A.O. method showed broad agreement with the F.A.O. diagnoses of resistance. However, there were three strains of this species where the two methods differed. When first tested, eight months separated the rapid test from the F.A.O. test and whilst the F.A.O. test diagnosed them as resistant, the rapid test results were not conclusive. Fearing that the populations may have changed genetically in that time, re-tests were done with both methods, only a week apart. In the re-tests, the rapid test showed the presence of the resistance gene but the F.A.O. test results were reversed and now suggested that the strains were susceptible.

As with S. oryzae, the fact that the F.A.O. test no longer detected resistance may be due to the frequency of the gene in the population having changed. In addition, unlike the rapid test, the F.A.O. test was never specifically designed to detect heterozygotes. These two points would go some way to explaining the results with the Platt, Bridgewater and Melksham strains. In the early tests, there were enough homozygous insects for the F.A.O. test to have sampled and detected them. In the eight months which elapsed before the first rapid test, the population was not exposed to any selection pressure and the majority of insects carrying the resistance gene would be heterozygotes. The fact that the responses of the susceptible insects overlap with those of the known heterozygotes, suggests that in the early rapid tests, the heterozygotes present in the test sample were as susceptible as some of the laboratory susceptible insects and therefore the results were not conclusive. In the later tests, the F.A.O. test was unable to detect the heterozygotes but the rapid test sampled some of the more tolerant portion of heterozygotes and some evidence of resistance was observed.

The discriminating knockdown time for this species is based on the $KD_{99.99}$ of the Barlby strain, 225 min (3 hr, 45 min).

One point underlined by the current work is that sample sizes should be as large as possible. The F.A.O. test recommends two replicates of 50 insects. The rapid test was limited to 3 replicates of 30 insects so that the individual insects could be observed for knockdown. This limitation was an artefact of the development of the test only and does not hold true for subsequent testing. A large number of insects can be placed on cones, in the recommended concentration of gas and left for the corresponding discriminating time for a given species.

After that period, any insects still not knocked down, carry the resistance gene, either in its heterozygous or homozygous form.

The rapid test is as efficient as the F.A.O. test for phosphine resistance and has the additional advantages of speed and of being able to detect heterozygote insects. This gives an early warning of an emerging resistance problem and should encourage the adoption of a dosage schedule designed to control homozygous resistant insects. The collection of adult insects and the use of this test should be encouraged before fumigating large bulks of grain with phosphine. In this way the appropriate dosage schedule can be used.

TOXICITY OF PHOSPHINE TO IMMATURE STAGES OF THE RESISTANT STRAINS

As the immature stages of many species have a much higher tolerance of phosphine than adults (Hole *et al.*, 1976), there is a need to examine the tolerance levels of the developmental stages of those strains showing resistance in tests on adults to assess the implications for practical control measures.

METHODS

Three species of beetle were tested at 15°C, 60% r.h.; *O. surinamensis*, collected from Palmital in Brazil and homozygous for phosphine resistance, *S. oryzae* 476s, collected in India in 1973 and selected for phosphine resistance and *C. ferrugineus* BC12s, collected from Bangladesh and also selected for phosphine resistance. The two latter strains and the *S. granarius* combined selected strain were tested at 10°C, 60% r.h.. At 15°C, two tests were carried out at a nominal concentration of 1.8 g m-3 for all the species, two tests at 2.0 g m-3 for *S. oryzae,* one test at 2.0 g m-3 and one at 1.0 g m-3 for *C. ferrugineus* and two tests at 1.0 g m-3 for *O. surinamensis*.

Preparation of Test Insects

Insects for fumigation were reared at 25°C, 60% r.h. with the exception of *C. ferrugineus* which was reared at 30°C, 60% r.h. to accelerate its life cycle in line with the other species. All the strains tested were bred on food mixtures specially selected to permit rapid development and optimum yield (see table below). The food media, with the exception of the brewers' yeast, were sterilised before use for 16 hours in a hot air oven set at 70°C.

Diets for Test Species

SPECIES	FOOD MIXTURES
C. ferrugineus BC12s	12 parts rolled oats 6 parts whole-wheat flour 1 part dried yeast
O. surinamensis Palmital	Rolled oats
Laboratory susceptible strains of *S. granarius* and *S. oryzae* 476	Whole wheat

Replicate cultures were dosed to increase the total sample number of insects and allow a greater probability of survival in the longer exposures. For each species, a minimum of two replicates for each exposure were prepared with three replicates for the longer exposure to increase the total sample number still further. Each replicate consisted of the progeny of 50 unsexed adult beetles added to 500 ml glass jars, each containing appropriate food. The cultures were then placed at their respective breeding temperatures for a period equivalent to approximately half their life cycle. After this period the original 50 adults were removed and discarded and a second set of cultures was prepared for each strain, in the same manner as the first. By the time of the test, the first set of cultures would provide older stages (predominantly pupae and older larvae) and the second set younger stages (predominantly younger larvae and eggs). All cultures were incubated until a few days prior to the proposed test, at which time the younger cultures were sieved to remove the original 50 egg-laying adults.

All test cultures were conditioned down in temperature in steps of 5°C for periods of 24 hours until they reached the test temperature.

During each exposure period the concentration of phosphine in the chamber was measured by using a gas chromatograph fitted with a flame photometric detector (FPD). The concentrations achieved were used to calculate the concentration x time product (CTP), expressed as g h m^{-3} for each exposure period.

All the insect material remained at the test temperature until the longest exposure cultures had been removed from the chamber. The jars were left for at least a day to air and then returned to 25°C, 60% r.h. in steps of 5°C. During the week following the fumigation test and on a weekly basis after that, each older culture was examined for adult emergence to assess survival. The counts on the younger cultures were started approximately three weeks later, to allow time for the younger stages to develop into adults. Sample numbers were estimated from the number of insects emerged from the control cultures.

RESULTS

Results for *S. oryzae, C. ferrugineus* and *O. surinamensis* immature stages at 15°C are summarised in Tables 10 to 15 and for older immature stages *of C. ferrugineus, S. oryzae* and *S. granarius* at 10°C in Table 16.

Table 10. Mortality data for older stages of *S. oryzae* 476 tested at 15°C, 60% r.h.

Nominal Concentration (gm-3)	Exposure (days & hours)	CTP (g h m-3)	Number Emerging	Kill (%)
1.8 (Preliminary test)	15° C Control	-	2968	0
	8d 5h	324.4	1	99.97
	10d 8h	395.8	0	100
	13d	494.5	0	100
	16d 2h	610.3	0	100
	19d 6h	720.8	0	100
1.8	15° C Control	-	5177	0
	5d	192.8	247	95.2
	6d	225.9	66	98.7
	9d	326.9	16	99.7
	10d 5h	366.9	21	99.6
	12d	425.6	5	99.9
2.0	15° C Control	-	1679	0
	14d	652.9	1	99.94
	16d	732.9	1	99.94
	18d	767.2	4	99.76
	21d	895.1	1	99.94
	24d	1023.0	0	100
2.0	15° C Control	-	6467	0
	10d	504.5	21	99.68
	12d	518.4	13	99.80
	14d	664.7	9	99.86
	16d	721.9	5	99.93
	18d	756.6	1	99.99

Table 11. Mortality data for younger stages of *S. oryzae* 476 tested at 15°C, 60% r.h.

Nominal Concentration (gm-3)	Exposure (days & hours)	CTP (g h m-3)	Number Emerging	Kill (%)
1.8 (Preliminary test)	15° C Control	-	3056	0
	2d	84.2	23	99.25
	3d	118.4	0	100
	4d	159.2	0	100
	6d 5h	241.0	0	100
	8d 5h	324.4	0	100
1.8	15° C Control	-	10793	0
	24h	34.5	2317	78.53
	41h	58.2	470	95.65
	55h	83.3	149	98.62
	3d	118.8	59	99.46
	4d	156.6	8	99.93
2.0	6d	165.2	0	100
	8d	366.5	0	100
	10d	463.0	0	100
	12d	549.7	0	100
	14d	652.9	0	100
2.0	15° C Control	-	7183	0
	3d	168.2	685	90.46
	4d	216.0	91	98.73
	6d	293.1	72	99.00
	7d	344.7	24	99.67
	8d	391.0	1	99.98

Table 12. Mortality data for older stages of *C. ferrugineus* BC12s tested at 15°C, 60% r.h.

Nominal Concentration (gm-3)	Exposure (days & hours)	CTP (g h m-3)	Number Emerging	Kill (%)
1.8 (Prelim. test)	15° C Control	-	816	0
	5d	201.8	209	74.38
	6d 4h	241.0	66	91.91
	8d	324.4	6	99.26
	10d 8h	395.8	0	100
	13d	494.5	0	100
1.8	15° C Control	-	2848	0
	5d	192.8	430	84.90
	6d	225.9	296	89.61
	9d	326.9	3	99.89
	10d 5h	366.9	1	99.98
	12d	425.6	0	100
2.0	15° C Control	-	1876	0
	10d	463.0	34	98.19
	12d	549.7	2	99.89
	14d	652.9	0	100
1.0	15° C Control	-	3918	0
	7d	142.4	687	82.47
	9d	171.8	322	91.78
	11d	214.3	24	99.39
	13d	239.8	1	99.98
	15d	282.4	0	100

Table 13. Mortality data for younger stages of *C. ferrugineus* BC12s tested at 15°C, 60% r.h.

Nominal Concentration (gm-3)	Exposure (days & hours)	CTP (g h m-3)	Number Emerging	Kill (%)
1.8 (Prelim. test)	15° C Control	-	2808	0
	2d	84.2	104	96.30
	3d	118.4	70	97.51
	4d	159.2	7	99.75
	5d	201.8	1	99.96
	6d 4h	241.0	2	99.93
1.8	15° C Control	-	4439	0
	4d	156.6	115	97.41
	5d	192.8	137	96.91
	6d	225.9	39	99.12
	9d	326.9	1	99.97
	10d 5h	366.9	0	100
2.0	4d	116.2	0	100
	10d	463.0	0	100
	12d	549.7	0	100
1.0	15° C Control	-	4254	0
	4d	83.5	129	96.97
	5d	99.8	71	98.34
	7d	142.4	13	99.69
	9d	171.8	6	99.86
	11d	214.3	0	100

Table 14. Mortality data for older stages of *O. surinamensis* Palmital tested at 15°C, 60% r.h.

Nominal Concentration (gm-3)	Exposure (days & hours)	CTP (g h m-3)	Number Emerging	Kill (%)
1.8	15° C Control	-	1098	0
(Prelim. test)	24h	42.5	106	90.35
	40h	70.7	32	97.09
	56h	98.1	6	99.45
	72h	118.4	3	99.73
	96h	159.2	0	100
1.8	15° C Control	-	539	0
	23.5h	34.5	205	61.97
	40h	58.2	96	82.19
	55h	83.3	50	90.72
	3d	118.8	3	99.39
	4d	156.6	0	100
1.0	15° C Control	-	494	0
	4d	116.2	120	75.71
	5d	138.1	60	87.85
	6d	165.2	23	95.40
	7d	190.2	1	99.88
	9d	244.3	0	100
1.0	15° C Control	0	1220	0
	3d	59.0	637	47.79
	4d	83.5	25	97.98
	5d	99.8	1	99.95
	6d	121.4	0	100
	7d	142.4	0	100

Table 15. Mortality data for younger stages of *O. surinamensis* Palmital tested at 15°C, 60% r.h.

Nominal Concentration (gm-3)	Exposure (days & hours)	CTP (g h m-3)	Number Emerging	Kill (%)
1.8	15° C Control	-	1879	0
(Prelim. test)	16h	28.2	923	50.88
	24h	42.5	515	72.59
	32h	56.0	228	87.87
	40h	70.7	2	99.89
	56h	98.1	1	99.95
1.8	15° C Control	-	4958	0
	23.5h	34.5	1355	72.67
	31h	45.5	374	92.46
	40h	58.2	3	99.94
	55h	83.3	0	100
	3d	118.8	0	100
1.0	15° C Control	-	2024	0
	24h	29.05	1947	3.8
	48h	57.77	519	74.37
	72h	87.16	33	98.35
	96h	116.2	0	100
	5d	138.1	0	100
1.0	15° C Control	-	3776	0
	40.5h	34.6	189	94.99
	48h	41.5	1	99.98
	55.5h	48.3	1	99.98
	3d	59.0	0	100
	4d	83.5	0	100

Table 16. Mortality data for older stages of three species, tested at 10°C 60% r.h. with a nominal concentration of 2 gm-3 phosphine.

Species	Exposure (days)	CTP (g h m-3)	Number Emerging	Kill (%)
C. ferrugineus BC12s	10° C Control	-	3159	0
	7	361.1	193	93.9
	9	419.3	361	88.6
	11	549.5	26	99.2
	14	697.1	9	99.7
S. oryzae 476	10° C Control	-	4018	0
	14	617.2	4	99.9
	17	749.5	4	99.9
	21	922.4	4	99.9
	28	1189.1	1	99.98
S. granarius combined selected	10° C Control	-	1350	0
	14	617.2	4	99.7
	17	749.5	0	100
	21	922.4	0	100

DISCUSSION

At 15°C, the older stages of all the species were more tolerant than the younger stages (Tables 10-15). Furthermore, observation of the timing of emergence indicated that, of the older larvae and pupae present in the older cultures, it was the pupae which were the tolerant stage. Of the three species tested, *S. oryzae* 476 was the most tolerant to phosphine, surviving a CTP of 895 g h m^{-3} and was controlled by 1023 g h m^{-3}. This may be due to the fact that, unlike the other species tested at this temperature, the pupae develop inside the grain. *C. ferrugineus* BC12s followed in the order of tolerance, surviving 550 g h m^{-3} and controlled by 653 g h m^{-3}. The least tolerant, *O. surinamensis* Palmital did not survive a CTP of 244 g h m^{-3}.

The relative tolerance of *S. oryzae* 476 and *C. ferrugineus* BC12s was confirmed in the tests with older stages at 10°C. However, neither species was controlled by the CTPs achieved at this temperature, despite the fact that a CTP of 1189 g h m^{-3} was achieved with *S. oryzae* 476. The combined selected strain of *S. granarius* survived 617 g h m^{-3} but was controlled by 750 g h m^{-3} (Table 16).

Among the results for *C. ferrugineus* there were three occasions when an increase in CTP did not result in an increase in mortality, at 241 g h m^{-3} and 193 g h m^{-3} at 15°C (Table 13) and at 361 g h m^{-3} at 10°C (Table 16). This can be attributed to a combination of factors. There will be different proportions of the most tolerant age groups represented in the cultures, due to natural variation in development rate and also to ageing during the treatment itself. The tolerance of pupae to phosphine changes with age and younger pupae are the most tolerant (Winks, 1986). Slight differences in the start times during the test, can result in different age distributions being exposed to the gas and this will cause variations in the mortality levels obtained.

FIELD TRIALS

A commercial fumigation of 2500 tonnes of barley was monitored to assess the prospects of controlling resistant insects through conventional means. A microprocessor-controlled dosing system was developed for use with a cylinder based supply of phosphine and compared with the Siroflo^{R} system developed by the Australian Commonwealth Scientific and Industrial Research Organisation. The dosing system was also used to treat a part of a large bulk of grain.

METHODS

Gas Sampling and Temperature and Wind Speed Recording.

At all field sites gas was sampled using nylon 6 gas sampling line inserted at various positions in the grain. The gas sampling lines were taken to a mobile laboratory and connected to a Hewlett Packard 5890A gas chromatograph (GC) fitted with a photo-ionisation detector, an automatic gas sampling loop, two 16 position gas sampling valves and a 1 m x 3.2 mm OD glass lined stainless steel column packed with Porapac QS.

Ambient temperature and the temperature at various positions in the grain were monitored using copper-constantan thermocouples. Wind speed and direction were also monitored using a weather station. Wind and temperature data were recorded using a Yokogawa HR2300 hybrid chart recorder in the mobile laboratory.

Monitoring a Commercial Fumigation.

The bulk of grain to be fumigated was made up of 2500 tonnes of barley and contained two hot spots (fig. 4). An endemic infestation of *Oryzaephilus surinamensis* was present throughout the grain, particularly in the heating areas. Four shafts were driven into the grain and were attached to the outlet of four mixing fans on the surface of the grain. The gas sampling lines and thermocouples were placed at various positions in the grain along with escape-proof cages containing a bioassay of the tolerant pupae of both a laboratory phosphine susceptible strain of *Cryptolestes ferrugineus* and a strain of the same species,

BC12s, which originated in Bangladesh and which had been selected in the laboratory to be highly resistant (Price and Mills, 1988).

Phosphine was applied in two ways to give a total dose of 6.15 kg (2.5 g tonne^{-1}). Nine tins of Fumitoxin pellets (1660 pellets per tin, 332g phosphine per tin) were dosed into 27 Fumisleeves which had been pushed into the grain. One Fumisleeve was placed by each of the hot spots and 25 were spread around the edge of the bulk (2 meters from the edge and 2 meters apart). A further 3.16 kg phosphine was applied as 28 chains of 10 Detia bags which were spread evenly over the surface (11.3 g phosphine per bag).

The bulk was then sheeted using 75 μm LDPE and the mixing fans were switched on. The fans were switched off after 6 days but were switched back on after 12 days because concentrations had become uneven. The sheeting was removed after 18 days.

The Automated Dosing System.

A microprocessor-controlled dosing system was developed for use with methyl bromide (Wontner-Smith *et al*, 1994). It was converted for use with a cylinder based supply of phosphine by changing the sensor from a thermal conductivity detector to an electro-chemical detector and altering the programming.

The dosing system (fig. 5) can serve up to sixteen separate areas. A sample of gas is drawn from each area in sequence via nylon 6 gas sampling lines (2 mm bore) to the main cabinet of the system where the concentration of phosphine is measured by the detector. The microprocessor compares the measured concentration level from every area with a pre-set threshold level. If a particular area is below the threshold level then it will receive phosphine for a programmed period (dose-time).

The phosphine is supplied via 9.5 mm nylon dosing lines which are opened and closed by a series of rack-mounted solenoid valves. The valves are controlled by the microprocessor in the main cabinet of the system to which they are connected via cables and interface with a gas manifold connected to a cylinder containing 2 % (v/v) phosphine in carbon dioxide. Gas from the cylinder is regulated using a finned regulator designed for use with liquid off-take cylinders.

When every area has been sampled and dosing has occurred where necessary, the cycle is repeated. After a predetermined period the microprocessor terminates the sampling and dosing process. All variables are set using a Psion Organiser.

Initial Tests Developing the Use of the Automated Dosing System.

After testing the dosing system in the laboratory, two preliminary tests were undertaken in the field. The first took place at a farm store containing 450 tonnes of Ribald feed wheat. As a result of this trial the dosing system was modified slightly so that it would dose for 5 second bursts followed by a 55 second delay before dosing again in order to prevent problems due to freezing of the regulator.

The second trial took place on a 270 ton bulk in another farm store. The results from this trial suggested that re-circulation was necessary to achieve a more even concentrations through out the bulk.

The Siroflo^{R} System.

The Siroflo^{R} system (fig. 6) was supplied by the Australian Commonwealth Scientific and Industrial Research Organisation's Stored Grain Research Laboratory, Canberra and was designed to treat silos containing up to 2000 tonnes of grain or a small floor store. The unit provides a constant flow of air from a fan which is laced with phosphine from a cylinder containing 2 % (v/v) phosphine in carbon dioxide. The rate of flow of air and the concentration of phosphine are set in such a way that any leakage from the structure under fumigation is overcome by the constant flow.

A Comparison of the Automated Dosing System and the Siroflo^{R} System in a Silo.

Three trials were undertaken to compare the automated dosing and the Siroflo^{R} systems.
in a silo containing 700 tonnes of feed wheat (fig. 7). Gas lines and thermocouples were placed at various positions in the grain and the grain was sheeted using Bromotek sheeting from Lawson Mardon Packaging Ltd. The auger was sealed using polythene shrink wrap. After each trial phosphine was blown out of the grain and samples were taken for residue analysis.

Trial 1: Phosphine from a Cylinder Without Re-circulation.

Phosphine from a cylinder containing 2 % (v/v) phosphine in carbon dioxide was bled into the bin from the duct at a flow of 700 ml min^{-1} using a flow meter. After 5 days phosphine had not reached the grain surface. A 9.5 mm OD dosing line was pushed through the sheet until the end was 0.3 m below the surface of the grain and the sheeting was then re-sealed around the dosing line. Phosphine was bled into the top and bottom of the bin for the remainder of the trial from two flow meters. The flow to the top of the bin was set at 700 ml min^{-1} and the flow to the bottom of the bin was set at 400 ml min^{-1}. The following day the flow to the bottom of the bin was reduced to 250 ml min^{-1} to conserve gas. Five days later the gas was switched off and the test was terminated. The test had run for 12 days.

Trial 2: The Automated Dosing System with Re-circulation.

One end of a 50 mm OD nylon hose was covered in nylon mesh and then pushed 0.25 m below the grain surface. The other end was connected to the inlet of a small centrifugal pump. Another piece of 50 mm OD nylon hose was used to connect the outlet of the centrifugal pump with the duct at the bottom of the bin. A gas sampling line for the automated dosing system was positioned in the centre of the bin 1 m below the surface of the grain. The sheeting was then resealed around the sampling line and the hose.

One end of a 9.5 mm nylon dosing line was connected to the duct at the bottom of the bin and the other end was connected to the dosing system. The threshold was set at 150 ppm and the dose time was set at 14 minutes.

After 11 days the dosing system was switched off and the test was terminated.

Trial 3: The Siroflo^{R} System.

The hose for the re-circulation system was removed and the sheet was resealed. The Siroflo^{R} system was connected to the bottom of the bin using a 10 cm OD flexible hose and switched on. The Siroflo^{R} system was run for eight days after which the test was terminated.

A Comparison of the Automated Dosing System and the Siroflo^{R} System in a Floor Store.

A similar set of three trials were undertaken in a floor store containing 150 tonnes of feed wheat. Thermocouples and gas lines for the dosing system and for gas sampling were placed

at various positions in the grain and the ends of two 50 mm OD flexible hoses were covered in nylon mesh and then pushed 0.25 m below the grain surface (fig. 8). The two hoses were joined with a T-piece and then connected to the suction end of a centrifugal pump capable of moving 2 m^3 min^{-1} of air for re-circulation. One end of another piece of two 50 mm OD flexible hose was connected to the outlet of the pump and the other end was connected to a length of perforated lay flat tubing which had been laid out in one of the ducts. The grain was then sheeted using Bromotek sheeting from the Lawson Mardon Packaging Ltd.

Between each trial the phosphine was blown out of the bulk and samples of grain were taken for residue analysis.

The first trial was using the automated dosing system with the re-circulation pump switched off. Four dosing lines were connected to four ducts (fig. 8). The ducts were then sealed using Bromotek sheeting. The threshold was set at 150 ppm, the dose time was set at 10 minutes and the dosing system was started. After eight days the dosing system was switched off.

The second trial was identical to the first except that the re-circulation pump was switched on and the automated dosing system was switched off after seven days.

In the third trial used the bulk was dosed using the Siroflo^R system into a duct in the middle of the bulk (fig. 9) via a 10 cm OD flexible hose. After 7 days the Siroflo^R was switched off.

A Spot Fumigation (Partial Bulk Treatment) with Phosphine Using the Automated Dosing System.

A commercial floor store containing 9,000 tonnes of barley had a localised infestation of *O. surinamensis* (fig. 10). The problem area was surrounded by 5 probes (fig. 11) which were pushed into the grain. A sixth probe was pushed into the grain in the centre of the problem area. The probes were attached to the dosing system using dosing lines. Gas sampling lines and thermocouples were positioned in the grain and the problem area was sheeted using 75 μm LDPE.

The level of the dosing system was set at 150 ppm, the dose time was set at 8 minutes and the maximum time between cycles was 2 hours 20 minutes. The dosing system was left to run for 12 days and then was switched off. the concentration was monitored for a further 2 days and then the grain was un-sheeted and the test was terminated.

RESULTS

The Commercial Fumigation

Table 17 gives the Concentration-Time Products (CTPs), bioassay results and residues for the commercial fumigation. The CTPs ranged between 80 and 139 g h m^{-3} except at position F where the CTP was only 42 g h m^{-3}. As expected from the concentration results, there were no detectable survivals of the endemic *O. surinamensis* even in the cooler grain. The susceptible *C. ferrugineus* pupae were controlled except at positions K and L where gas concentrations were low due to leakage. As expected, the resistant *C. ferrugineus* pupae survived at every location at which they were placed. The maximum measured residue was 1.0 ppb which is not significant compared with the maximum residue limit of 100 ppb.

The Grain Silo Tests

Table 18 gives the temperature and wind speed data for the trials in the grain silo and Tables 19 to 21 give the CTP and concentration data for 8 days and for the whole treatment period. Figure 12 shows the average concentration of phosphine at a depth of 1 m in the silo for the three trials. In the trial using flow meters a good distribution of phosphine, giving concentrations of over 0.05 g m^{-3} at every position, was never established. In the other two methods concentrations of over 0.05 g m^{-3} at every position were reached by 20 hours in the case of the Siroflo^{R} system and by 80 hours in the case of the automated dosing system with re-circulation. Table 22 shows the amount of phosphine used in the first eight days in the three trials. Less gas was used in the case of the automated dosing system and higher CTPs were achieved. After all three trials the highest residue measured was 1.4 ppb.

The Floor Store Trials

Table 23 gives the temperature and wind speed data for the floor store trials and Tables 24 to 26 give the CTP and concentration data for 7 days and for the whole treatment period. Figure 13 shows the average concentration of phosphine in the grain against time for the three trials.

Using the automated dosing system without re-circulation did not provide a good distribution of phosphine. In the other two methods concentrations of over 0.05 g m^{-3} at every position were reached by 15 hours in the case of the Siroflo^{R} system and by 31 hours in the case of the automated dosing system with re-circulation. Table 27 shows the amount of phosphine used in the first 7 days in the three trials. More gas was used using the automated dosing system but much higher CTPs were reached. After all three trials had been completed the highest residue measured was 4.4 ppb.

The Partial Bulk Treatment

Table 28 gives the concentration, temperature and residue data for the spot fumigation trial. Concentrations of over 0.05 g m^{-3} at every position in the problem area were reached by 57 hours. After 5 days concentrations of over 0.05 g m^{-3} were reached everywhere except at position C. Over the 12 days that the automated dosing system ran, 68.2 kg of phosphine in carbon dioxide was used. The highest residue measured was 1.4 ppb. The infestation had spread beyond the problem area as originally defined and so there were insect survivals.

DISCUSSION

The CTPs at the commercial fumigation were high enough to kill all stages of susceptible *C. ferrugineus* everywhere except at position F where the CTP was only 42 g h m^{-3} and at K and L where there were survivals of susceptible insects in the bioassay (Table 17). Positions F, K and L were all in the same area which was against the back wall which was made of painted breeze block. It is probable that there was a flaw in the wall or in the paint work below the level of the grain which resulted in a major leak in this area. The fumigation was not designed to control all stages of resistant *C. ferrugineus*. This would not be possible in this store using conventional fumigation techniques.

It was not possible to achieve adequate treatments in the grain silo or the floor store by using flow meters or the automated dosing system alone. In the grain silo a high overall average concentration of 0.380 g m^{-3} was obtained over 8 days but in the top 1 m the average concentration was only 0.026 g m^{-3} (Table 22). In the floor store the average concentration was over 0.05 g m^{-3} at all positions (Table 24). However, at three positions the concentration did not remain over 0.05 g m^{-3} for the whole treatment and so control of all stages of insects

could not be guaranteed. In both sets of tests, the phosphine residues, even after the multiple exposures, were not significant compared with the maximum residue limit of 100 ppb.

Using Siroflo^{R} and the automated dosing system with simple re-circulation equipment adequate concentrations were achieved at every position in the grain silo and in the floor store. Higher concentrations and CTPs were achieved using the automated dosing system compared with the Siroflo^{R} system in both the grain silo and the floor store (figs 12 and 13). In the case of the silo this was achieved using less gas (Table 22). In the floor store the Siroflo^{R} used only 55 % of the gas than was used by the dosing system with re-circulation but the average concentration was only 28 % of that obtained using the dosing system (Table 27).

By using the automated dosing system with more efficient re-circulation it may be possible to optimise the distribution of gas. This would make it possible to achieve adequate concentrations in floor-stored bulks using less gas.

In the spot fumigation concentrations of over 0.05 g m^{-3} were reached everywhere by 5 days except at position C which was 3 m outside the problem area (fig. 10). There were insect survivals because the infestation had spread beyond the problem area probably before the treatment had begun.

Table 17. Concentration-Time Products, Bioassay Results and Residues at the Commercial Fumigation.

Position	Depth (m)	Concentration-Time Product (g h m^{-3})	Susceptible insect survival	Resistant insect survival	Average temperature (°C)	Phosphine residue (ppb)
A	2	80	No	Yes	17.3	< 1
A	1	97	-	-	-	-
A	Surface	139	No	Yes	14.4	< 1
B	3	101	-	-	-	-
B	1.5	100	No	Yes	18.0	-
B	Surface	93	No	Yes	12.3	-
C	2	105	-	-	-	< 1
C	1	105	-	-	-	-
C	Surface	105	-	-	-	1.01
D	1	102	-	-	-	-
E	2	91	No	Yes	19.1	-
E	Surface	97	No	Yes	-	-
F	0.5	42	-	-	-	< 1
G	2	108	-	-	-	-
G	1	106	-	-	-	-
G	Surface	106	-	-	-	-
H	1	91	No	Yes	18.7	-
I	2	98	-	-	-	-
I	1	97	-	-	-	-
I	Surface	106	-	-	-	-
J	2	-	No	Yes	18.0	-
J	Surface	-	No	Yes	12.3	-
K	2	-	Yes	Yes	28.9	-
K	Surface	-	No	Yes	-	-
L	2	-	Yes	Yes	-	-
L	Surface	-	Yes	Yes	35.6	-

Table 18. Temperature and wind speed data for the grain silo trials.

	Depth from the grain surface (m)	Cylinder trial without re-circulation (°C)	Dosing system trial with re-circulation (°C)	Siroflo^{R} trial (°C)
Average temperature at the east position (°C)	3 Surface	14.2 13.1	13.9 12.8	14.0 12.6
Average temperature at the centre position (°C)	5 Surface	14.2 13.1	14.6 12.6	14.5 12.8
Average temperature in the free space (°C)	-	13.8	12.3	12.5
Average ambient temperature (°C)	-	13.1	11.7	11.4
Average wind speed (m s^{-1})	-	2.7	3.5	2.4

Table 19. Concentration data for the grain silo treatment using phosphine in carbon dioxide from flow meters without re-circulation.

Position	Depth from grain surface (m)	Total CTP ($g\ m^{-3}\ h^{-1}$)	Average Concentration ($g\ m^{-3}$)	CTP over 8 days ($g\ m^{-3}\ h^{-1}$)	Average concentration over 8 days ($g\ m^{-3}$)	Time taken to reach concentration of 0.05 $g\ m^{-3}$ (hours)
East	5m	26.5	0.084	6.8	0.035	165
	3m	15.7	0.050	5.0	0.025	202
	1m	12.1	0.038	5.6	0.028	224
	Surface	9.7	0.031	2.8	0.014	287
West	3	22.4	0.071	7.1	0.036	182
	1	12.5	0.040	3.2	0.016	287
	Surface	14.4	0.046	4.1	0.021	240
North	1	10.3	0.033	2.8	0.014	290
South	1	11.4	0.036	2.9	0.014	240
Centre	5	486	1.55	262	1.35	118
	3	1045	3.33	640	3.29	119
	1	33.7	0.11	13	0.069	122
	Surface	17.9	0.057	5.6	0.029	116
Free space over centre	-	44.2	0.141	26	0.132	-
Duct at bottom of bin	-	530	1.69	429	2.21	-

Table 20. Concentration data for the grain silo treatment for the automated dosing system with re-circulation.

Position	Depth from grain surface (m)	Total CTP ($g\ m^{-3}\ h^{-1}$)	Average Concentration ($g\ m^{-3}$)	CTP over 8 days ($g\ m^{-3}\ h^{-1}$)	Average concentration over 8 days ($g\ m^{-3}$)	Time taken to reach concentration of 0.05 $g\ m^{-3}$ (hours)
East	5m	42.9	0.151	26.9	0.141	28
	3m	28.8	0.101	17.4	0.091	52
	1m	20.6	0.072	11.9	0.062	69
	Surface	14.3	0.050	8.7	0.046	80
West	3	29.5	0.104	17.7	0.092	57
	1	21.9	0.077	12.1	0.064	75
	Surface	22.6	0.079	13.7	0.071	75
North	1	20.1	0.070	10.5	0.055	80
South	1	21.4	0.075	13.4	0.070	80
Centre	5	36.0	0.126	17.2	0.090	46
	3	29.0	0.101	14.6	0.076	58
	1	21.4	0.075	11.4	0.060	72
	Surface	21.2	0.074	12.4	0.065	75
Free space over centre	-	0.90	0.003	0.573	0.003	-
Duct at bottom of bin	-	180	0.633	96.9	0.507	-

Table 21. Concentration data for the grain silo treatment using the Siroflo^{R} system.

Position	Depth from grain surface (m)	Total CTP ($g\ m^{-3}\ h^{-1}$)	Average Concentration ($g\ m^{-3}$)	CTP over 8 days ($g\ m^{-3}\ h^{-1}$)	Average concentration over 8 days ($g\ m^{-3}$)	Time taken to reach concentration of 0.05 $g\ m^{-3}$ (hours)
East	5m 3m 1m Surface	13.7 13.2 12.4 12.1	0.068 0.065 0.061 0.060	13.5 12.9 12.1 11.8	0.070 0.067 0.063 0.062	8.5 11.0 15.0 15.0
West	3 1 Surface	13.6 12.9 12.6	0.067 0.063 0.062	13.4 12.7 12.3	0.070 0.066 0.064	9.0 12.0 12.0
North	1	12.6	0.062	12.2	0.064	14.0
South	1	12.7	0.062	12.0	0.063	16.0
Centre	5 3 1 Surface	13.8 12.6 12.2 11.7	0.068 0.062 0.060 0.058	13.0 12.2 11.6 11.1	0.068 0.064 0.061 0.058	15.0 15.0 19.0 20.0
Free space over centre	-	1.5	0.008	1.4	0.008	-
Duct at bottom of bin	-	16.1	0.084	16.1	0.084	-

Table 22. The amount of phosphine used over a 8 day period in the grain silo using all methods.

Method of fumigation	Amount of 2 % phosphine in carbon dioxide used over 8 days (kg)	Average Concentration over 8 days ($g\ m^{-3}$)	Average Concentration over 8 days in the top 1 m ($g\ m^{-3}$)
Flow meters without re-circulation	17.4	0.380	0.026
Dosing system with re-circulation	24.8	0.076	0.062
Siroflo^{R}	27.1	0.065	0.063

Table 23. Temperature and wind speed data for the floor store trials.

	Depth from the grain surface (m)	Average Temperature in the dosing system trial without re-circulation (°C)	Average Temperature in the dosing system trial with re-circulation (°C)	Average Temperature in the Siroflo^{R} trial (°C)
Average temperature at position A (°C)	2.25 Surface	13.6 13.8	8.8 10.5	11.9 12.2
Average temperature at position B (°C)	1	16.4	11.3	13.0
Average temperature at position C (°C)	Surface	15.8	11.6	12.8
Average ambient temperature (°C)	-	17.0	14.8	12.8
Average wind speed ($m\ s^{-1}$)	-	0.3	0.5	0.6

Table 24. Concentration data for the floor store trial using the automated dosing system without re-circulation.

Position	Depth from grain surface (m)	Total CTP ($g\ m^{-3}\ h^{-1}$)	Average Concentration ($g\ m^{-3}$)	CTP over 7 days ($g\ m^{-3}\ h^{-1}$)	Average concentration over 7 days ($g\ m^{-3}$)	Time taken to reach concentration of 0.05 $g\ m^{-3}$ (hours)
A	2.25 1 Surface	59.9 60.9 61.8	0.126 0.128 0.130	43.1 43.0 43.9	0.257 0.256 0.261	14.4 6.4 3.2
B	2.75 1 Surface	109.6 67.1 15.6	0.231 0.141 0.033	95.9 49.7 12.5	0.571 0.296 0.074	4.8 11.2 -
C	1.75 Surface	19.5 67.7	0.041 0.143	14.9 51.6	0.089 0.307	- 12.8
D	2.25 1 Surface	55.3 62.2 52.1	0.117 0.131 0.110	40.0 37.8 37.6	0.238 0.225 0.224	12.8 6.4 23.0
E	1	74.4	0.157	60.7	0.362	1.6
F	0.2	52.1	0.110	41.9	0.249	-
Duct	-	46	0.097	32.7	0.195	-

Table 25. Concentration data for the floor store trial using the automated dosing system with re-circulation.

Position	Depth from grain surface (m)	Total CTP ($g\ m^{-3}\ h^{-1}$)	Average Concentration ($g\ m^{-3}$)	CTP over 7 days ($g\ m^{-3}\ h^{-1}$)	Average concentration over 7 days ($g\ m^{-3}$)	Time taken to reach concentration of 0.05 $g\ m^{-3}$ (hours)
A	2.25 1 Surface	36.2 26.1 24.0	0.176 0.127 0.116	34.0 24.6 22.8	0.203 0.146 0.136	12.7 8.7 8.7
B	2.75 1 Surface	173.1 24.8 23.3	0.839 0.120 0.113	169.8 23.3 22.1	1.011 0.139 0.132	2.7 8.7 6.7
C	1.75 Surface	74.3 23.0	0.360 0.111	73.1 21.9	0.435 0.130	2.7 8.7
D	2.25 1 Surface	56.1 26.3 20.9	0.272 0.127 0.101	53.4 24.6 19.8	0.318 0.146 0.118	6.7 12.7 30.6
E	1	23.2	0.113	22.2	0.132	8.7
F	0.2	33.0	0.160	31.9	0.190	0.4
Duct	-	11.8	0.057	11.6	0.069	-

Table 26. Concentration data for the floor store trial using the Siroflo^{R} system.

Position	Depth from grain surface (m)	Total CTP ($g\ m^{-3}\ h^{-1}$)	Average Concentration ($g\ m^{-3}$)	CTP over 7 days ($g\ m^{-3}\ h^{-1}$)	Average concentration over 7 days ($g\ m^{-3}$)	Time taken to reach concentration of 0.05 $g\ m^{-3}$ (hours)
A	2.25 1 Surface	12.6 12.5 12.0	0.065 0.064 0.062	11.7 11.4 10.8	0.070 0.068 0.064	5.6 11.2 15.4
B	2.75 1 Surface	13.0 10.4 12.9	0.067 0.054 0.067	12.6 9.9 12.3	0.075 0.059 0.073	1.7 4 4
C	1.75 Surface	12.9 12.8	0.066 0.066	12.7 12.6	0.076 0.075	2.5 2.5
D	2.25 1 Surface	12.7 12.5 12.0	0.066 0.064 0.062	12.2 11.9 11.2	0.073 0.071 0.067	5.6 7.8 11.2
E	1	12.8	0.066	12.8	0.076	1.7
F	0.2	12.5	0.064	12.0	0.071	7.8
Duct	-	2.9	0.015	2.8	0.017	-
Siroflo^{R} outlet	-	13.2	0.078	0.017	0.078	-

Table 27. The amount of phosphine used over a 7 day period in the floor store using all methods.

Method of fumigation	Amount of 2 % phosphine in carbon dioxide used over 7 days (kg)	Average Concentration over 7 days ($g\ h^{-1}\ m^{-3}$)
Dosing system without re-circulation	23.4	0.262
Dosing system with re-circulation	38.2	0.249
Siroflo^{R}	21.2	0.071

Table 28. Concentration, temperature and residue data for the spot fumigation trial.

Position	Depth from grain surface (m)	Total Concentration Time Product ($g\ m^{-3}\ h^{-1}$)	Average concentration ($g\ m^{-3}$)	Time taken to reach concentration of 0.05 $g\ m^{-3}$ (hours)	Average temperature (°C)	Phosphine residue (ppb)
A	3	123	0.348	3.8	-	-
	1.5	90.4	0.255	6.2	-	-
	Surface	85	0.241	10.9	-	-
B	3	77	0.216	3.8	-	-
	1.5	60	0.169	37.3	-	-
	Surface	78	0.219	33.3	-	-
C	3	83	0.234	13.3	11.4	-
	1.5	27	0.075	102	-	0.4
	Surface	16	0.045	296	9.0	0
D	2	83	0.233	27.9	-	1.4
	Surface	86	0.242	27.9	-	0.4
E	2	49	0.137	21.5	-	-
	Surface	24	0.068	135	-	-
F	3	157	0.444	9.7	-	-
	1.5	136	0.384	9.7	-	1.0
	Surface	116	0.326	19.2	-	0.6
G	3	72	0.203	5.0	-	-
	1.5	92	0.258	9.7	-	-
	Surface	45	0.128	56.8	-	-
H	3	84	0.237	16.8	15.9	-
	1.5	56	0.157	64.8	-	-
	Surface	16	0.049	-	12.8	-

METHYL PHOSPHINE TESTS.

Methyl phosphine is a closely related molecule to phosphine. It is possible that it can be formulated with carbon dioxide in the same way as phosphine. This would make it available for use with the automated dosing system. Previous studies at CSL on adult insects (Chaudhry *et al.*, 1996) have demonstrated that methyl phosphine kills normal phosphine-susceptible strains but that phosphine-resistant strains are killed at lower doses. The present project aims to demonstrate that the same effect occurs with immature stages.

METHODS

The first test was carried out in a steel chamber of 1700 litres volume at 25°C and 60% r.h. Seven cultures containing the older immature stages, including the tolerant pupae, were prepared for the phosphine-resistant strain of *C. ferrugineus,* BC12s. The intention was to expose a culture for 16, 24, 40, 48, 72 and 96 hours to 0.635 g m^{-3} of methyl phosphine, equivalent to 0.45 g m^{-3} of phosphine mole for mole. An untreated control was kept. Methyl phosphine was prepared in the laboratory according to the method of Chaudhry *et al.* (1996) and used to dose the chamber to a higher concentration than required. The concentration in the chamber was monitored using a Hewlett Packard 5890 gas chromatograph (GC) fitted with a flame photometric detector. The concentration was carefully adjusted to 0.635 g m^{-3} by partially successively evacuating the chamber to and then returning it to atmospheric pressure by allowing the ingress of air. During the first night of the test the concentration fell rapidly, approximately halving every 5 minutes. By the morning only a trace of gas was left in the chamber. A single culture of each strain was kept following an 18-hour exposure to the falling concentration. Other cultures were not examined since the test was abandoned because so little methyl phosphine remained.

The controls and the cultures that had been exposed for 18 hours were held at the same temperature and humidity and left for 5 weeks for adult insects to emerge.

A second test was carried out using pupae of a phosphine-susceptible strain and a phosphine resistant strain (BT1s) of *Tribolium castaneum* at the same conditions of temperature and humidity. Three batches of 50 pupae of the susceptible strain and two batches of 30 pupae of

the resistant strain were placed in a 6 litre glass desiccator without food. The desiccator was then dosed with 0.07 g m^{-3} of methyl phosphine and the concentration of gas was monitored by GC. A similar dose of phosphine would allow survival of approximately 2% of the susceptible strain (Price and Mills, 1988). After 48 hours the pupae were removed from the desiccators and then held at the same conditions of temperature and humidity to allow adults to emerge. Mortalities were corrected for control mortality.

RESULTS

The results obtained on immature stages are summarised in Tables 29 and 30.

Table 29. Mortality of two strains of *Cryptolestes ferrugineus* older stages in methyl phosphine (18 h exposure to a falling concentration). Data for phosphine toxicity using large sample numbers is given for comparison.

	% mortality	
Strain	Methyl phosphine	Phosphine
BC12s resistant	23.9	24.0 a
Reference susceptible	10.8	100 a

a - older immature stages tested at 0.15 g m^{-3} for a 48 hour exposure.

Note: The table cannot be used to make a comparison of the relative toxicity of the two gases because of the falling concentration of methyl phosphine and the short exposure period.

Table 30. Mortality of two strains of *T. castaneum* 0-2 day old pupae in methyl phosphine at 0.062 g m^{-3}(48 h exposure). Data for phosphine toxicity using large sample numbers is given for comparison.

	% mortality	
Strain	Methyl phosphine	Phosphine
BT1s resistant	100 a	97 b
Reference susceptible	94.4 a	100 b

a - the average concentration of methyl phosphine was 0.062 g m^{-3}.
b - all immature stages tested at 0.07 g m^{-3} for a 96 hour exposure. Survival of pupae.

DISCUSSION.

Since the *C. ferrugineus* test was carried out there is evidence that methyl phosphine may be heavily sorbed on some commodities (T. Wontner-Smith, peers. comm.) though the rate of sorption is considerably less on grain than on wheat flour. This would explain the rapid drop in concentration observed in the first test since the chamber contained an insect culture medium which would be expected to be sorptive. The concentration profile experienced by the cultures over the 18-hour period is, therefore, not typical of that which would be expected in a grain fumigation. However, it is worth recording the two-fold difference in mortality, probably in larvae, between strains which experienced the same concentration profile. The higher mortality in the phosphine resistant strain is as would be expected from the research on adult insects (Chaudhry, *et al.,* 1996). The same effect was noted with pupae of *T. castaneum* despite the level of phosphine resistance being less than in the strain of *C. ferrugineus*.

CONCLUSIONS AND RECOMMENDATIONS

1. A rapid diagnostic test for resistance to phosphine based on the knockdown response of adult insects has been developed and refined for several beetle pests of stored grain. For *Sitophilus oryzae, Cryptolestes ferrugineus, Oryzaephilus surinamensis* and *Tribolium castaneum* is it possible to diagnose the presence of resistant individuals in less than four hours. Attempts to confirm resistance in *Sitophilus granarius* by the FAO or rapid techniques were unsuccessful due to the high variation of natural tolerance of susceptible strains. There was some overlap between the responses of the susceptible and heterozygous resistant insects but the homozygous
resistant insects required in excess of 24 hours for knockdown. The FAO test for resistance requires 14 days to produce a result.

It is recommended that the rapid test is used prior to the fumigation of large grain bulks in structures which have proven difficult to fumigate successfully in the past.

2. It was possible to control the immature stages of resistant strains at 15°C by longer exposures periods at concentrations between 1 and 2 g m^{-3}. At 10°C, a small survival of resistant *S. oryzae* occurred after a 4-week exposure to 2 g m^{-3}. At 15°C, this species required an exposure of 24 days to 2 g m^{-3} for complete control.

It is recommended that if resistance is detected, fumigation is impracticable unless the temperature exceeds 15°C.

3. The automated dosing system gave results comparable with the Australian Siroflo^{R} system when used with recirculation. In silos, without recirculation, the movement of gas was dependent on ambient conditions resulting in uneven distribution and a slow arrival of gas at the grain surface. In floor stores, the use of the automated dosing system with recirculation ensured a minimum concentration of 0.05 gm^{-3} was achieved and held at all points within the fumigation after an initial 3-day period. The Siroflo^{R} system achieved the same result within 24 hours. This coverage of all parts of the grain during conventional fumigations using solid phosphide formulations cannot be guaranteed. The innovative use of solid formulations in conjunction with recirculation can produce effective results. The advantage of the automated

dosing system is that it can compensate for unforeseen circumstances such as changes in wind velocity and direction and temperature fluctuations since it operates on a feed-back basis. Both Siroflo^{R} and the automated dosing system have the potential to achieve fully efficacious treatments, even for the control of resistant strains.

It is recommended that further effort is placed in the design of recirculation systems for bulk grain to optimise economy of gas use for effective treatment.

4. Methyl phosphine has been shown to be more effective against the immature stages and adults of phosphine-resistant strains in comparison with susceptibles. There are concerns about its sorption on cereal products but on dry grain it has potential to be used in controlling resistance to phosphine.

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Fig. 4 Gas sampling positions at the commercial fumigation.

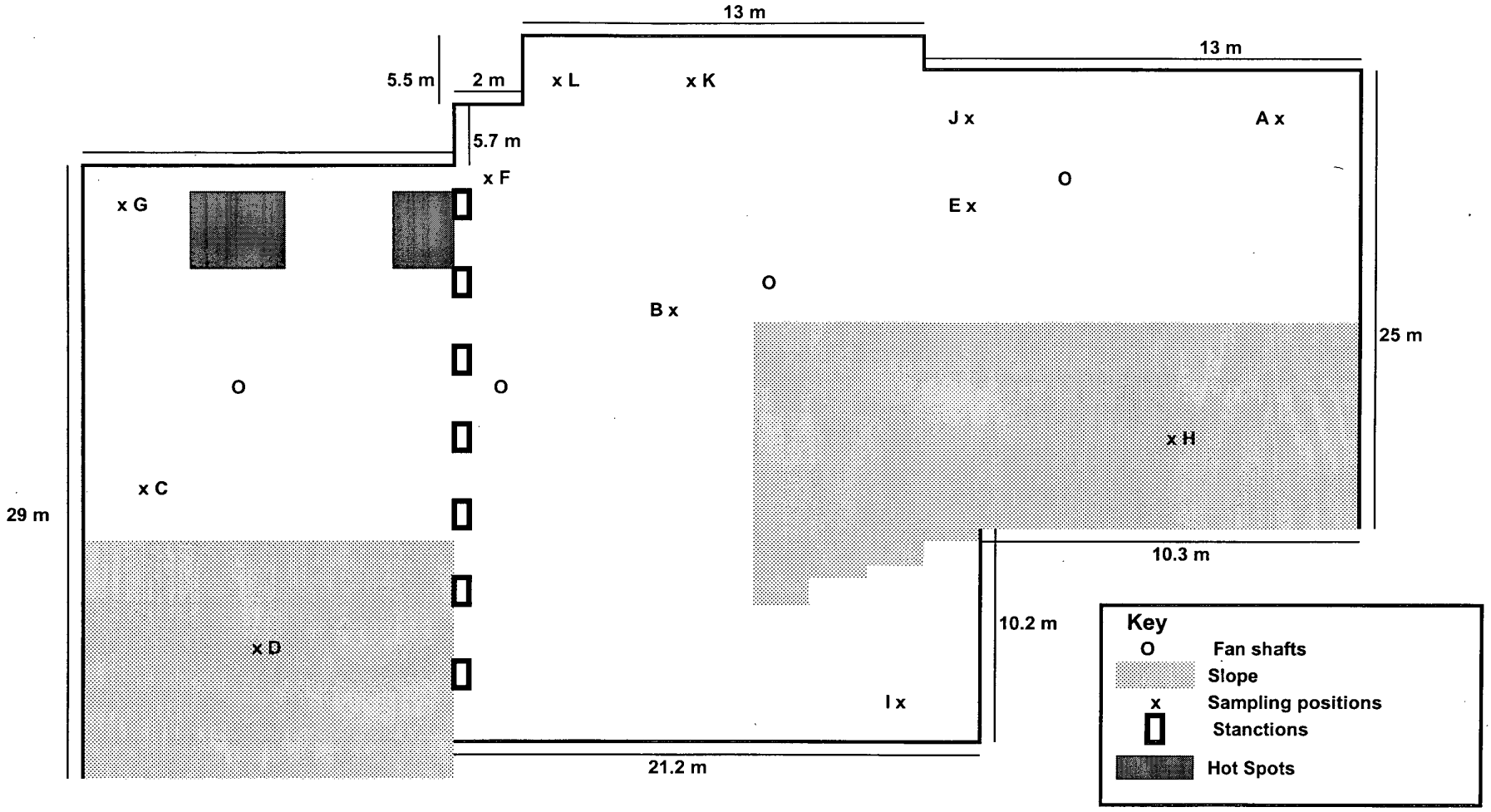


Fig. 5 Microprocessor-controlled dosing system.

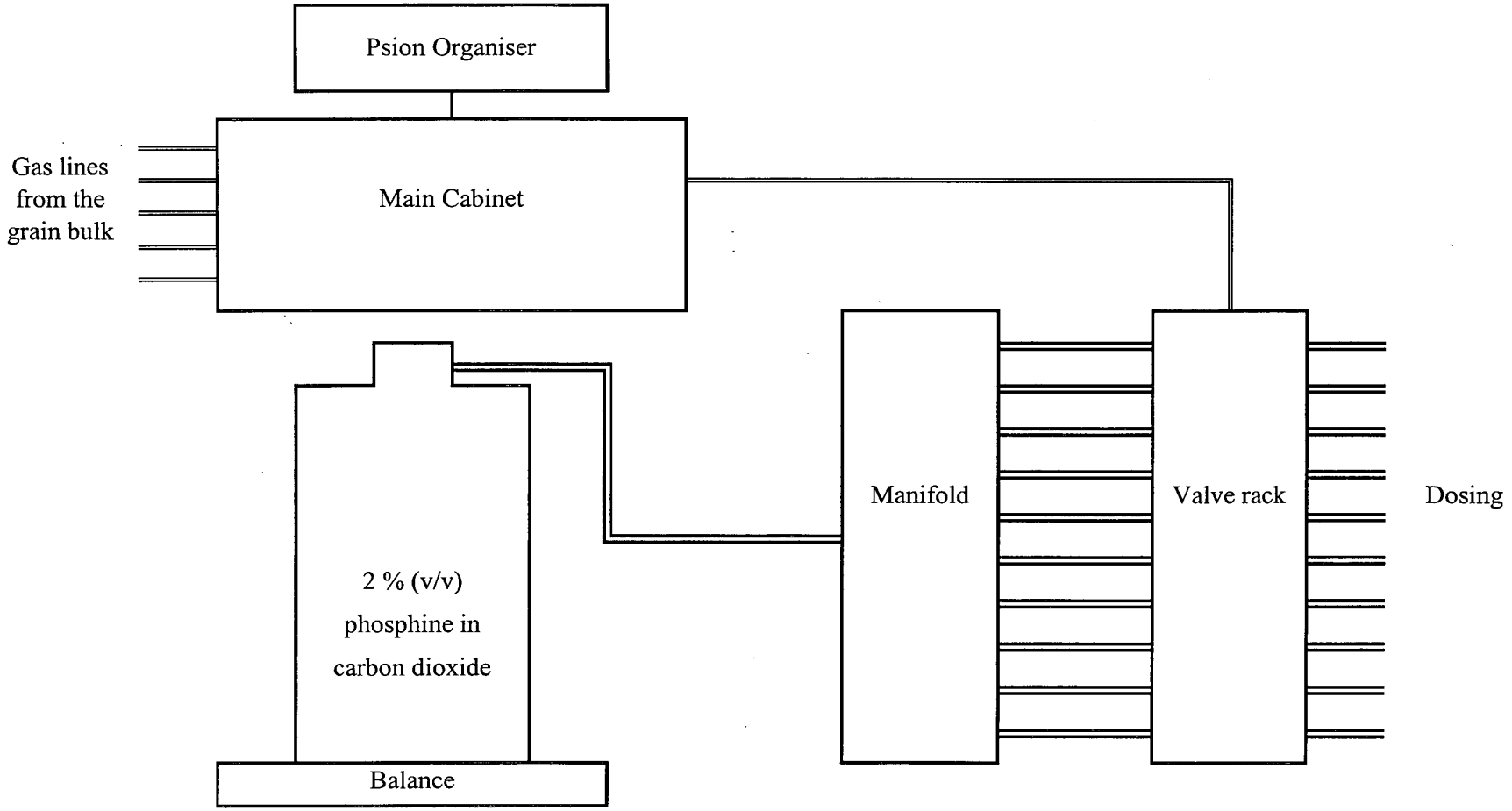


Fig 6. The Siroflo System.

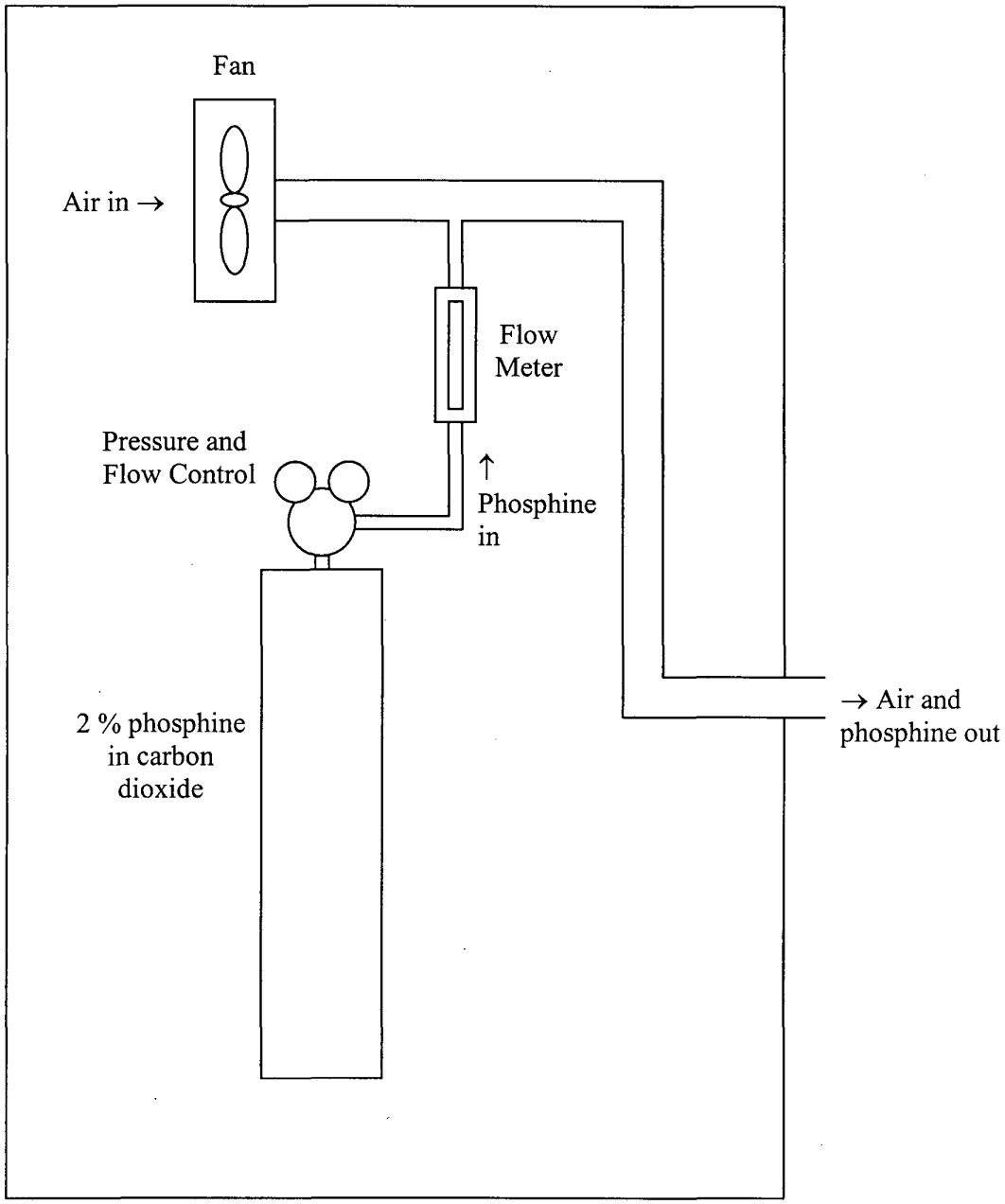


Fig 7. Sampling positions for the grain silo trials.

Height of bin = 11.0 m

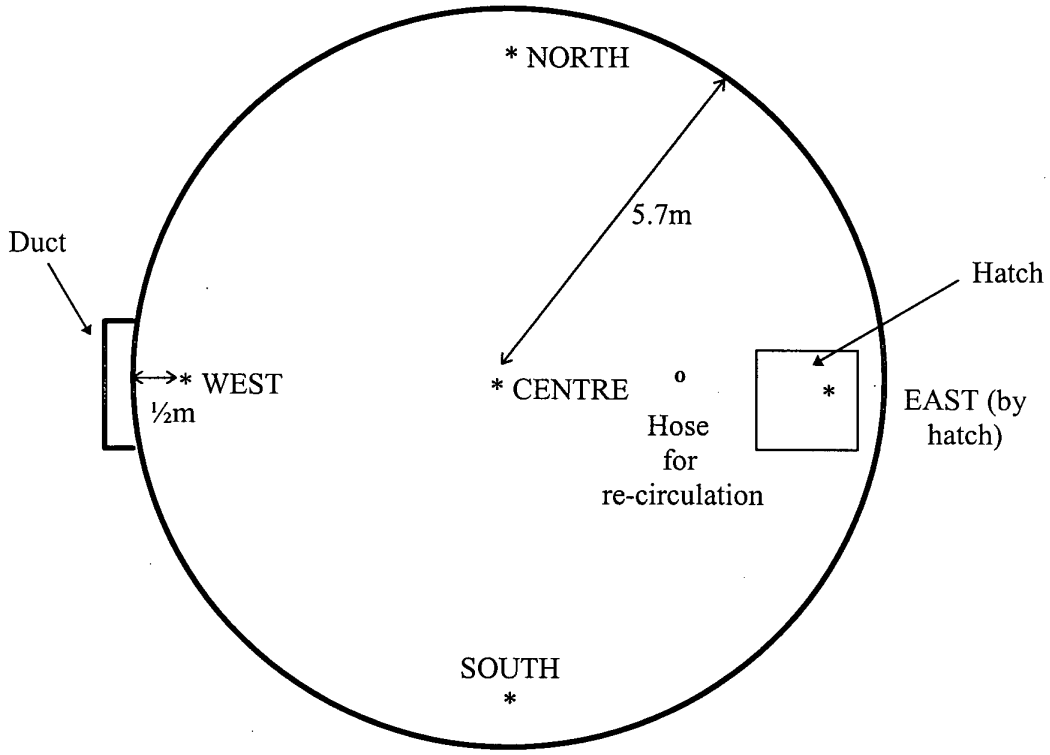


Fig 8. Dosing and sampling positions for the floor store trials using the automated dosing system

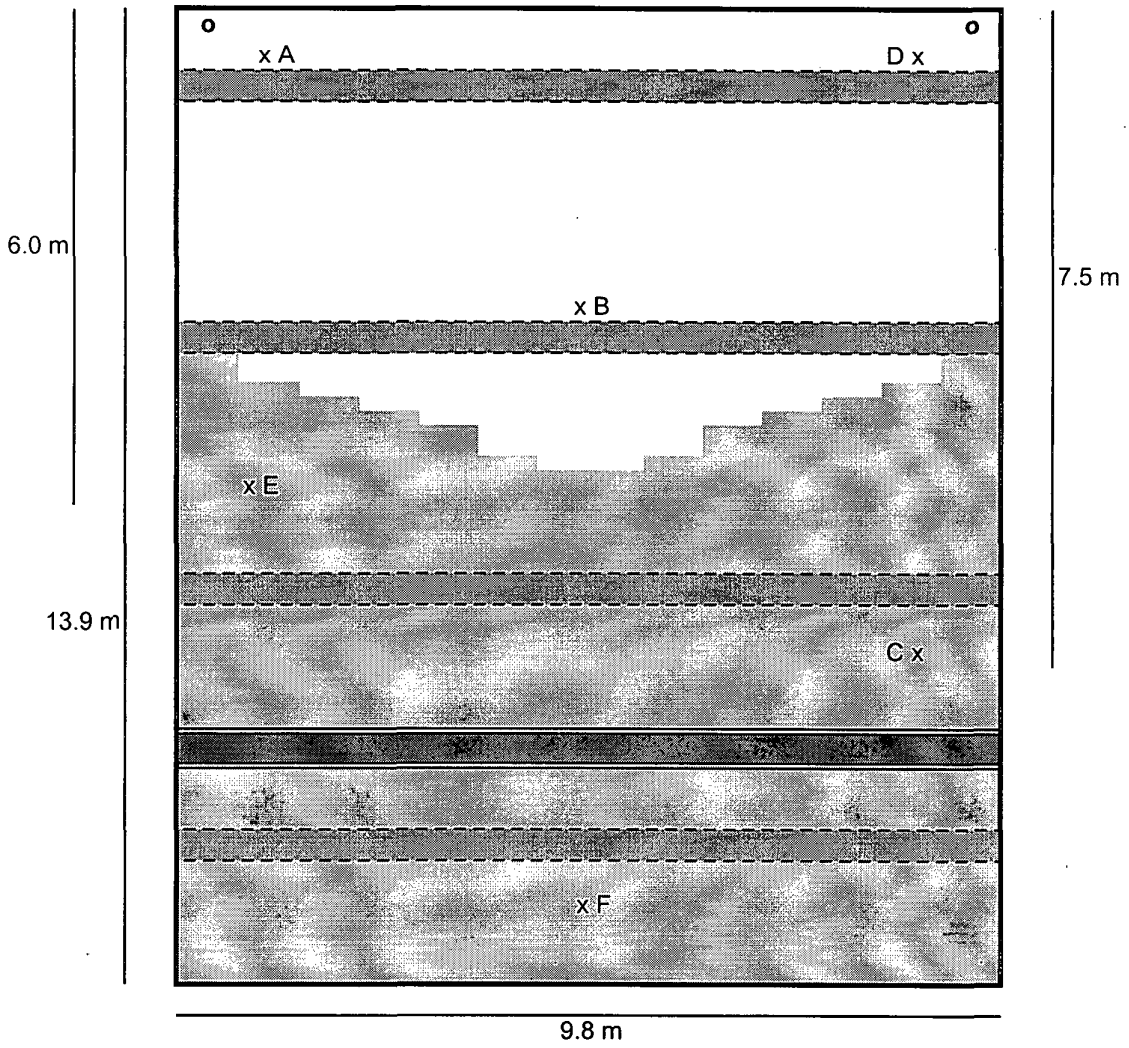


Fig 9. Dosing and sampling positions for the floor store trials using the Siroflo system

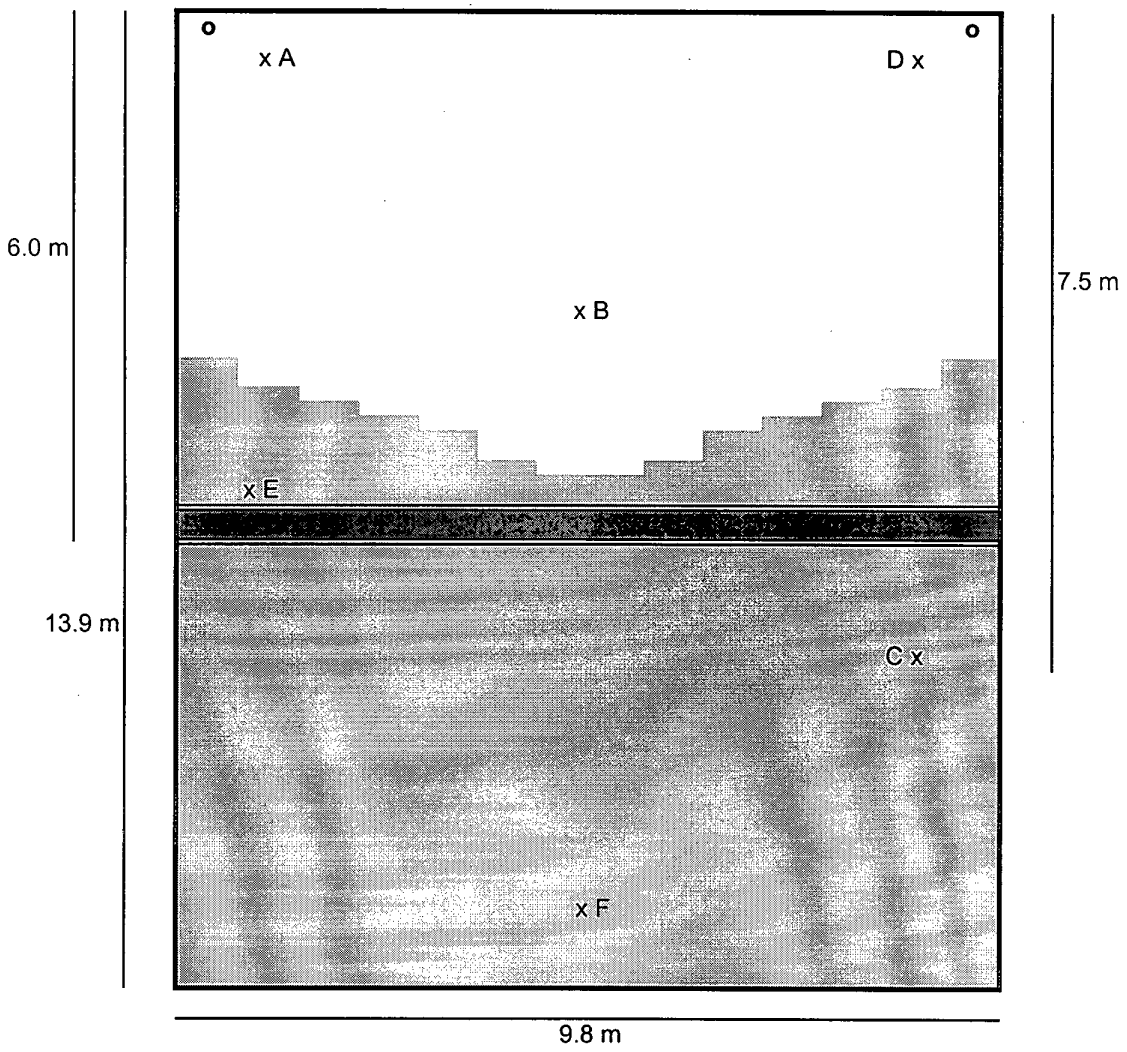


Fig 10. Dosing and sampling positions for the spot fumigation trial

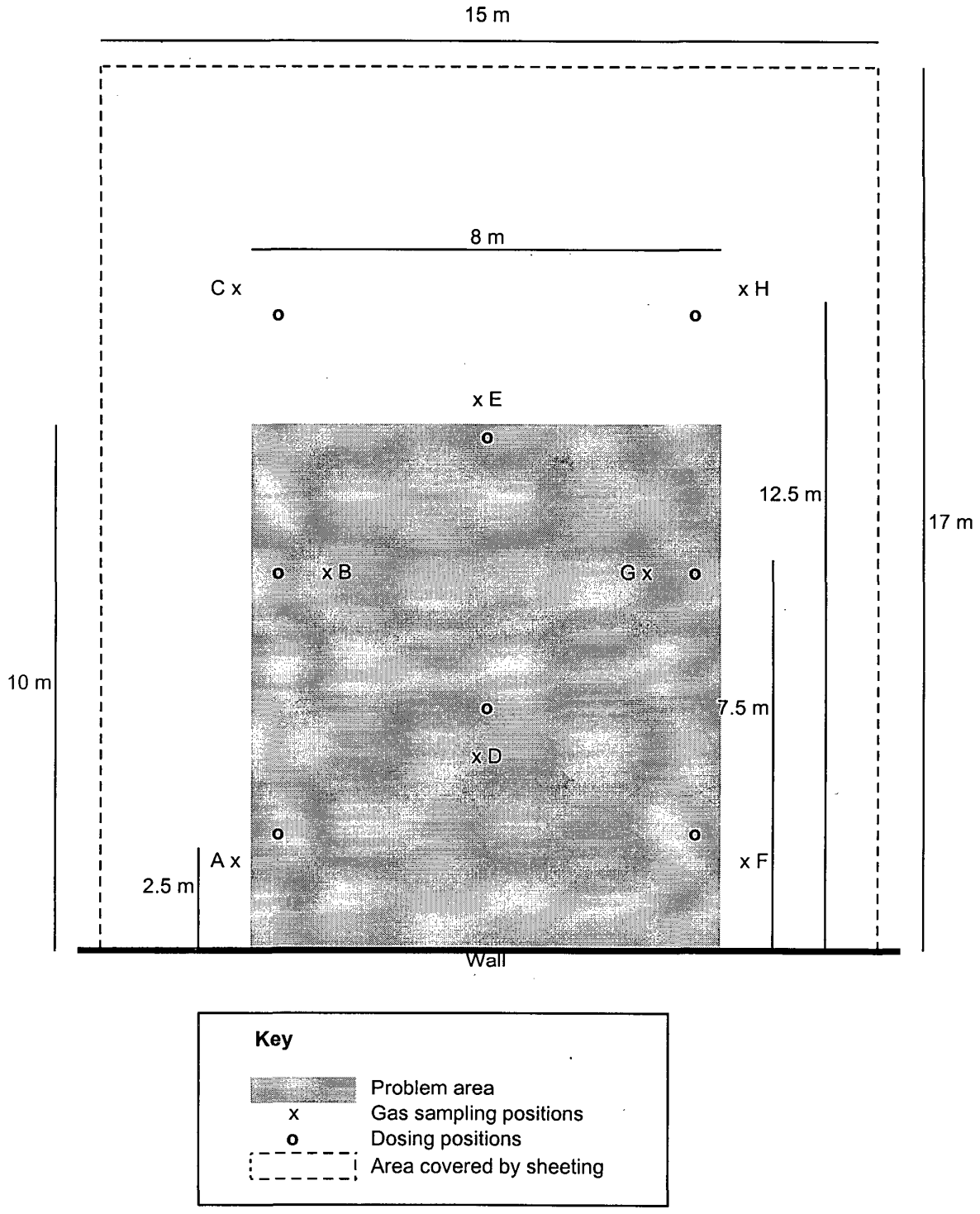


Fig 11. Dosing probes for the spot fumigation.

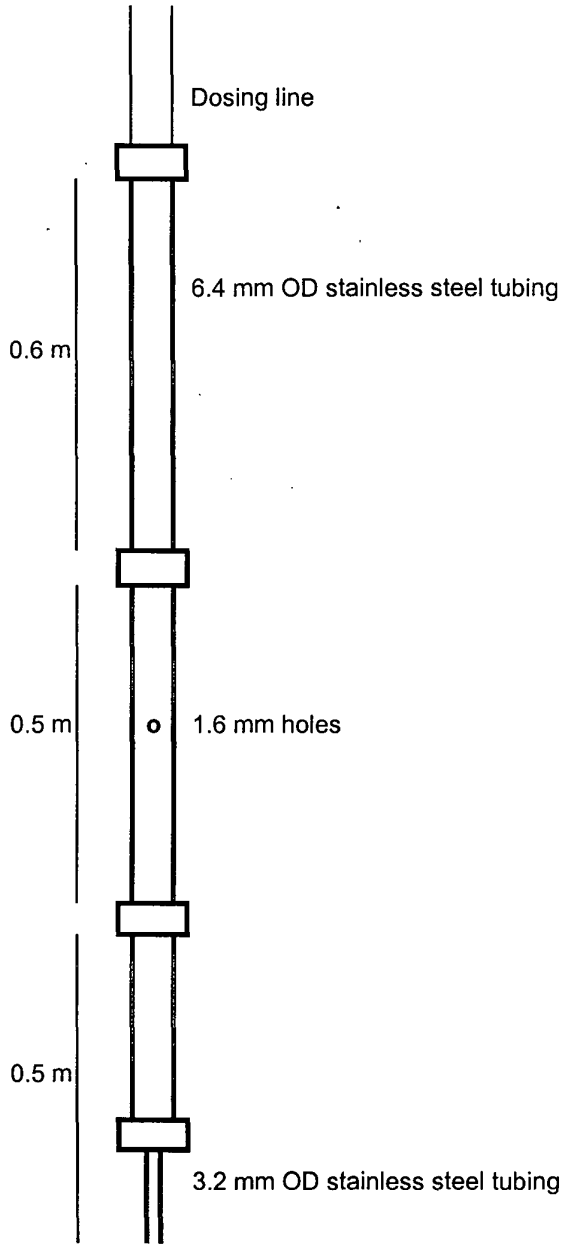


Fig 12. Average concentrations at a depth of 1 m in the silo trials over the first 8 days.

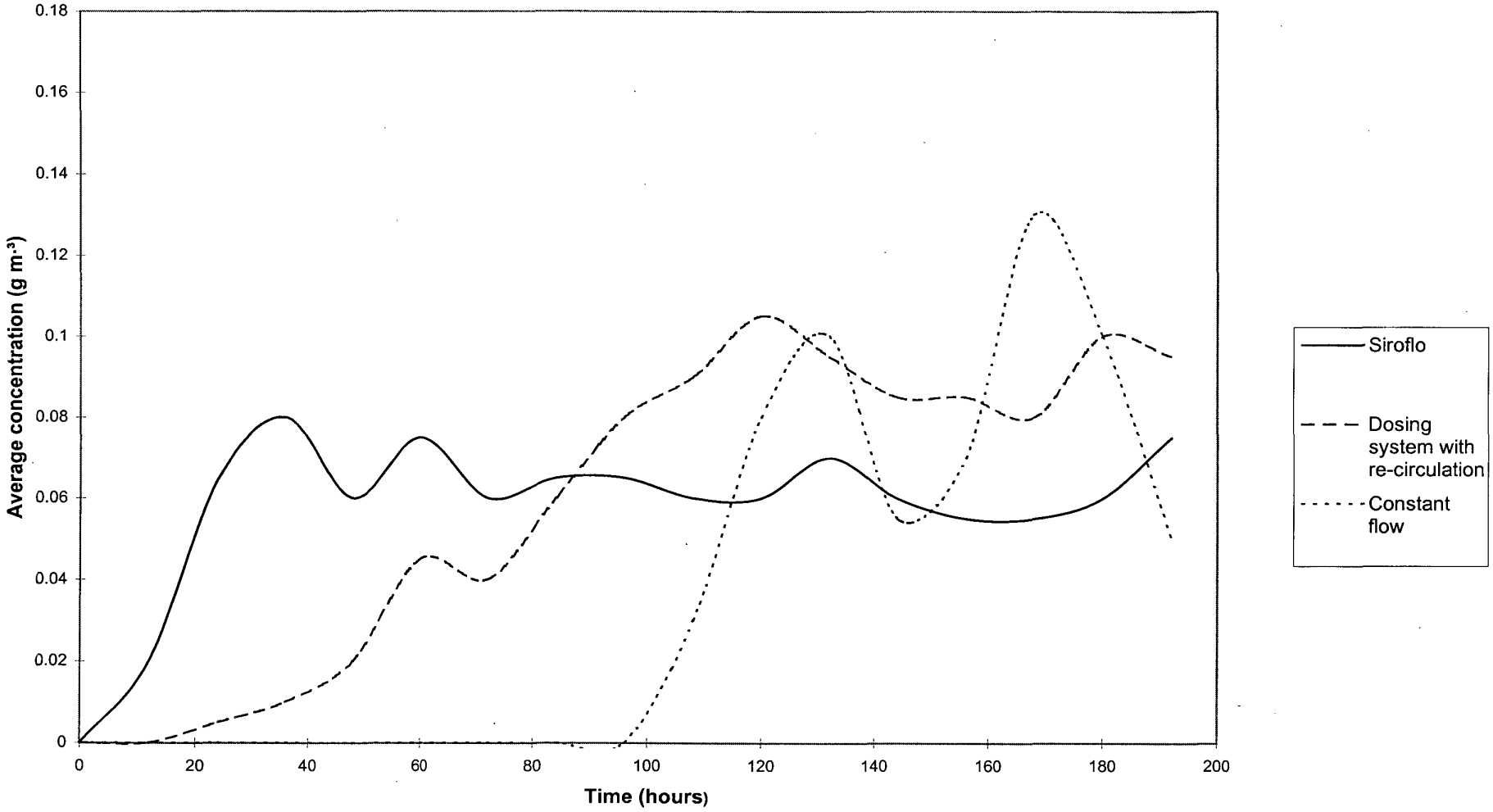
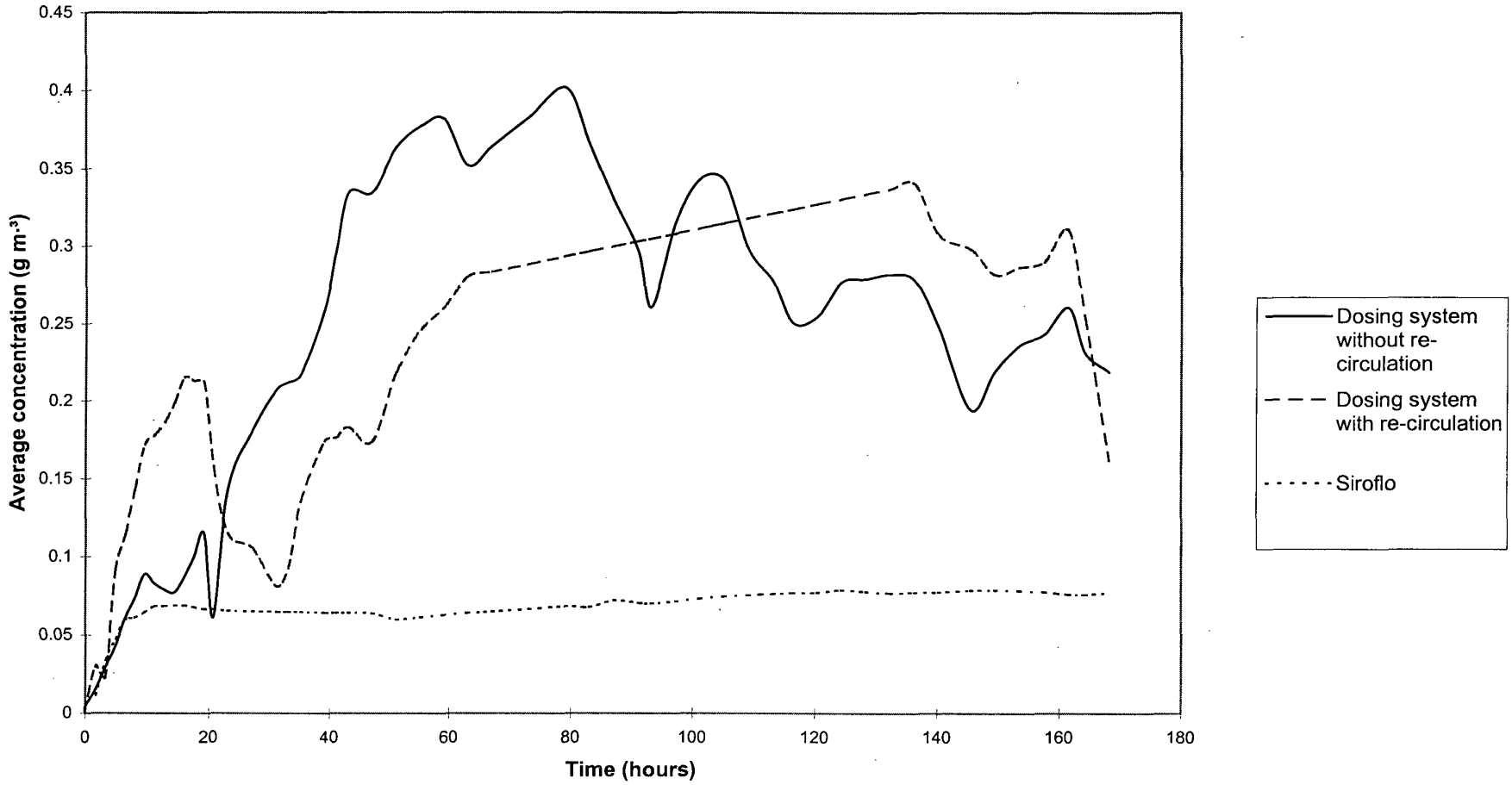


Fig 13. Average concentrations in the floor store trials over the first 7 days.



HGCA

PROJECT REPORT No. 180

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by

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Contents

Abstract

The main objective of this project was to identify factors contributing to the reliability of production and the optimum management of winter malting barley on heavy land. The trial was over three cropping years for the harvests of 1991, 1992 and 1993. Two winter barley malting varieties, Pipkin and Puffin were grown at 4 nitrogen rates (0, 80, 120 and 160 kg ha-1 N) and, under 4 plant growth regulator regimes(PGR), (1) Nil, (2) chlormequat only [as New 5-C Cycocel], (3) 2-chloroethyl phosphonic acid only [as Terpal], and (4) a sequence of (2) and (3). In each year the trial was done at four heavier soil sites and one light land site. The four heavy land sites were selected as being good wheat growing soils, rather than malting barley land, and the fifth site was on a sandy loam with a history of production of malting barley. Satisfactory grain yields and quality were achieved at all sites. At all nitrogen rates and across all sites, Puffin (6.14 t ha-1) slightly outyielded Pipkin (5.96 t ha-1), and Pipkin had lower grain nitrogen (1.54%) than Puffin (1.60% N). Yield increased with increasing nitrogen rates, as did grain nitrogen content. The optimum nitrogen rate for yield and quality varied between 80 and 120 kg ha-1 N at individual sites in the three years. Puffin produced less small grain than Pipkin, and this was especially evident where lodging was severe. The small grain fraction was less than 6%, so only slight screening losses would have been incurred in reducing screenings to <5%. Lodging was significant only at one site in 1991. It occurred at all sites in 1992 and at two sites in 1993. In all cases it increased with increasing nitrogen rates. Pipkin was worst affected but good control was achieved with Terpal alone or the chlormequat Terpal sequence. Chlormequat on its own did not reduce lodging or significantly increase yield.

All treatments taken individually produced significant differences in all variates; the exceptions being no significant effect of nitrogen on 1000 grain weight in 1992, and PGR on small grain fractions in 1993. This abundance of significant effects, and the annual variation between the performance of sites both in yield and quality show variability to be a problem. The traditional malting site was the most consistent at achieving the required quality. Management regimes should be designed to improve consistency at the non-malting sites.

Micromalting evaluation was done on the lowest grain nitrogen samples selected from all sites. As a result most samples tested were from the 80 kg N ha-1 treatment from various PGR treatments. Three samples per site were tested from the 1991 harvest, and five per site in 1992 and 1993. In 1992 and 1993, samples from the nil and 120 kg ha-1 were included. Samples that showed low germinative energy on receipt for micromalting were not tested. Using Hot Water Extract as the main malting quality parameter showed quality to be inversely correlated with grain nitrogen, as were other quality parameters to varying degrees. There were no abnormal features in the micromalt analyses.

This project shows that malting barley can be grown on heavy land provided the soil mineral nitrogen status is monitored, so to avoid excessive fertiliser use and high grain nitrogen content. Marketable varieties must be selected, and a reliable efficient PGR programme used.

INTRODUCTION

Malting barley has traditionally been grown on the lighter soils with modest nitrogen inputs (Archer, 1985) and where winter barley is grown on heavy land, high yielding feed varieties predominate. Concern about high grain nitrogen levels and lodging has put most growers off trying to grow malting varieties on these heavy soils. HGCA funded research has shown that heavy land and its higher moisture holding capacity can be suited to producing quality malting samples. Indeed, light soils have relatively low available water capacity (AWC) and this can lead to lower yields and higher grain nitrogen contents than malting crops produced on heavier soils with high AWCs (Garstang, Vaughan and Dyer, 1993). With adequate moisture heavier soils can permit the use of slightly higher rates of nitrogen fertiliser for the same grain nitrogen.

Recent years have seen a marked increase in England and Wales in winter barley production (Anon, 1992) at the expense of the spring crop. This winter sowing enables the crop to be established more reliably on heavier soils in the autumn. The higher profitability of winter wheat compared to winter barley results in these soils carrying winter wheat as the predominant cereal, and these wheat crops are frequently grown with pulses or oilseeds as break crops. Where the production of high protein bread wheats is the target. alternating break crops with just one or two wheat crops is common. If malting barley can be reliably produced there will be greater flexibility of cropping on these heavier soils with improved margins from barley crops.

Modern malting winter barley variety introductions have stiffer straw than the old variety Maris Otter, and its widely grown derivatives Halcyon and Pipkin. This change allows more scope to avoid lodging on heavier soils, and any tendency for varieties to take up marginally higher amounts of nitrogen has become less of a problem as the swing to lager type beers has increased the demand for barleys with up 1.75% nitrogen (Patterson, 1991). This is the cut-off level taken as an acceptable grain sample for malting throughout this report.

With these research findings, varietal introductions, and changes in the industry's requirements in mind the experiment described here was done in the three harvest years 1991, 1992 and 1993.

OBJECTIVES

The general objective was to test the feasibility of malting barley production on heavier soils. Within this objective two main variables of crop management were to be investigated

1. The optimum nitrogen rates for weak and stiff strawed malting barley varieties grown on heavy, typically 'non-malting' soils.

2. The growth regulator programmes most suitable for the production of high quality malting barley on these sites.

MATERIALS AND METHODS

Five sites, four in England and one in Scotland, were drilled at seed rates calculated to deliver 400 seeds per square metre. Trials were located at the following sites:

	Site	Location	Main soil type
1.	Little Oakley	Essex	sandy loam
2.	Hardwick	Cambridgeshire	silty clay loam
3.	Goole	Humberside	sandy clay loam
4.	Much Wenlock	Shropshire	sandy silt loam
5.	Penicuik	Midlothian	clay loam

All treatments other than nitrogen and plant growth regulator were as normal farm practice. Full site details are given on pages 31 -33.

Treatments and Trial Design

The two varieties Puffin and Pipkin were used in a factorialy designed trial with four nitrogen rates and four plant growth regulator (PGR) programmes (including nil) to produce blocks of 32 plots. These were replicated three times and the treatments applied in a randomised block

design.

Treatments

Varieties	1.	Pipkin
	2.	Puffin
Nitrogen (kg ha-1)	1.	0
	2	80
	3.	120
	4	160
Growth Regulator	1.	Nil
	2.	1612.5 g chlormequat chloride + 80 g choline chloride as 2.5 l ha-1 of New 5C Cycocel (BASF plc) applied at growth stage (GS) 30.
	3.	310 g 2-chloroethylphosponic acid + 310 g mepiquat chloride as 2 1 ha-1 of Terpal (BASF plc) applied at GS 37.
	4.	Treatments 2 and 3 in sequence.

Sprays were applied at the growth stage shown in a volume of 2001 ha-1 using a CO_2-pressurised knapsack sprayer at a pressure of 200 kPa to give a medium spray quality. Nitrogen, as ammonium nitrate, was applied by hand as a single application just before mid-March at all sites.

ASSESSMENTS

Soil cores were taken in the autumn and spring to determine the level of soil mineral nitrogen (SMN) in the 0-30 cm, 30-60 cm and 60-90 cm horizons of each site.

Assessments of % crop area leaning and lodging were made as and when it occurred and again at harvest. An assessment of fertile tillers was made for both varieties at all nitrogen rates but only the nil and 5C Cycocel treatments

Samples of ears were collected at harvest and grain numbers per ear determined (Sylvester-Bradley, Grylls and Roebuck 1985). The crops were harvested by combine and ex-plot yields were weighed by on-board weighing equipment. Grain samples were taken for correction of grain yield to 85% dry matter and for the determination of specific weight, thousand grain weight and for grain size assessments through 2.2 mm, 2.5 mm and 2.8 mm sieves. Grain nitrogen content was determined by Near Infra-red Reflectance.

For each years results the means of grain yield (at 15% moisture), specific weight, thousand grain weight, grain nitrogen content (% in dry matter), and sieving fractions were compared by analysis of variance using Genstat 5, release 1.3. Site, variety, nitrogen and PGR were the single factors analysed along with their first and second order interactions; for each years analysis this gave 346 error degrees of freedom.

Micro-malting tests were undertaken on the 'best' samples by the Brewing Research Foundation International. These were selected from Pipkin from each site as judged by grain nitrogen, specific weight and screenings were used to prepare micromalt samples. The same nitrogen/PGR plots of Puffin were used to provide equivalent samples. Three samples per site per variety were selected in 1991 and all came from the 80 kg ha-1 nitrogen treatment. In 1992 and 1993 five samples were tested to allow a wider range of treatments including nil and 120 kg ha-1 nitrogen treatments. The micro-malting evaluation measured the hot water extract (HWE) from 0.2mm and 0.7mm grist (l° kg-1), and thus the coarse/fine difference (C/F); colour using the European Brewing Convention scale (Colour EBC); total soluble nitrogen (TSN%); total nitrogen (TN%); soluble nitrogen ratio (SNR%); free ammonia nitrogen (FAN mg l-1); pH; Fermentability (%); Viscosity (mPa) and Friability (%).

RESULTS

The results are presented in three parts. In the first part the soil mineral nitrogen figures in the spring are given to explain in part the subsequent responses to nitrogen. The second part

looks at the production and quality aspects needed by the grower; grain yield, specific weight, thousand grain weight, grain nitrogen content, lodging, fertile tiller number and grain size are all details which the grower attempts to control, and are all factors that can affect the crop's profitability. The third part looks at the quality aspects such as hot water extract and nitrogen content. Because of the sample selection for micro-malting, the results represent the 'best' samples that would be provide from heavy land sites for the maltsters and brewers.

Part I - Soil mineral nitrogen

Table 1: Soil mineral nitrogen (kg N ha-1) in top 90 cm

Spring	Cropping year		
Site	1990/91	1991/92	1992/93
Essex	42	17	25
Cambs	68	124	53
Humberside	23	29	54
Midlothian	49	24	49
Shropshire	73	29	26

The crop grown in Cambridgeshire in 1991/92 was preceded by wheat, and the crop prior to the wheat was peas. The 1992/93 crops in Cambridgeshire and Humberside were similarly preceded by wheat preceded by oilseed rape. While many factors contribute to the actual amount of nitrogen available, the 1991/92 Cambridgeshire figures highlight the possible conflict between using break crops to maintain high soil nitrogen levels for wheat, and the impact of this on malting barley quality. This is shown later in the grain nitrogen figures. The traditional malting site had the lowest mean spring SMN level.

Part II - Grower requirements

The impact of treatments across all sites on production criteria valued by the grower are shown in table 2. The table lists the F-test probability values from the analyses of variance. Values of 0.05 or less indicate there was a significant difference between the treatments in the left hand column for the variate at the head of the column. Values of <0.001 indicate a highly significant difference. Thus, and not surprisingly, there were significant grain yield differences between sites in every year. Indeed all variates differed significantly between sites, highlighting the need for individual management of malting crops.

Table 2: F test probability values. All treatments and interactions.

	Grain Yield	Specific weight	1000 grain	Grain N %	Sievings (%)				N uptake in grain	% lodging
					>2.8 mm	2.8-2.5 mm	2.5-2.2 mm	<2.2 mm		
1991										
Site (S)	<0.001	<0.001	<0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	
Variety (V)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	At
Nitrogen (N)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	one
PGR	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	0.021	site
SxV	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.003	only
SxN	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	
VxN	0.006	0.218	0.555	0.117	0.792	0.897	0.018	0.005	<0.001	
SxPGR	<0.001	<0.001	<0.001	0.272	<0.001	<0.001	<0.001	<0.001	<0.001	
VxPGR	0.097	0.118	0.092	0.263	0.002	0.003	0.003	<0.001	0.674	
NxPGR	0.099	0.379	0.875	0.727	0.017	0.579	<0.001	<0.001	0.570	
SxVxN	0.043	0.151	0.258	0.402	<0.001	<0.001	<0.001	<0.001	0.562	
SxVxPGR	0.065	0.437	<0.001	0.002	0.783	<0.001	0.009	<0.001	0.090	
SxNxPGR	0.208	0.475	0.061	0.181	0.108	0.128	0.151	<0.001	0.362	
VxNxPGR	0.392	0.154	0.688	0.380	0.407	0.055	0.013	0.033	0.631	
1992										
Site (S)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	0.001	<0.001	<0.001
Variety (V)	<0.001	0.003	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Nitrogen (N)	<0.001	<0.001	0.102	<0.001	0.030	<0.001	<0.001	<0.001	<0.001	<0.001
PGR	<0.001	<0.001	0.033	0.013	<0.001	0.007	<0.001	<0.001	0.025	<0.001
SxV	<0.001	<0.001	<0.001	0.074	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
SxN	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
VxN	<0.001	0.380	0.176	0.152	0.126	<0.001	0.014	<0.001	<0.001	<0.001
SxPGR	0.011	0.010	0.003	0.118	0.268	0.307	0.128	0.140	0.184	0.172
VxPGR	0.211	0.011	0.168	0.131	0.001	0.524	<0.001	<0.001	0.104	0.007
NxPGR	0.109	0.380	0.089	0.042	0.793	0.850	0.140	0.022	0.032	0.007
SxVxN	0.006	0.004	<0.001	0.421	<0.001	<0.001	<0.001	<0.001	0.141	0.0.14
SxVxPGR	0.035	0.841	0.769	0.529	0.348	0.189	0.004	0.205	0.215	0.115
SxNxPGR	0.467	0.877	0.024	0.313	0.067	0.108	0.201	0.113	0.045	0.953
VxNxPGR	0.613	0.795	0.841	0.373	0.012	0.716	0.317	0.092	0.110	0.187
1993										
Site (S)	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Variety (V)	<0.001	0.044	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Nitrogen (N)	<0.001	<0.001	0.006	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
PGR	<0.001	<0.001	0.002	<0.001	0.012	<0.001	0.081	0.692	0.003	<0.001
SxV	<0.001	<0.001	<0.001	0.011	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
SxN	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
VxN	0.012	0.308	0.755	<0.001	0.023	<0.001	0.007	0.027	0.285	<0.001
SxPGR	<0.001	<0.001	<0.001	0.054	<0.001	<0.001	<0.001	0.001	<0.001	<0.001
VxPGR	0.238	0.131	0.424	0.613	0.249	0.100	0.993	0.027	0.756	0.344
NxPGR	0.443	0.083	0.126	0.673	0.061	0.032	0.254	0.436	0.586	0.056
SxVxN	0.066	0.001	0.976	0.078	0.209	<0.001	<0.001	0.240	0.285	<0.001
SxVxPGR	0.832	0.423	0.056	0.916	<0.001	0.002	0.002	0.002	0.863	0.492
SxNxPGR	0.510	0.149	0.144	0.291	0.205	0.450	0.113	0.494	0.149	0.376
VxNxPGR	0.497	0.556	0.247	0.431	0.573	0.185	0.952	0.376	0.225	0.525

All the treatments taken individually (rows 2-4 of the year tables) produced significant

differences in all variates; the few exceptions being the impact of nitrogen on 1000 grain weight in 1992, and the effect of PGR on the two smallest grain fractions in 1993.

The above widespread significant differences are to be expected in view of the well established responses known for the treatments. Of more interest in input management trials like these are the interactions. In these categories the significance indicates that, for example on the SxV row (Site x Variety interaction), the sites produced different grain yields, and the differences between varieties differ between sites. The VxN (Variety x Nitrogen interactions) show that although in grain yield Pipkin and Puffin respond differently to nitrogen, possibly due to lodging, the specific weight and thousand grain weight produce no interaction (i.e. the two varieties respond in a similar fashion), and only in one year out of three (1993) was there an interaction in the way the grain N% responded to nitrogen.

The bulk of the three way interactions were not significant. The only consistent theme was the significant SxVxN interaction in the sieving fractions. Lodging and supply are implicated in this interaction.

The various interactions are discussed separately under each heading

Grain yield and effect of site and nitrogen

All sites yielded satisfactorily and nitrogen treatments that produced suitable nitrogen contents would have produced profitable crops of malting barley. The Cambridge and Midlothian sites were the highest yielding overall giving mean yields of 6.42 and 6.45 t ha-1 respectively over the 3 years. The light sand site in Essex also yielded consistently well giving a mean yield of 6.11 t ha-1. Yields at the other 2 sites were more variable. In 1991, the Shropshire site yielded poorly as did the Humberside site in 1993 and their overall mean yields were 5.30 and 5.53 t ha-1 respectively. The yields at each nitrogen rate are shown for each site in Appendix 1.

There is a significant site x nitrogen interaction ($P<0.001$) in all 3 years, largely as a result of the different response from the silty clay of the wheat land site in Cambridgeshire. The crossed

lines in Figs. 1-3 for these sites give an indication of this effect in comparison with the other sites which tended to perform more like the Essex malting site than the Cambridge 'wheat' site. Lodging was a contributory factor at the Cambridgeshire site in all years, and the Humberside side in 1993. This is seen in the way the response lines of these sites cross the other sites. Lodging is discussed later, but the greater lodging in Pipkin particularly at the Cambridgeshire site contributed to the significant SxVxN interactions in 1991 (P=0.043) and in 1992 (P=0.006).

The traditional malting site in Essex site was characterised by the highest response to nitrogen between Nil and 80 kg ha-1 in all years. This rapid increase in yield up to 80 kg was followed by increases similar to the other sites at the higher rates of 120 and 160 kg ha-1 nitrogen. The response to applied nitrogen was the lowest from the Cambridge site at all rates of nitrogen, which is in line with its higher than average soil mineral nitrogen status, and the greater amounts of lodging.

Varieties

At the malting site in Essex the two varieties performed similarly in all three years, with Puffin having a slightly higher yield in 1992 and 1993. At the Cambridgeshire site however Pipkin yielded the lowest in all three years, with the difference in yield increasing as the nitrogen rates increased. The difference between Puffin and Pipkin grain yield at 160 kg ha-1 nitrogen was 0.73 t ha-1 in 1991, 1.35 tonnes in 1992 and 0.82 tonnes in 1993. Again lodging of the weaker strawed variety was having an effect.

Overall Puffin consistently outyielded Pipkin in all three years under all PGR regimes. (Appendix I). The differences were most apparent at the 120 and 160 kg ha-1 nitrogen rates again partly due to the increased lodging of Pipkin at the higher nitrogen rates. The overall mean yield of Puffin in these trials was 6.10 t ha-1 compared to 5.82 t ha-1 for Pipkin; this 4.8% higher yield was less than the 6.7% difference in the 1991 Recommended List (NIAB 1991).

PGR

Overall PGR treatment significantly increased yield (P<0.001) in every year. The impact of

PGR treatments on grain yields at the lodging prone crop at the Cambridgeshire site in 1991 can be seen clearly in Fig. 4. Pipkin shows an increase of almost a tonne per hectare, and Puffin 0.5 t ha-1. Lodging at other sites was minimal although cycocel was associated with slight yield increases. In 1992 lodging was more widespread and Pipkin showed a variable yield increase at all bar the Humberside site (Fig 5) where the nil treatment produced the highest yield. Puffin showed its most marked increase in yield from the use of cycocel when compared with no PGR, at the Essex site in 1992. In 1993 lodging was most severe at Cambridgeshire and Humberside and these sites show the largest grain yield increases from PGR use (Fig 6). The figures in Appendix V show a progressive decline in lodging in line with these yield increases. This variation in lodging at different sites is shown by the significant SxPGR term in table 2, although this perhaps indicative of lower lodging pressure at some sites, rather than greater PGR efficacy. The absence of significance in the VxPGR and NxPGR interactions show PGRs affected the two varieties in a similar manner. There was no differential effect in the response to nitrogen.

In the severe lodging conditions of 1992 the SxVxPGR interaction was significant largely as result of the different response of the two varieties at the Essex, Cambridgeshire and Midlothian sites (Fig 5).

Specific weight

The responses and interactions seen in specific weights are similar to those produced in grain yield. The data is listed in Appendix II. Dense smooth grains which pack well produce high bulk densities, and grain from high yielding crops tends to have these characteristics. Figures 7 - 9 show how the specific weight varies markedly between regions over the years, and how the response to nitrogen varies between varieties at the same site and at different sites, particularly in 1992 and 1993 when significant SxVxN interactions occurred.

Specific weights were generally satisfactory, but in each year some sites were poorer than others, at all rates of nitrogen. Figures 10 - 12 show that at sites where specific weights of untreated crops are around 65 kg hl-1 or less, PGR treatments 3 and 4 tend to depress them further. Patterns of response at sites with specific weight of 70 kg hl-1 or above tend to be more varied. This effect is supported by Figures 13 - 15 where the adverse effects of PGR are

worse at the nil nitrogen rate. The exception being in 1991 when there was a fall of 1.61 kg hl-1 in the 160 kg ha-1 nitrogen treatment receiving Terpal only. This arose primarily from the response at the Shropshire site.

Thousand grain weight

The significance response of the thousand grain weights to treatments followed very closely the response of specific weights. The only differences being the highly significant second order interaction (SxVxPGR) for thousand grain weight in 1991, whereas for specific weight the interaction was not significant. In 1992 nitrogen had no overall significant effect on thousand grain weight although it produced a reduction (significant $P< 0.05$) at the Cambridgeshire site. This is one of the few examples where a main treatment failed to produce a significant difference in the overall trial analysis. The VxPGR interaction was significant for specific weight but not for thousand grain weight, and the SxNxPGR interaction was significant for thousand grain weight but not for specific weight. In 1993 the significance of responses was very similar with no significant second order interaction for thousand grain weight, but the specific weight SxVxN interaction being highly significant (see above).

Irrespective of treatment there is a component of variation between Pipkin and Puffin thousand grain weight that is largely genetically based rather than influenced by management. Pipkin is Sergeant x Maris Otter line, whereas Puffin is cross of (Athos x Maris Otter) x Igri. Other straight Maris Otter crosses like Halcyon (Warboys x Maris Otter) share this small grain trait.

Grain nitrogen

The grain nitrogen contents were very satisfactory in 1991 with all samples from the 120 kg N ha-1 or less, having grain below 1.75% in DM. Even at 160 kg N ha-1 two sites of Pipkin (Essex and Midlothian) averaged 1.75% or below, and one Puffin site produced grain at 1.75%. The Midlothian and Essex sites had the lowest overall mean nitrogen contents of 1.51%. The Shropshire site, with the lowest yield, had the highest grain nitrogen contents. The large increases in grain yield at the Essex site between the nil and 80 kg ha-1 nitrogen applications produced some evidence of dilution of grain nitrogen content in 1991, with only an increase 0.03% N in DM resulting from the 80 kg ha-1 application. (Appendix IV).

In 1992 drier conditions caused a general increase in the grain nitrogen, although the effect of dry conditions was not uniform across all soil types. The soil moisture deficits (SMD) were similar in late May and June at the Essex and Cambridgeshire. sites at between 100 and 110 mm, but the former produced the lowest mean grain nitrogen contents, and the latter the highest (1.59% and 2.05% respectively). The spring soil mineral nitrogen levels were the lowest in Essex (17 kg ha-1) and the highest in Cambridgeshire (124 kg ha-1). This unavoidable extra nitrogen at the Cambridgeshire. site produced the highest grain nitrogen contents at all rates of applied nitrogen and at all PGR treatments. In 1992 the increase in grain nitrogen was almost linear at the Essex site which started from the lowest level at nil nitrogen (1.31%). At the two highest rates of nitrogen the Humberside site produced the lowest grain nitrogen with 1.79% at 160 kg ha-1 nitrogen.

In 1993, the grain nitrogen contents at the Essex, Midlothian and Shropshire sites were much lower than the other two sites (Cambridgeshire and Humberside), where acceptable malting samples were only produced at nil and 80 kg ha-1 N. The higher grain nitrogens were associated with significantly lower yields at these two sites.

In 1991 there was little difference in the grain nitrogen between the two extremes of soil type at the Essex and Cambridgeshire. sites, and between the two varieties Pipkin and Puffin at both sites. Pipkin had the lowest mean nitrogen content at the Essex site (1.47%) and Puffin had the lowest mean nitrogen content at the Cambridgeshire site (1.53 %) (Figure 16). In 1992 at the Cambridgeshire. sites, where the SMN contents were markedly higher than in 1991, the silty clay Cambridgeshire. site produced grain of approximately 0.5% higher grain nitrogen than the Essex site, across the entire range of nitrogen rates (Figure 17). This effect was also evident in 1993 although the difference was smaller (0.3%) (Figure 18). Puffin consistently produced higher grain nitrogens overall in all three years and this effect was seen across all the individual nitrogen rates. Overall, the mean grain nitrogen level for Pipkin was 1.59% compared to 1.67% for Puffin, despite the fact that Puffin consistently outyielded Pipkin. The optimum nitrogen for yield and malting quality varied between sites and season but was normally in the range between 80 and 120 kg N ha-1 . In all years and for both varieties increasing grain yield was positively correlated with grain nitrogen. Table 3 below shows the correlation coefficients between grain yield and grain nitrogen, for both varieties at all sites, and for individual varieties

at all sites.

Table 3 Correlation coefficients for total grain yield and grain nitrogen %

	1991	1992	1993
Both Varieties	0.6078	0.6324	0.6030
Pipkin	0.6162	0.5827	0.5845
Puffin	0.5969	0.5423	0.6390

Yields increased by nitrogen fertiliser were clearly linked with higher nitrogen. Where nitrogen is applied to increase yield it tends to increase grain nitrogen content. If the yield increment, rather than absolute yield, is correlated with grain nitrogen or increment in grain nitrogen the values in table 4 are obtained.

Table 4 Correlation coefficients for increment of grain yield and grain nitrogen %

Yield increase: grain N% increase	1991	1992	1993
Both Varieties	0.4767	-0.4428	-0.4232
Pipkin	0.3225	-0.6239	-0.5145
Puffin	0.6426	-0.3686	-0.4004
	1991*	1992*	1993*
Both Varieties	0.1674	0.1913	-0.1199
Pipkin	0.1831	0.1696	-0.2367
Puffin	0.1257	0.1790	-0.0582

*excluding Cambridgeshire high N site

Most of the negative values for 1992 and 1993 in the top of the table 4 result from very low or a negative yield response at the Cambridge site (where soil nitrogen levels were above average). Removing this site reduces correlation values to non-significant low negative or positive values. Lodging at various sites in 1992 and 1993 would have also contributed to negative correlations. Although 1991 had yields that were positively correlated with grain nitrogen the average N% levels in 1991 were the lowest of the three years. Overall the correlations of yield increment and grain N% increment are low. This data suggests dilution of grain N content by high yields was not a clearly defined phenomenon in these trials.

The overall effect of PGRs on grain nitrogen content is to slightly reduce values. Figures 19 - 21 show the tendency for a fall in grain nitrogen contents, although a wide range of fluctuations occur. As many of the factors which affect grain nitrogen content have their impact during grain fill, the interaction with PGRs is hard to predict.

Lodging

Lodging was very limited at all sites except at the Cambridgeshire. site in 1991, and to a lesser extent in 1992. (Appendix V). There was some lodging at all sites in 1992. The mean percentage crop area lodged was 23%, 20%, 14%, 7% and 6% for Cambridgeshire, Essex, Humberside, Midlothian and Shropshire respectively. In 1993 lodging occurred at the Cambridgeshire. site (mean 24%) and the Humberside site (13.2%). Lodging was consistently most severe on the high nitrogen plots and the weaker strawed Pipkin was worse affected than Puffin. The effects of PGR treatments on lodging were quite variable although the Terpal and Cycocel/Terpal sequences gave the most consistent lodging control.

Figures 22 shows the extent of lodging at the Cambridgeshire site in 1991 where lodging was particularly severe, especially in Pipkin. The application of nitrogen produced an almost linear increase in lodging. Cycocel applied alone reduced lodging only slightly whereas the other PGR treatments gave significant control, but were less cost-effective to apply (Figures 29 -32). Both varieties lodged to a similar extent at 160 kg ha-1 of nitrogen fertiliser either untreated or with Cycocel. At lower nitrogen rates lodging was less in the Puffin and none existent at the nil nitrogen level. The introduction of Terpal into the PGR treatments produced significant reductions in lodging at all nitrogen rates in both varieties. In sequence with Cycocel, it almost completely prevented lodging in Puffin even at the highest nitrogen rate.

In 1991, without any PGR treatment, 94% of the crop area of Pipkin and 90% of the Puffin area lodged at 160 kg ha-1 nitrogen. Lodging in Puffin increased sharply from 35% at 120 kg ha-1 nitrogen. The economic benefits accruing from PGR use are reviewed in the discussion section.

In 1992 the pattern of lodging was variable if related to the increasing rates of nitrogen when viewed at all the five sites.(Figure 23) However when all sites are meaned and the impact of

nitrogen is shown for each of the PGR treatments (Figure 25) the effect of nitrogen is very clearly seen. The chlormequat only treatment having a very worthwhile effect on the variety Pipkin, but virtually no effect on the shorter stiffer Puffin. In 1993 the overall impact of nitrogen and PGR on lodging was similar, although the chlormequat treatment produced significant reductions in lodging in Puffin also.

The 1993 results were similar to those in 1991 (Figures 26-28). Large yield responses were associated with the Terpal and Cycocel/Terpal treatments both of which significantly reduced lodging at the Cambridgeshire and Humberside sites. Again chlormequat applied on its own was the least effective at controlling lodging and did not increase yield.

Fertile tiller production

Table 5. **Fertile tiller production :** F-test probability values for fertile tiller counts (tillers/m^2). Comparisons between all N rates, varieties, and the nil and Cycocel only PGR treatments

	Nitrogen	Variety	PGR
1991			
Essex	0.428	<0.001	0.530
Cambs.	<0.001	<0.001	0.964
Humberside	<0.001	<0.001	0.158
Shropshire	<0.001	<0.001	0.561
1992			
Essex	<0.001	0.075	0.700
Cambs.	0.501	0.086	0.127
Humberside	<0.001	<0.001	0.778
Shropshire	0.010	<0.001	0.423
1993			
Essex	<0.001	0.020	0.903
Cambs.	<0.001	0.002	0.396
Humberside	<0.001	<0.001	0.108
Shropshire			

PGR's had no significant effect on fertile tiller numbers in any of the three years.

Nitrogen consistently increased fertile tiller numbers except in 1991 at the Essex site, and in 1992 at the Cambridgeshire site. At the latter site in 1992, when SMN levels were 124 kg ha-

1, there were no significant differences in fertile tiller number resulting from either nitrogen use, variety choice or PGR programme. One consequence of high SMN levels, is that nitrogen is available to the crop from the start of the season leading to a vigorous early season vegetative growth, high tiller populations and well developed, lodging prone crops.

Grain size distribution

The percentages of grain in sieving groups >2.8 mm, 2.8 -2.5 mm, 2.5 - 2.2 mm, and < 2.2 mm are interlinked. Situations that encourage small grains decreased the proportion of large grains, and vice versa. Hence significant differences are to be found in all the size groups in their response at different sites and to the individual treatments, and to many of the two way interactions (Table 2). The one exception was the two smaller grain fractions were unaffected by PGR in 1993.

As expected, Pipkin had a higher percentage of small grains as a result of its genotype. This was consistently seen at all sites. Nitrogen increased the number of large grains, but this effect was most consistent over the increase from nil to 80 kg ha-1 nitrogen.

The effects of PGR's on the crop are very dependent on the growth stage of the crop and the weather at application. Responses, particularly to chlormequat products, tend to be variable. However a repeated effect, although not consistent, is for the treatments with chlormequat PGR (treatments 2 and 4) to produce a lower percentage of large grains. In 1991 the Midlothian site showed this effect in both varieties, while Puffin showed it to a lesser degree at more sites. In 1992 the effect was more widespread.

There is a large range of possible interactions between two varieties with different sized grain, sites with different SMN status and PGRs applied in a range of growing conditions and in different local climates. The scope of such variability is shown by the wide range of significant differences in table 2.

Part III

Micromalting tests

The results of the micromalting tests are shown in Appendix VIII. The traditional malting site

in Essex and the Cambridgeshire and Midlothian sites produced satisfactory samples each year when tested for germinative energy to micromalting evaluation. In 1992 the Humberside and Shropshire sites were not readily maltable, and the Humberside site also proved unsatisfactory in 1993. Further conditioning and treatment of these samples may have produced maltable grains, but they were discarded for the comparative purposes of this trial. In the samples that were malted there were more samples with fermentability of 70% or less in 1992 and 1993, than in 1991.

The hot water extract (HWE) from the two grist sizes 0.2 mm and 0.7 mm, produced slightly lower extract from coarser grist, but overall the C/F differences are very consistent between varieties and years and do not show any marked differences in modification; only the finer grist HWE results are given here. The full data is shown in Appendix VIII. Table 5 shows the correlation coefficients between HWE and both total nitrogen and total soluble nitrogen in the malted grain for both varieties at all sites.

Table 6: Correlation coefficients - Hot Water Extract (HWE) and total nitrogen (tn), total soluble nitrogen (tsn), and grain N%

	1991		1992		1993	
	Pipkin	Puffin	Pipkin	Puffin	Pipkin	Puffin
HWE:malt tn	-0.437	-0.887	-0.612	-0.691	-0.560	-0.764
HWE:malt tsn	-0.605	-0.724	-0.406	-0.722	-0.257	-0.365
HWE:grain N	-0.391	-0.787	-0.375	-0.478	-0.314	-0.583
	-0.517	-0.755	-0.586	-0.668	-0.363	-0.428

As the malting samples were pre-selected for low grain nitrogen (see method section) and were drawn largely from the 80 kg ha-1 nitrogen treatments, the very high correlations are to be expected. However all values show the negative correlation values expected between grain nitrogen and extract. Additionally, the correlation coefficients between HWE and malt tn were always higher than those between HWE and the original grain. All correlation values for the Puffin samples were slightly higher than the Pipkin values. These stronger negative values support the view that Puffin has a stronger developed protein matrix within the endosperm leading to greater reductions in modification and extract levels as grain N% increases.

Overall the analyses present a fairly typical data set. Again, this is to be expected given their

selection for suitability for malting. The PGR use has no effect on quality. The main effects on HWE are clearly site, and total grain nitrogen; the latter being an expression of various site characteristics. Figures 33 to 38 uses the data in Appendix VIII and shows how HWE declines as nitrogen content increases for both Pipkin and Puffin in each of the three years across all sites. However as the values are made up of sample groups from each trial site the regression equations and correlations represent extract prediction equations for low nitrogen grain grown largely with 80 kg ha-1 of applied nitrogen. The position of the site sample groups, although not entirely discrete, show a degree of separation that indicates different 'populations' at each site. As the ANOVA shows significant difference between sites is the most repeatable difference across all variates. It is note worthy that the sandy loam 'traditional' malting site in Essex was a consistently good site. The performance of this site was approached by the Midlothian site in 1991 when the crop was grown on a loam soil, and in 1993 by the Shropshire site when a sandy loam was available.

Figures 39 to 44 show how in each of the three years HWE declined with increasing nitrogen at the Essex, Cambridgeshire and Midlothian sites. Although the three annual data groups could be viewed as different populations, with different sowing dates, soils nitrogen and management, the correlation of the data from the sandy loam malting site in Essex showed higher correlation between grain nitrogen and HWE over the three seasons. The Essex data also showed a much steeper decline in HWE with increasing grain nitrogen; although the equations for the Essex site had higher intercept values, and much lower standard errors for the regression (table 7) . At the highest nitrogen levels the HWE from the Essex samples was 3-4 l°/kg higher than the other two sites. The total nitrogen levels in the Essex malt were between 0.07% and 0.35% lower than the other sites.

The main feature of the Cambridgeshire and the Midlothian sites that differed from the traditional malting site in Essex, was the clear split in the annual groupings. At the Cambridgeshire site the 1991 grouping, which produced usable malting grain was separate from the mixed 1992 and 1993 groupings. The Midlothian site produced grain where the HWE groupings clustered separately for each of the three years, with the 1991 crop grown on a loam soil having the lowest grain nitrogen levels and the higher HWE values. The variation in clustering again shows the variability between non-malting sites.

Table 7 Grain nitrogen/HWE regression - Standard errors

	Pipkin	Puffin
Essex	0.0860	0.0830
Cambs	0.1229	0.1280
Midlothian	0.1323	0.1307

The other data from the micromalting assessments in Appendix VIII show free ammonia nitrogen levels to be lowish, but this can be expected in micromalt evaluations, while pH levels are slightly high. The majority of soluble nitrogen ratios fall between the 36 - 42 range which would be acceptable for the lager to UK A malt markets.

DISCUSSION

The study has produced a wide array of data with many significant differences. This variation represents the problem facing the grower who wants to produce malting barley for the first time. What decisions should be taken, and which ones are the most critical in determining the acceptability of the grain to the maltster? This series of trials has aimed to help clarify the questions; Which site? Is a heavier soil suitable? If a heavy soil site can be used does it affect variety choice? Having selected the most suitable variety what scope is there in the management of nitrogen and growth regulators for assuring the quality criteria are met?

Site

Table 8 shows that grain nitrogen and the nitrogen in the malt have the largest percentage differences between the traditional malting site and the 'non-malting'. For both varieties nitrogen contents from the 'non-malting' sites were >10% higher than from the traditional malting site. Nitrogen is easily measured and is probably the main standard determining acceptability, once cleanliness, specific weight and physical soundness have been shown to be satisfactory.

The main quality parameter determined by processing is hot water extract. In contrast to the nitrogen the percentage differences are small between site type in both Pipkin and Puffin, (1.27% and 1.03% higher on the malting sites respectively). The higher the value the better the quality. Even smaller differences exist between the fermentability of grain from malting and other sites. Values of -0.02% and 0.51% for Pipkin and Puffin respectively, indicates fermentability was not markedly affected by site.

Differences between malting and non-malting sites in characteristics like viscosity and free ammonia nitrogen are lower than those for the nitrogen content, but greater than those for HWE and fermentability. The non-malting sites have the higher values. If the difference between components are low percentage values their impact on the malting value is lessened, but collectively if all values tend to show fractionally lower values the net effect is malting barley of slightly lower overall value. This appears to be the situation with malting barley from the 'non-malting' sites. However as individual data in the results section shows the problem is

as more one of variability rather than consistently poor quality; low nitrogen samples from Midlothian in 1991 and Shropshire in 1993 produced HWEs equal to those from the malting site.

Table 8 : Micromalt analyses: Traditional malting site and mean of four 'non-malting' sites for Pipkin and Puffin

Pipkin

	1991		1992		1993		3 yr mean		Malting as
	Malting	Non-malt	Malting	Non-malt	Malting	Non-malt	Malting	Non-malt	% Non-malt
Grain N% (DM)	1.37	1.46	1.43	1.72	1.33	1.49	1.38	1.56	-11.56
N% (malt)	1.28	1.43	1.3	1.64	1.35	1.45	1.31	1.51	-13.05
HWE (lo/kg)	313.3	309.6	313.6	309.5	312	308	312.97	309.03	1.27
SNR%	39	37.25	39.2	35.4	40.4	37.27	39.53	36.64	7.90
FAN(mg/l)	117	122.5	112.6	121.9	110	100	113.20	114.80	-1.39
Ferm (%)	79	78.67	78	77.3	75.4	76.47	77.47	77.48	-0.02
Visc (mPa)	1.53	1.57	1.52	1.65	1.53	1.61	1.53	1.61	-5.18
Friab (%)	91.67	86.5	94.4	81.3	66	81.67	84.02	83.16	1.04

Puffin

	1991		1992		1993		3 yr mean		Malting as
	Malting	Non-malt	Malting	Non-malt	Malting	Non-malt	Malting	Non-malt	% Non-malt
Grain N% (DM)	1.46	1.54	1.55	1.81	1.45	1.63	1.49	1.66	-10.44
N% (malt)	1.47	1.55	1.42	1.76	1.41	1.58	1.43	1.63	-12.07
HWE (lo/kg)	312.7	309.3	315	310.8	312.2	310.2	313.30	310.10	1.03
SNR%	38.67	38.5	41	37.6	42	39.87	40.56	38.66	4.92
FAN(mg/l)	120.67	129.5	131	129.1	104	110	118.56	122.87	-3.51
Ferm (%)	78	77.25	77.8	76.38	74	75	76.60	71.12	0.51
Visc (mPa)	1.54	1.59	1.56	1.67	1.54	1.62	1.55	1.63	-4.92
Friab (%)	86.33	82.67	90.6	74.65	81.4	79	86.11	76.27	9.31

The mean differences in the main quality parameters are low. Heavier textured soils can produce good quality malting grain. If soil mineral nitrogen supply to the crop is low, in dry seasons the higher AWC of heavier soils can be of benefit in producing low nitrogen grain (Garstang *et al* 1993). In contrast, as these trials show, heavier non-malting soils are more lodging prone unless adequate precautions are taken to control it. The risks and costs associated with the PGR programme are discussed below.

Variety choice

When this experiment was planned Pipkin was perceived as being a better malting variety than Puffin. Being longer established in the market may have helped in this. Also, as a variety with

very weak straw it was protected from over generous applications of nitrogen through the growers fears of lodging. Puffin in contrast was a stiff strawed malting variety, and had perhaps produced some samples offered for malting after generous nitrogen use. Since then the industry has seen the introduction of many strong strawed malting varieties with high HWEs (e.g. Fanfare, Regina, Gleam: NIAB 1998) and the reputation of malting barleys now no longer relies on weak straw to keep nitrogen use to acceptable levels.

Table 9: Micromalt analyses: Comparison of site differences and variety differences

	Difference between malting and other sites (Malting as % of other) within variety		Difference between varieties (Puffin as % of Pipkin) within sites	
	Pipkin Malting v Non-malt	Puffin Malting v Non-malt	Malting Puffin v Pipkin	Non-malt Puffin v Pipkin
Grain N% (DM)	-11.56	-10.44	7.99	6.64
N% (malt)	-13.05	-12.07	9.41	8.19
HWE (lo/kg)	1.27	1.03	0.11	0.35
SNR%	7.90	4.92	2.59	5.50
FAN(mg/l)	-1.39	-3.51	4.73	7.03
Ferm (%)	-0.02	0.51	-1.12	-1.64
Visc (mPa)	-5.18	-4.92	1.31	1.04
Friab (%)	1.04	9.31	2.48	-5.27

In table 9 the differences between malting and non-malting sites in columns 2 and 3 of the table, can be compared with the differences between varieties at the same sites in columns 4 and 5. Generally the differences between malting and non-malting site are larger than those between varieties. Nitrogen content, HWE , SNR and viscosity showed smaller differences between varieties than between sites. The nitrogen supplied by each site has been shown to vary considerably in these trials, being made up of the sum of applied nitrogen, mineralised nitrogen available at the start of the growing season, and additional nitrogen mineralised during the growing period. Given this variability it is not surprising that site effects are larger than variety effects for both nitrogen content and SNR. Similarly, with the strength of the relationships of grain nitrogen on HWE, (Bathgate 1987), it is again to be expected that site effects on HWE are larger than varietal differences.

From the above the selection of the site is more important in achieving premiums than, within obvious limits, the variety. The selection of a feed variety may have altered this assertion, but

no one would choose such a variety if malting barley production was their intention

High SMN resulted in high grain and malt total nitrogen such as at the Cambridgeshire site in 1992 (Puffin mean total N% 1.86). This trend was also linked with elevated free ammonia nitrogen levels. In contrast, where total nitrogen percentages were low, friability percentages tended to be increased, (correlation coefficient of -0.624). Friability percentages >90 were obtained in samples of Pipkin from Essex and Midlothian in 1991, Pipkin and Puffin from Essex and 1992, and Pipkin from Shropshire in 1993. Applying the converse of these findings, choice of variety becomes more important where higher nitrogen levels contribute to reduced friability or elevated FAN, but where grain nitrogen levels are low, and HWE levels are satisfactory both varieties in this trial produced similar samples.

Nitrogen

The responses to nitrogen shown in figures 1-3 are typical of many malting crops. The interactions of site x nitrogen and variety x nitrogen are clearly shown in the crossed response lines of the crops from the Cambridgeshire site. This arises largely as a result of the consistently higher nil N yield at the Cambridgeshire site for both varieties in all years. The impact of this site in reducing the malting reliability of varieties has been outlined above through its impact on total nitrogen contents and HWE. The reduced response shown in figures 1-3 also arises from the high N0 yields and lost yield due to lodging. Figures 22 - 28 show how severely lodging affected crops grown on the silty clay loam at the Cambridgeshire site. The figures in table 2 show an average spring SMN of 82 kg ha-1, to which must be added nitrogen mineralised during the period of March to the end of May, and the nitrogen applied as fertiliser. With total soil nitrogen reserves in silty clay loams and heavy clays ranging from 9.9 t ha-1 to 15.8 t ha-1, compared with 6.9 t ha-1 on sandy loams (Macdonald *et al* 1997), the scope for additional soil nitrogen supply is considerable. But in the equation $\log (N_o - N_t) = \log N_o - k/2.303(t)$ derived by Stanford and Smith (1972) time t, and k the mineralisation constant are the main determinants of N mineralisation, rather than N_o the potentially mineralisable N. Stanford, Frere and Schwaninger (1973) used the soil samples of Stanford and Smith to show that k, approximately doubled for each 10°C rise between 5 and 35°C, but did not differ significantly between soils. On this basis the total nitrogen supply available to these crops up to and including the grain fill period would be the variable SMNs shown in table 2,

the applied fertiliser, plus any nitrogen mineralised between the SMN sampling date and the cessation of uptake by the crop in June; only variation in local edaphic and climatic conditions would cause significant variation in the latter nitrogen source. However, temperature differences between the sites are insufficient to account for variation in grain nitrogen arising from this latter source. Indeed, Essex the most southerly and warmest site could have been expected to have high mineralisation rates. Under these circumstances it appears that managing rotations to reduce soil mineral nitrogen levels is the most important aspect of keeping grain nitrogen levels low.

Other aspects of crop management will have knock-on effects that reduce quality. If drought or inadequate disease control reduce the response to nitrogen, applied fertiliser may end up increasing grain N% in the reduced bulk of grain produced. Low yields at high nitrogen rates at the Cambridgeshire and Humberside sites in 1993 were associated with significantly higher N% than at other sites.

PGRs

The financial benefits from using PGRs varied between varieties. The three year average margin over cost for the three treatments are shown in Figures 29 -32. If grain fails to make malting premiums and sells for £70 t -1, only Pipkin grown on the Cambridgeshire boulder clay site produced a positive margin from all PGR treatments. The stiffer Puffin only showed a positive margin at four of the five sites with the cheap chlormequat treatment.

The use of PGRs should arguably be viewed as an insurance premium to reduce the risk of reduced saleability. In which case the negative values shown for PGR use on Puffin in Figure 31 represent 'insurance' premia of between approximately £10 and £25 per hectare. If they prevent lodging and the nitrogen levels meet market requirements, the majority of sites produce increases in margin. It is noteworthy that even at the Essex and Shropshire sites where losses were still shown from PGR use with grain at £85 t-1, the most expensive *and most effective* treatment produced an increase in margin. When grain prices are low profitable PGR use on stiff strawed varieties should be based on a cheap option like chlormequat; for weak strawed varieties on high yield potential 'strong' soils (eg Cambridgeshire) all PGR treatments are profitable. Where lodging risk is less likely chlormequat again becomes the best option.

If it is assumed a malting premium can be secured by PGR use and grain prices increases, the most consistent PGR treatment for increasing margins in both weak and stronger strawed varieties is sequence of chlormequat and Terpal. When prices obtained are high, and probably representative of malting premia weak strawed varieties tend to show a progressive increase in return as the efficacy (and cost) of the PGR programme increases. On stronger strawed varieties this trend differs in that the intermediate program of a single late season treatment (treatment No 3) is less cost effective than a single early season chlormequat treatment. The 'strong' Cambridgeshire boulder clay site was an exception and on such soils the response to PGR efficacy was akin to that obtained with weaker strawed varieties.

Risk and profit

The market pays premiums for low risk, reliable varieties. The results in Figure 45 show that traditional malting sites are more consistent at producing malting quality grain year on year, as judged by HWE. However, the 'non-malting' sites can produce equally good samples which should attract a malting premium, but less reliably on an annual basis. In such a situation the selection of a variety which reduces risk and increase the chance of attracting a premium is a sensible initial step. At the time the trial started, this would have entailed selecting Pipkin over Puffin if the market acceptability was taken as a guide, but Figure 45 shows Puffin be equally acceptable in 1992 and 1993 if HWE is the main selection criteria. With the pre-selected samples sent for micromalting, in these trials Pipkin had a 94% chance of successfully meeting these standards when later assessed on the micromalt analysis, while Puffin with higher nitrogen levels, ranked an 80% chance of acceptability. All failures arose as a result of high grain nitrogen in samples from the Cambridgeshire site. So after the risk has been minimised by selection of the best variety, risk can be further reduced by knowledge of the site's soil nitrogen status.

In addition to the selection of the correct variety, the use of a PGR progamme suitable for the likely lodging risk is a wise insurance against loss for the grower.

However, from a buyers point of view the main concern must be to avoid the risk of poorer quality when buying grain from non-malting sites. If there is a market requirement for such

material it should attract an appropriate premium, and provide this is acceptable to both grower and buyer, producing such grain from heavy non-malting sites will be worth while. Figures 46 - 48 show the margins from various premium regimes above feed barley prices of £70, £80 and £90 per tonne. The regimes are Pipkin or Puffin sold at :

1. All grain at all nitrogen rates from non-malting sites sold as feed - possibly the normal situation. (Other as feed)*
2. Grain from non-malting sites sold at a malting premium of 15% over feed. (Other as malt)*
3. The pricing regime for non-malting sites as the previous example, but with the premium at 20% over feed. (Other as malt 20%)*
4. The malting barley site selling at 20% over feed.

** Captions - figures 46 -48. Regimes 1-3 mean of all non-malting sites.*

The figures are based on the experiments production raised by 10% to anticipate the use of modern higher yielding varieties. The margin for all these sites is an approximation of a net margin derived from:

[Yield (t/ha) * £/t (include premium)] - [N input(kg/ha)* 30p/kg] - £650 per hectare

The £650 per hectare is a total cost of combined variable and fixed costs for mainly cereal farms (Nix 1999), excluding nitrogen. Under these regimes the range of margins is from -£218 ha -1 for feed Pipkin grown with 80 kg ha-1 N selling £70 per tonne, to £155 ha-1 from Puffin malting barley grown using 120 kg ha -1 from the malting site selling at a premium of 20%. While there are many other pricing regimes that could be applied, such an example serves to show a) that under the present low grain prices contribution to any profit is hard to achieve, b) even with grain at £90 premiums are essential for profit, c) feed barley needs yields above those obtained from malting levels of nitrogen to make a profit.

Arguably combining the yields of all the non-malting sites has reduced the overall yields levels of the 'Other' columns in the histograms, but such a reduction does allow the effects of losses from lodging and other heavier soil effects to be shown. However, even if the Essex malting site is used as an example of what may be achieved the three points in the paragraph above still apply.

CONCLUSION

This series of trials provides a definition of a malting site as one that can consistently produced good, profitable grain yields with low grain nitrogen. As we have shown non-malting sites can produce equally good samples on a less consistent basis. The concluding points below show what management decisions should be taken to reduce the risk of failing to meet market standards, and to increase the consistency.

- Select a variety that is a well established malting variety, with an established premium reputation. Newer varieties are best grown, initially at least, on the traditional malting sites. The choice of variety becomes more important where nitrogen levels may be high.

- Site characteristics have a greater effect on malting quality than variety, so use soil mineral nitrogen to, a) ensure your rotation has not excessively high SMN levels that will jeopardise malting premiums, and b) tailor nitrogen use to expected yield and soil nitrogen supply.

- Use a PGR programme that will prevent lodging. This will almost certainly involve PGR use at the late tillering/early stem extension growth stages, and again around flag leaf emergence.

- Recent changes in malting barley buying patterns gives the seller time to have the grain nitrogen independently tested. This trial series show that with the correct management more grain than hitherto sold for malting may attract premiums.

- If grain is dried and stored on farm prior to sale care must be taken to maintain germinative energy, and avoid heat damage during drying or storage

As the weather, soil moisture status and consequent nitrogen fluxes into and within the plant are beyond the growers control during the critical grain filling period the risk of failure to meet the quality standards remains.

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Site and Husbandry details (1990/91)

	Essex	Cambs.	Humberside	Midlothian	Shropshire
Soil type	Sandy loam	Silty clay loam	Sandy clay loam	Loam	Sandy silt loam
pH	7.7	8.35	6.9	6.7	6.6
P:K indices	5:2	4:3	3:2	24:98 [mg/kg]	2:2
Previous cropping					
1990	Winter Barley	Winter Wheat	Winter Wheat	Winter Wheat	Winter Barley
1989	Winter Wheat	Winter Wheat	Sugar Beet	Winter wheat	Winter Barley
1988	Spring Barley	Oilseed Rape	Winter Wheat	Potatoes	Winter Barley
Cultivations	Plough & press Spring tine Drill	Burn 2 cultivations Roterra Drill	Plough Power harrowx2 Drill	Plough Cultivate Drill	Plough Power harrow Drill
Sowing date	5 Oct 1990	9 Oct 1990	26 Sept 1990	13 Sept 1990	10 Sept 1990
Harvest date	3 August 1991	29 July 1991	1 August 1991	5 August 1991	8 August 1991
Basal Fertiliser (& Trace elements)	20 Nov 1990 250 kgha-1 0:24:24 +125 kgha-1 Muriate of K	15 March 1991 90 kgha-1 46% superphosphate	5 Dec 1990 0:62:94 kgha-1	23 Oct 1990 0:80:80 kgha-1 25 March 1991 10 lha-1 Cutonic Manganese	15 Nov 1990 0:75:75 kgha-1
Fungicide	29 March 1991 0.9 lha-1 Sportak 45	23 April 1991 0.45lha-1 PunchC + 0.65lha-1 Corbel 20 May 1991 0.5lha-1 Punch C	30 March 1991 0.5lha-1 Tilt Turbo	5 Nov 1990 0.5lha-1 Tilt 25 March 1991 0.5 lha-1 Mistral 22 April 1991 1.5 lha-1 Sportak Alpha+ 0.7 lha-1 Bavisitin 23 May 1991 1.0 lha-1 Tilt Turbo	14 April 1991 0.3lha-1 Corbel + 0.17kgha-1 Stempor 6 June 1991 0.3 lha-1 Corbel
Herbicide	2 Nov 1990 1.5 lha-1 Javelin +3.5 lha-1 Hytane	29 Nov 1990 5 lha-1 Javelin Gold	23 Oct 1990 5lha-1 Isotop IPU 30 March 1991 1.0 lha-1 Briotril Plus	23 Oct 1990 2.0 lha-1 Panther	22 Oct 1990 1.0lha-1 Panther 9 April 1991 15gha-1 Ally
Insecticide	2 Nov 1990 (as TM) 250 mlha-1 Cypermethrin	29 Nov 1990 (as TM) 200 mlha-1 Cypermethrin	23 Oct 1990 (as TM) 0.25lha-1 Decis	N/A	22 Oct 1990 (as TM) 0.1lha-1 Decis

Site and Husbandry details (1991/92)

	Essex	Cambs.	Humberside	Midlothian	Shropshire
Soil type	Sandy loam	Silty clay loam	Sandy clay loam	Clay loam	Sandy silt loam
pH	7.1	8.35	6.9	5.7	6.6
P:K indices	5:1	4:3	3:2	5:3	2:2
Previous cropping					
1991	Kale (Seed)	Winter Wheat	Winter Wheat	Winter Barley	Winter Barley
1990	Winter Barley	Peas	Sugar Beet	Winter Wheat	Winter Barley
1989	Winter Wheat	Winter Wheat	Winter Wheat	Winter Wheat	Winter Barley
Cultivations	Plough & press Spring tine Drill	Plough, Disc Roterra Drill	Plough Power harrow Drill		Plough & press Power harrow Drill
Sowing date	23 Sept 1991	8 Oct 1991	27 Sept 1991	27 Sept 1991	10 Sept 1991
Harvest date	28 July 1992	29 July 1992	18 July 1992	14 August 1992	28 July 1992
Basal Fertiliser	N as trail - only	N as trail - only	3 Dec 1991 0:73.5:113 kgha-1	23 Oct 1991 0:70:70 kgha-1	14 Oct1991 0:59:59 kgha-1
Fungicide	23 March 1992 0.9 lha-1 Sportak 45 + 0.5lha-1 Corbel 19 May 1992 1.0 lha-1 Tilt-Turbo	13 May 1992 1.0lha-1 Dorin + 1.4lha-1 Impact Excel 12 June 1992 3.25 lha-1 MultiW +0.4lha-1 Calixin	5 April 1992 0.6lha-1 PunchC	5 March 1992 1.0lha-1 Tilt-Turbo 8 April 1992 0.5lha-1 Corbel+ 0.25kgha-1 Bavistin 4 May 1992 0.75lha-1 Sportak Alpha + 0.5 lha-1 Corbel 20 May 1992 1.0lha-1 Tilt-Turbo	9 April 1992 0.5lha-1 Corbel + 0.25kgha-1 Stempor 21 May 1992 0.35 lha-1 Corbel +0.49 kgha-1 Stempor
Herbicide	11Nov 1991 1.5 lha-1 Javelin +3.5 lha-1 Hytane 10 Feb 1992 0.6lha-1 Duplosan	27 Nov 1991 2 lha-1 Panther 21 March 3.0lha-1 Cheetah	14 Nov 1991 5lha-1 Isotop IPU 5 April 1992 1.5 lha-1 Briotril Plus + 1.5lha-1 Optica	28 Oct 1991 2.0lha-1 Panther	21 Oct 1991 1.0lha-1 Panther 9 April 1992 0.74lha-1 MCPA 16 July 1992 1.6 lha-1 Roundup
Insecticide (& molluscicide)	11Nov 1991 (as TM) 250 mlha-1 Cypermethrin	27 Nov 1991 (as TM) 200 mlha-1 Cypermethrin	14 Nov 1991 (as TM) 0.25lha-1 Toppel	17 Oct 1991 5kgha-1 Draza 3kha-1 Draza on 23 Oct, 18 Nov, & 29 Nov 1991	Nil

Site and Husbandry details (1992/93)

	Site				
	Essex	Cambs.	Humberside	Midlothian	Shropshire
Soil type	Sandy loam	Sandy clay loam	Sandy clay loam	Clay loam	Sandy loam
pH	7.6	8.1	7.8	5.7	7.4
P:K indices	4:2	4:2	2:1	2:2	3:2
Previous cropping					
1992	Winter Barley	Winter Barley	Winter Wheat	Winter Barley	Winter Barley
1991	Kale (Seed)	Oilseed Rape	Oilseed Rape	Winter Wheat	Winter Barley
1990	Winter Barley	Winter Barley	Winter Wheat	Winter Wheat	Winter Barley
Cultivations	Plough & roll Spring tine Drill	Plough, Power harrow Drill	Plough Power harrow Drill	Plough Power harrowx2 Drill	Plough & press Power harrow Drill
Sowing date	7 Oct 1992	7 Oct 1992	9 Oct 1992	9 Oct 1992	24 Sept 1992
Harvest date	23 July 1993	2 August 1993	8 August 1993	27 August 1993	3 August 1993
Basal Fertiliser	N as trail - only	N as trail - only	N as trail - only	15 Oct 1992 0:60:60 kgha-1	12 Oct 1992 0:67:88 kgha-1
Fungicide	15 March 1993 0.8 lha-1 PunchC+ 0.5lha-1 Corbel 15 May 1993 1.0 lha-1 Tilt-Turbo	13 March 1993 1.0lha-1 Glint 23 May 1993 4 lha-1 Cosmic	2 April 1993 0.6lha-1 PunchC + 0.3lha-1 Fusion 3 June 1993 1.0lha-1 Fenpropmph.+ tridemorph	26 March 1993 1.0lha-1 Corbel +0.625 lha-1 PunchC 28 April 1993 1.5lha-1 Sportak Alpha+Mistral 24 May 1993 1.0lha-1 Tilt-Turbo	10 April 1993 BAS46402F 0.49lha-1+ 0.5lha-1 Benlate 19 May 1993 0.5 lha-1 Delsene50+ BAS46402F 0.333lha-1+ 0.17lha-1 Tilt
Herbicide	15Nov 1992 5 lha-1 Javelin Gold	6 March 1993 2lha-1 Panther 22 April 1993 1.0lha-1 Starane			4 Nov 1992 0.5lha-1 Panther+ 1.5lha-1 IPU 13 April 1992 1.0lha-1 Asset+ 15gha-1 Ally
Insecticide (& molluscicide)	15Nov 1992 (as TM) 250 mlha-1 Cypermethrin	14 Oct 1992 5.5 kgha-1 Draza	2 Feb 1993 250 mlha-1 Ambush 3 June 210mlha-1 D-s-m	9 Oct 1992 3kgha-1 Draza with seed 10 Oct 1992 3 kgha-1 Draza	4 Nov 1992 (as TM) 0.26lha-1 Cyperkill

Grain Yield (t/ha - 85% DM) - 1991

Malting site and heavy sites

	PIPKIN					PUFFIN					
	Nitrogen rate (kg/ha)										Site
	0	80	120	160	Mean	0	80	120	160	Mean	Mean
Essex	3.89	6.43	7.06	7.41	6.20	3.90	6.28	7.06	7.48	6.18	6.19
Cambs	5.52	6.44	6.59	6.74	6.32	5.53	6.86	7.42	7.47	6.82	6.57
Humberside	3.69	5.97	6.55	7.00	5.80	4.19	6.21	6.99	7.46	6.21	6.01
Midlothian	4.43	6.59	7.26	7.78	6.52	4.34	6.59	7.40	7.90	6.56	6.54
Shropshire	2.96	4.86	5.73	6.33	4.97	2.81	4.91	5.67	6.39	4.95	4.96
Mean	4.10	6.06	6.64	7.05	5.96	4.15	6.17	6.91	7.34	6.14	6.05

	Growth Regulator treatment (Nos. as method)									
	1	2	3	4		1	2	3	4	
Essex	6.09	6.13	6.31	6.26	6.20	6.09	6.19	6.10	6.35	6.18
Cambs	5.82	6.04	6.70	6.73	6.32	6.57	6.72	6.90	7.08	6.82
Humberside	5.72	5.79	5.77	5.94	5.81	5.99	6.44	6.15	6.26	6.21
Midlothian	6.20	6.62	6.49	6.72	6.51	6.44	6.66	6.52	6.61	6.56
Shropshire	5.00	5.05	4.82	4.99	4.97	4.93	4.96	4.91	4.98	4.95
Mean	5.77	5.93	6.02	6.13	5.96	6.00	6.19	6.12	6.26	6.14

	Growth Regulator treatment (Nos. as method)									
	1	2	3	4		1	2	3	4	
Nitrogen (kg/ha)										
0	4.05	4.12	4.10	4.12	4.10	4.03	4.33	4.03	4.22	4.15
80	5.74	6.05	6.18	6.27	6.06	6.09	6.17	6.13	6.30	6.17
120	6.46	6.49	6.75	6.84	6.64	6.68	6.92	6.95	7.08	6.91
160	6.85	7.04	7.04	7.29	7.06	7.23	7.35	7.35	7.43	7.34
Mean	5.78	5.93	6.02	6.13	5.96	6.01	6.19	6.12	6.26	6.14

SED's

Site	0.102	SxV	0.111	SxVxN	0.155
Variety	0.028	SxN	0.128	SxVxPGR	0.155
Nitrogen	0.04	VxN	0.056	SxNxPGR	0.199
PGR	0.04	SxPGR	0.128	VxNxPGR	0.112
		VxPGR	0.056		
		NxPGR	0.079		

Grain Yield (t/ha - 85% DM)-1992

Malting site and heavy sites

	PIPKIN					PUFFIN					
	Nitrogen rate (kg/ha)										Site
	0	80	120	160	Mean	0	80	120	160	Mean	Mean
Essex	3.72	6.69	6.76	6.90	6.02	3.86	6.85	7.16	7.23	6.28	6.15
Cambs	6.34	6.57	6.33	6.07	6.33	6.30	7.29	7.40	7.42	7.10	6.71
Humberside	4.22	5.80	6.07	6.23	5.58	4.33	5.81	6.29	6.47	5.73	5.65
Midlothian	5.55	7.31	7.56	7.57	7.00	5.91	7.78	8.14	8.60	7.61	7.30
Shropshire	4.17	5.40	5.82	6.25	5.41	4.74	5.98	6.37	7.01	6.03	5.72
Mean	4.80	6.35	6.51	6.60	6.07	5.03	6.74	7.07	7.35	6.55	6.31

	Growth Regulator treatment (Nos. as method)									
	1	2	3	4		1	2	3	4	
Essex	5.98	6.07	5.89	6.13	6.02	5.99	6.54	6.12	6.45	6.28
Cambs	5.84	6.57	6.28	6.62	6.33	7.02	7.14	7.10	7.14	7.10
Humberside	5.69	5.55	5.62	5.46	5.58	5.69	5.87	5.61	5.73	5.73
Midlothian	6.73	6.95	7.14	7.18	7.00	7.61	7.63	7.68	7.52	7.61
Shropshire	5.24	5.30	5.49	5.61	5.41	5.99	5.99	5.95	6.18	6.03
Mean	5.90	6.09	6.08	6.20	6.07	6.46	6.63	6.49	6.60	6.55

	Growth Regulator treatment (Nos. as method)									
	1	2	3	4		1	2	3	4	
Nitrogen (kg/ha)										
0	4.75	4.74	4.92	4.79	4.80	4.88	5.04	5.14	5.04	5.03
80	6.10	6.35	6.35	6.61	6.35	6.63	6.79	6.71	6.84	6.74
120	6.31	6.59	6.47	6.67	6.51	7.17	7.11	6.92	7.09	7.07
160	6.42	6.68	6.59	6.73	6.61	7.17	7.59	7.19	7.44	7.35
Mean	5.90	6.09	6.08	6.20	6.07	6.46	6.63	6.49	6.60	6.55

SED's

Site	0.215	SxV	0.223	SxVxN	0.261
Variety	0.035	SxN	0.236	SxVxPGR	0.261
Nitrogen	0.05	VxN	0.071	SxNxPGR	0.305
PGR	0.05	SxPGR	0.236	VxNxPGR	0.141
		VxPGR	0.071		
		NxPGR	0.1		

Grain Yield (t/ha - 85% DM)-1993

Malting site and heavy sites

	PIPKIN					PUFFIN					
	Nitrogen rate (kg/ha)										Site
	0	80	120	160	Mean	0	80	120	160	Mean	Mean
Essex	3.82	6.08	6.67	7.00	5.89	3.77	6.17	7.02	7.33	6.07	5.98
Cambs	5.18	5.83	5.92	5.70	5.66	5.55	6.57	6.55	6.52	6.30	5.98
Humberside	4.43	5.62	5.77	5.83	5.41	4.39	5.72	6.09	6.13	5.58	5.5
Midlothian	3.24	5.68	6.06	6.56	5.39	3.12	5.19	5.56	6.37	5.06	5.22
Shropshire	2.63	4.87	5.62	6.22	4.84	2.82	5.00	5.77	6.48	5.02	4.93
Mean	3.86	5.62	6.01	6.26	5.44	3.93	5.73	6.20	6.57	5.61	5.52

	Growth Regulator treatment (Nos. as method)									
	1	2	3	4		1	2	3	4	
Essex	5.76	5.80	5.96	6.04	5.89	6.10	6.10	5.99	6.11	6.08
Cambs	5.35	5.42	5.85	6.02	5.66	6.05	6.03	6.53	6.58	6.30
Humberside	5.12	5.30	5.56	5.68	5.42	5.37	5.47	5.69	5.81	5.59
Midlothian	5.28	5.45	5.46	5.35	5.39	4.92	5.16	5.01	5.15	5.06
Shropshire	4.68	4.92	4.80	4.95	4.84	5.02	5.03	4.96	5.07	5.02
Mean	5.24	5.38	5.53	5.61	5.44	5.49	5.56	5.64	5.74	5.61

	Growth Regulator treatment (Nos. as method)									
	1	2	3	4		1	2	3	4	
Nitrogen (kg/ha)										
0	3.73	3.78	3.90	4.02	3.86	3.90	3.89	3.94	3.99	3.93
80	5.37	5.64	5.69	5.76	5.62	5.68	5.58	5.72	5.95	5.73
120	5.86	5.89	6.11	6.18	6.01	6.07	6.19	6.25	6.28	6.20
160	6.00	6.19	6.40	6.47	6.27	6.32	6.58	6.63	6.76	6.57
Mean	5.24	5.38	5.53	5.61	5.44	5.49	5.56	5.64	5.75	5.61

SED's

Site	0.183	SxV	0.187	SxVxN	0.214
Variety	0.027	SxN	0.197	SxVxPGR	0.214
Nitrogen	0.038	VxN	0.053	SxNxPGR	0.245
PGR	0.038	SxPGR	0.197	VxNxPGR	0.107
		VxPGR	0.053		
		NxPGR	0.075		

Specific Weight (kg/hl) - 1991

Malting site and heavy sites

	PIPKIN					PUFFIN					
	Nitrogen rate (kg/ha)										Site
	0	80	120	160	Mean	0	80	120	160	Mean	Mean
Essex	69.93	71.72	71.98	72.02	71.41	69.70	70.80	71.55	72.04	71.02	71.22
Cambs	71.27	71.62	71.72	70.54	71.29	72.07	73.07	72.79	72.61	72.64	71.96
Humberside	71.02	72.22	72.18	71.88	71.83	70.12	70.95	70.87	69.97	70.48	71.15
Midlothian	69.73	71.55	72.45	72.55	71.57	68.75	69.95	71.53	71.36	70.40	70.98
Shropshire	60.77	63.29	64.59	64.46	63.28	57.97	60.88	62.83	63.47	61.29	62.28
Mean	68.54	70.08	70.58	70.29	69.87	67.72	69.13	69.91	69.89	69.16	69.52

	Growth Regulator treatment (Nos. as method)									
	1	2	3	4		1	2	3	4	
Essex	71.31	71.79	71.27	71.29	71.42	71.16	70.86	71.34	70.73	71.02
Cambs	71.29	71.37	70.30	72.18	71.29	72.33	72.55	72.58	73.07	72.63
Humberside	72.39	71.97	71.67	71.28	71.83	70.77	70.69	70.40	70.05	70.48
Midlothian	72.19	71.27	71.83	70.98	71.57	70.53	70.62	70.39	70.04	70.40
Shropshire	64.14	63.96	62.51	62.50	63.28	61.51	61.85	61.13	60.67	61.29
Mean	70.26	70.07	69.52	69.65	69.87	69.26	69.31	69.17	68.91	69.16

	Growth Regulator treatment (Nos. as method)									
	1	2	3	4		1	2	3	4	
Nitrogen (kg/ha)										
0	69.08	69.03	68.31	67.75	68.54	67.85	67.93	67.82	67.28	67.72
80	70.17	70.18	70.13	69.83	70.08	69.39	69.28	68.86	68.99	69.13
120	70.81	70.70	70.27	70.56	70.59	69.81	70.15	69.85	69.86	69.92
160	70.97	70.37	69.36	70.47	70.29	69.99	69.90	70.15	69.51	69.89
Mean	70.26	70.07	69.52	69.65	69.87	69.26	69.32	69.17	68.91	69.16

SED's

Site	0.379	SxV	0.409	SxVxN	0.555
Variety	0.097	SxN	0.463	SxVxPGR	0.555
Nitrogen	0.137	VxN	0.193	SxNxPGR	0.703
PGR	0.137	SxPGR	0.463	VxNxPGR	0.387
		VxPGR	0.193		
		NxPGR	0.274		

Specific Weight (kg/hl) 1992

Malting site and heavy sites

	PIPKIN					PUFFIN					
	Nitrogen rate (kg/ha)										Site
	0	80	120	160	Mean	0	80	120	160	Mean	Mean
Essex	69.58	70.78	70.82	70.88	70.52	68.33	70.27	70.98	71.39	70.24	70.38
Cambs	70.65	70.50	70.68	70.02	70.46	71.70	72.35	72.52	72.38	72.24	71.35
Humberside	62.68	65.19	65.63	66.13	64.91	63.11	64.74	65.18	64.80	64.46	64.68
Midlothian	72.01	72.49	72.35	72.97	72.46	70.40	71.37	71.92	71.94	71.41	71.93
Shropshire	60.54	62.00	61.86	62.16	61.64	62.74	63.48	63.77	62.66	63.16	62.40
Mean	67.09	68.19	68.27	68.43	68.00	67.26	68.44	68.87	68.63	68.30	68.15

	Growth Regulator treatment (Nos. as method)									
	1	2	3	4		1	2	3	4	
Essex	70.77	70.27	70.82	70.22	70.52	70.18	70.47	70.28	70.03	70.24
Cambs	70.22	70.28	70.93	70.42	70.46	72.37	72.39	72.03	72.15	72.24
Humberside	65.14	65.00	65.12	64.36	64.91	65.06	64.76	64.68	63.33	64.46
Midlothian	72.40	72.15	72.54	72.74	72.46	71.44	71.65	71.42	71.12	71.41
Shropshire	61.98	61.74	61.47	61.36	61.64	64.13	63.86	62.48	62.19	63.17
Mean	68.10	67.89	68.18	67.82	68.00	68.64	68.63	68.18	67.76	68.30

	Growth Regulator treatment (Nos. as method)									
	1	2	3	4		1	2	3	4	
Nitrogen (kg/ha)										
0	67.23	67.28	67.23	66.63	67.09	67.74	67.85	67.09	66.33	67.25
80	68.38	68.29	68.21	67.89	68.19	68.69	68.53	68.66	67.90	68.45
120	68.34	67.86	68.65	68.22	68.27	69.10	69.00	68.73	68.66	68.87
160	68.45	68.12	68.62	68.53	68.43	69.01	69.11	68.24	68.18	68.64
Mean	68.10	67.89	68.18	67.82	68.00	68.64	68.62	68.18	67.77	68.30

SED's

Site	0.427	SxV	0.456	SxVxN	0.599	
Variety	0.101	SxN	0.508	SxVxPGR	0.599	
Nitrogen	0.142	VxN	0.201	SxNxPGR	0.749	
PGR	0.142	SxPGR	0.508	VxNxPGR	0.402	
		VxPGR	0.201			
		NxPGR	0.284			

Specific Weight (kg/hl) 1993

Malting site and heavy sites

	PIPKIN					PUFFIN					
	Nitrogen rate (kg/ha)										Site
	0	80	120	160	Mean	0	80	120	160	Mean	Mean
Essex	72.77	74.15	74.67	75.26	74.21	72.97	73.43	73.06	72.86	73.08	73.65
Cambs	73.18	73.60	72.84	72.75	73.09	72.62	72.99	73.46	73.27	73.09	73.09
Humberside	66.11	66.52	65.62	64.89	65.79	66.72	67.03	65.23	64.91	65.97	65.88
Midlothian					-					-	
Shropshire	76.40	79.67	81.27	81.54	79.72	79.92	80.00	79.96	79.63	79.88	79.80
Mean	72.12	73.49	73.60	73.61	73.20	73.06	73.36	72.93	72.67	73.00	73.11

	Growth Regulator treatment (Nos. as method)									
	1	2	3	4		1	2	3	4	
Essex	74.52	74.74	73.36	74.24	74.22	72.97	73.43	73.06	72.86	73.08
Cambs	73.07	73.11	72.87	73.32	73.09	72.62	72.99	73.46	73.27	73.09
Humberside	66.44	66.27	65.41	65.02	65.79	66.72	67.03	65.23	64.21	65.80
Midlothian					0.00					0.00
Shropshire	79.80	79.92	79.43	79.74	79.72	79.92	80.00	79.96	79.63	79.88
Mean	73.46	73.51	72.77	73.08	73.20	73.06	73.36	72.93	72.49	72.96

	Growth Regulator treatment (Nos. as method)									
	1	2	3	4		1	2	3	4	
Nitrogen (kg/ha)										
0	72.93	72.42	71.28	71.84	72.12	72.58	72.77	72.02	71.28	72.16
80	73.33	73.75	73.07	73.79	73.49	73.13	73.47	72.90	72.84	73.09
120	73.71	74.06	73.37	73.27	73.60	73.24	73.42	73.15	73.16	73.24
160	73.86	73.82	73.34	73.42	73.61	73.28	73.80	73.64	73.40	73.53
Mean	73.46	73.51	72.77	73.08	73.20	73.06	73.37	72.93	72.67	73.01

SED's

Site	0.427	SxV	0.449	SxVxN	0.564	
Variety	0.099	SxN	0.491	SxVxPGR	0.564	
Nitrogen	0.139	VxN	0.197	SxNxPGR	0.689	
PGR	0.139	SxPGR	0.491	VxNxPGR	0.394	
		VxPGR	0.197			
		NxPGR	0.279			

Thousand Grain Weight (gm) - 1991

Malting site and heavy sites

	PIPKIN					PUFFIN					
	Nitrogen rate (kg/ha)										Site
	0	80	120	160	Mean	0	80	120	160	Mean	Mean
Essex	39.59	40.40	39.87	40.02	39.97	44.40	46.15	45.35	45.18	45.27	42.62
Cambs	36.07	35.32	34.02	35.21	35.16	42.70	41.50	40.69	40.64	41.38	38.27
Humberside	38.87	41.49	41.70	41.87	40.98	45.60	46.99	46.26	46.03	46.22	43.61
Midlothian	32.43	34.52	35.77	36.34	34.77	38.50	39.45	41.37	41.30	40.16	37.46
Shropshire	28.45	32.43	34.12	33.88	32.22	30.07	33.49	35.39	36.95	33.98	33.10
Mean	35.08	36.83	37.10	37.46	36.62	40.25	41.52	41.81	42.02	41.40	39.01

	Growth Regulator treatment (Nos. as method)								
	1	2	3	4		1	2	3	4	
Essex	40.31	40.41	39.43	39.73	39.97	45.15	43.57	46.42	45.94	45.27
Cambs	34.98	33.74	34.96	36.94	35.16	43.03	40.34	41.83	40.33	41.38
Humberside	41.73	41.02	40.53	40.67	40.99	47.01	46.61	45.81	45.46	46.22
Midlothian	35.17	34.52	34.82	34.54	34.76	40.78	40.63	39.52	39.69	40.16
Shropshire	32.92	33.26	31.27	31.42	32.22	34.91	34.72	33.37	32.90	33.98
Mean	37.02	36.59	36.20	36.66	36.62	42.18	41.17	41.39	40.86	41.40

	Growth Regulator treatment (Nos. as method)								
	1	2	3	4		1	2	3	4	
Nitrogen (kg/ha)										
0	35.63	35.24	34.51	34.95	35.08	41.01	40.05	40.40	39.56	40.26
80	37.32	36.65	36.92	36.44	36.83	42.07	41.60	41.16	41.24	41.52
120	37.45	36.95	36.61	37.37	37.10	43.13	41.04	42.12	40.97	41.82
160	37.68	37.52	36.78	37.88	37.47	42.50	42.02	41.87	41.70	42.02
Mean	37.02	36.59	36.21	36.66	36.62	42.18	41.18	41.39	40.87	41.40

SED's

Site	0.332	SxV	0.418	SxVxN	0.751
Variety	0.161	SxN	0.552	SxVxPGR	0.751
Nitrogen	0.228	VxN	0.322	SxNxPGR	1.041
PGR	0.228	SxPGR	0.552	VxNxPGR	0.644
		VxPGR	0.322		
		NxPGR	0.456		

The above interaction SED's are applicable except when some comparisons have the same factor level

Thousand Grain Weight (gm) 1992

Malting site and heavy sites

	PIPKIN					PUFFIN					
	Nitrogen rate (kg/ha)										Site
	0	80	120	160	Mean	0	80	120	160	Mean	Mean
Essex	33.92	35.16	35.23	34.29	34.65	39.20	41.52	38.88	38.38	39.50	37.07
Cambs	35.70	34.23	32.19	32.93	33.76	41.62	41.69	42.46	39.54	41.33	37.55
Humberside	37.58	40.12	40.61	41.12	39.86	45.37	45.84	46.09	46.25	45.89	42.87
Midlothian	38.73	36.78	37.89	37.14	37.64	44.15	46.43	46.22	46.59	45.85	41.74
Shropshire	28.52	28.33	28.69	28.64	28.55	34.95	35.51	34.07	35.08	34.90	31.73
Mean	34.89	34.92	34.92	34.82	34.89	41.06	42.20	41.54	41.17	41.49	38.19

	Growth Regulator treatment (Nos. as method)									
	1	2	3	4		1	2	3	4	
Essex	34.73	34.37	36.14	33.35	34.65	39.00	39.40	40.99	38.59	39.50
Cambs	33.63	33.74	33.48	34.20	33.76	41.66	41.47	41.43	40.75	41.33
Humberside	40.25	39.82	40.17	39.17	39.85	46.77	46.78	45.37	44.62	45.89
Midlothian	37.72	37.31	37.51	38.01	37.64	46.36	46.86	43.98	46.19	45.85
Shropshire	29.02	28.45	28.54	28.18	28.55	35.44	35.24	34.77	34.17	34.91
Mean	35.07	34.74	35.17	34.58	34.89	41.85	41.95	41.31	40.86	41.49

	Growth Regulator treatment (Nos. as method)									
	1	2	3	4		1	2	3	4	
Nitrogen (kg/ha)										
0	35.14	34.96	35.35	34.12	34.89	41.20	41.45	41.12	40.46	41.06
80	35.24	35.04	34.45	34.96	34.92	42.88	42.71	41.27	41.93	42.20
120	35.27	34.65	34.60	35.16	34.92	41.39	42.40	41.35	41.04	41.55
160	34.63	34.30	36.28	34.09	34.83	41.92	41.25	41.48	40.03	41.17
Mean	35.07	34.74	35.17	34.58	34.89	41.85	41.95	41.31	40.87	41.49

SED's

Site	0.583	SxV	0.655	SxVxN	0.982	
Variety	0.189	SxN	0.779	SxVxPGR	0.982	
Nitrogen	0.267	VxN	0.378	SxNxPGR	1.295	
PGR	0.267	SxPGR	0.779	VxNxPGR	0.755	
		VxPGR	0.378			
		NxPGR	0.534			

Thousand Grain Weight (gm) 1993

Malting site and heavy sites

	PIPKIN					PUFFIN					
	Nitrogen rate (kg/ha)										Site
	0	80	120	160	Mean	0	80	120	160	Mean	Mean
Essex	34.81	36.53	37.16	37.09	36.40	39.74	41.31	41.67	41.91	41.16	38.78
Cambs	38.74	38.45	38.63	36.61	38.11	45.94	46.24	45.35	43.76	45.32	41.71
Humberside	42.25	40.33	40.32	39.58	40.62	49.14	47.02	47.52	46.00	47.42	44.02
Midlothian					0.00					0.00	
Shropshire	31.80	34.69	35.12	35.08	34.17	38.58	41.52	40.80	41.72	40.66	37.41
Mean	36.90	37.50	37.81	37.09	37.32	43.35	44.02	43.84	43.35	43.64	40.48

	Growth Regulator treatment (Nos. as method)									
	1	2	3	4		1	2	3	4	
Essex	36.75	36.31	36.44	36.09	36.40	41.83	41.90	41.02	39.88	41.16
Cambs	38.28	37.85	38.55	37.74	38.11	44.94	43.80	46.35	46.20	45.32
Humberside	41.72	41.11	39.72	39.93	40.62	49.87	47.59	46.15	46.08	47.42
Midlothian					0.00					0.00
Shropshire	33.77	34.16	34.26	34.50	34.17	41.14	40.92	40.22	40.35	40.66
Mean	37.63	37.36	37.24	37.07	37.32	44.45	43.55	43.44	43.13	43.64

	Growth Regulator treatment (Nos. as method)									
	1	2	3	4		1	2	3	4	
Nitrogen (kg/ha)										
0	37.57	36.91	36.81	36.31	36.90	44.78	43.87	42.17	42.58	43.35
80	37.62	37.59	37.27	37.52	37.50	44.92	43.26	44.06	43.85	44.02
120	37.96	37.69	38.07	37.50	37.81	45.25	43.62	43.78	42.70	43.84
160	37.37	37.24	36.82	36.93	37.09	42.82	43.46	43.73	43.38	43.35
Mean	37.63	37.36	37.24	37.07	37.32	44.44	43.55	43.44	43.13	43.64

SED's

Site	0.32	SxV	0.405	SxVxN	0.729
Variety	0.175	SxN	0.535	SxVxPGR	0.729
Nitrogen	0.248	VxN	0.35	SxNxPGR	1.011
PGR	0.248	SxPGR	0.535	VxNxPGR	0.7
		VxPGR	0.35		
		NxPGR	0.495		

Grain nitrogen content -N% in DM - 1991

Malting site and heavy sites

	PIPKIN					PUFFIN					
	Nitrogen rate (kg/ha)										Site
	0	80	120	160	Mean	0	80	120	160	Mean	Mean
Essex	1.37	1.37	1.50	1.66	1.48	1.39	1.46	1.57	1.75	1.54	1.51
Cambs	1.28	1.49	1.67	1.76	1.55	1.27	1.46	1.61	1.77	1.53	1.54
Humberside	1.36	1.51	1.69	1.84	1.60	1.39	1.63	1.76	1.90	1.67	1.63
Midlothian	1.23	1.39	1.53	1.75	1.48	1.29	1.43	1.62	1.80	1.54	1.51
Shropshire	1.38	1.46	1.64	1.90	1.60	1.43	1.62	1.72	2.04	1.70	1.65
Mean	1.32	1.44	1.61	1.78	1.54	1.35	1.52	1.66	1.85	1.60	1.57

	Growth Regulator treatment (Nos. as method)									
	1	2	3	4		1	2	3	4	
Essex	1.52	1.44	1.50	1.44	1.48	1.56	1.53	1.58	1.50	1.54
Cambs	1.58	1.57	1.58	1.47	1.55	1.48	1.52	1.55	1.55	1.53
Humberside	1.65	1.57	1.61	1.57	1.60	1.69	1.65	1.69	1.66	1.67
Midlothian	1.53	1.45	1.48	1.44	1.48	1.55	1.56	1.53	1.51	1.54
Shropshire	1.57	1.65	1.59	1.57	1.60	1.76	1.68	1.72	1.67	1.71
Mean	1.57	1.54	1.55	1.50	1.54	1.61	1.59	1.61	1.58	1.60

	Growth Regulator treatment (Nos. as method)									
	1	2	3	4		1	2	3	4	
Nitrogen (kg/ha)										
0	1.34	1.31	1.35	1.30	1.33	1.36	1.35	1.37	1.34	1.36
80	1.46	1.46	1.45	1.41	1.45	1.52	1.50	1.54	1.52	1.52
120	1.63	1.62	1.61	1.57	1.61	1.70	1.63	1.68	1.63	1.66
160	1.84	1.76	1.80	1.72	1.78	1.85	1.87	1.87	1.81	1.85
Mean	1.57	1.54	1.55	1.50	1.54	1.61	1.59	1.62	1.58	1.60

SED's

Site	0.029	SxV	0.031	SxVxN	0.042
Variety	0.007	SxN	0.035	SxVxPGR	0.042
Nitrogen	0.01	VxN	0.015	SxNxPGR	0.053
PGR	0.01	SxPGR	0.035	VxNxPGR	0.029
		VxPGR	0.015		
		NxPGR	0.021		

Grain nitrogen content -N% in DM - 1992

Malting site and heavy sites

	PIPKIN					PUFFIN					
	Nitrogen rate (kg/ha)										Site
	0	80	120	160	Mean	0	80	120	160	Mean	Mean
Essex	1.29	1.43	1.66	1.80	1.55	1.33	1.55	1.71	1.93	1.63	1.59
Cambs	1.63	1.94	2.16	2.19	1.98	1.83	2.07	2.22	2.39	2.13	2.05
Humberside	1.47	1.57	1.61	1.72	1.59	1.52	1.62	1.71	1.85	1.68	1.63
Midlothian	1.55	1.71	1.91	2.01	1.80	1.60	1.83	1.98	2.05	1.87	1.83
Shropshire	1.49	1.64	1.78	2.01	1.73	1.55	1.73	1.84	2.13	1.81	1.77
Mean	1.49	1.66	1.82	1.95	1.73	1.57	1.76	1.89	2.07	1.82	1.77

	Growth Regulator treatment (Nos. as method)									
	1	2	3	4		1	2	3	4	
Essex	1.56	1.53	1.58	1.51	1.55	1.65	1.62	1.66	1.59	1.63
Cambs	2.00	1.97	2.02	1.93	1.98	2.10	2.15	2.20	2.06	2.13
Humberside	1.58	1.58	1.59	1.62	1.59	1.68	1.68	1.68	1.66	1.68
Midlothian	1.85	1.78	1.73	1.81	1.79	1.88	1.86	1.92	1.81	1.87
Shropshire	1.74	1.73	1.72	1.73	1.73	1.84	1.82	1.79	1.81	1.82
Mean	1.75	1.72	1.73	1.72	1.73	1.83	1.83	1.85	1.79	1.82

	Growth Regulator treatment (Nos. as method)									
	1	2	3	4		1	2	3	4	
Nitrogen (kg/ha)										
0	1.49	1.47	1.51	1.48	1.49	1.54	1.60	1.60	1.52	1.57
80	1.65	1.63	1.68	1.67	1.66	1.75	1.76	1.82	1.71	1.76
120	1.83	1.87	1.78	1.82	1.83	1.92	1.87	1.91	1.87	1.89
160	2.02	1.91	1.93	1.92	1.95	2.11	2.06	2.08	2.03	2.07
Mean	1.75	1.72	1.73	1.72	1.73	1.83	1.82	1.85	1.78	1.82

SED's

Site	0.028	SxV	0.031	SxVxN	0.048
Variety	0.009	SxN	0.038	SxVxPGR	0.048
Nitrogen	0.013	VxN	0.019	SxNxPGR	0.064
PGR	0.013	SxPGR	0.038	VxNxPGR	0.038
		VxPGR	0.019		
		NxPGR	0.027		

Grain nitrogen content -N% in DM - 1993

Malting site and heavy sites

	PIPKIN					PUFFIN					
	Nitrogen rate (kg/ha)										Site
	0	80	120	160	Mean	0	80	120	160	Mean	Mean
Essex	1.19	1.33	1.49	1.61	1.41	1.37	1.45	1.53	1.71	1.52	1.46
Cambs	1.38	1.62	1.78	1.95	1.68	1.54	1.77	1.85	1.96	1.78	1.73
Humberside	1.38	1.62	1.76	1.95	1.68	1.58	1.80	1.93	2.03	1.84	1.76
Midlothian	1.20	1.39	1.41	1.59	1.40	1.35	1.45	1.51	1.69	1.50	1.45
Shropshire	1.28	1.33	1.47	1.72	1.45	1.43	1.51	1.65	1.84	1.61	1.53
Mean	1.29	1.46	1.58	1.76	1.52	1.45	1.60	1.69	1.85	1.65	1.59

	Growth Regulator treatment (Nos. as method)									
	1	2	3	4		1	2	3	4	
Essex	1.42	1.42	1.40	1.38	1.41	1.54	1.50	1.50	1.52	1.52
Cambs	1.72	1.69	1.67	1.65	1.68	1.83	1.77	1.79	1.74	1.78
Humberside	1.71	1.68	1.66	1.66	1.68	1.84	1.83	1.81	1.85	1.83
Midlothian	1.47	1.37	1.41	1.34	1.40	1.56	1.49	1.48	1.47	1.50
Shropshire	1.45	1.44	1.47	1.44	1.45	1.60	1.60	1.62	1.59	1.60
Mean	1.55	1.52	1.52	1.49	1.52	1.67	1.64	1.64	1.63	1.65

	Growth Regulator treatment (Nos. as method)									
	1	2	3	4		1	2	3	4	
Nitrogen (kg/ha)										
0	1.31	1.28	1.28	1.26	1.28	1.47	1.44	1.46	1.45	1.46
80	1.47	1.49	1.47	1.42	1.46	1.63	1.59	1.59	1.58	1.60
120	1.65	1.58	1.56	1.54	1.58	1.72	1.68	1.67	1.70	1.69
160	1.79	1.74	1.77	1.76	1.77	1.88	1.85	1.85	1.81	1.85
Mean	1.56	1.52	1.52	1.50	1.52	1.68	1.64	1.64	1.64	1.65

SED's

Site	0.019	SxV	0.022	SxVxN	0.035
Variety	0.007	SxN	0.027	SxVxPGR	0.035
Nitrogen	0.01	VxN	0.014	SxNxPGR	0.047
PGR	0.01	SxPGR	0.027	VxNxPGR	0.028
		VxPGR	0.014		
		NxPGR	0.02		

Lodging % crop area at harvest - 1991

Cambridgeshire site 1991

	PIPKIN					PUFFIN					
	Nitrogen rate (kg/ha)										Site
	0	80	120	160	Mean	0	80	120	160	Mean	Mean
Cambs	5.0	40.0	60.0	74.0	44.8	0.0	11.0	21.0	48.0	20.0	24.0

	Growth Regulator treatment (Nos. as method)									
	1	2	3	4		1	2	3	4	
Cambs	70.0	64.0	30.0	16.0	45.0	39.0	33.0	3.0	4.0	19.8

Nitrogen (kg/ha)	Growth Regulator treatment (Nos. as method)									
	1	2	3	4		1	2	3	4	
0	17.0	3.0	2.0	0.0	5.5	0.0	0.0	0.0	0.0	0.0
80	75.0	72.0	13.0	0.0	40.0	30.0	13.0	0.0	0.0	10.8
120	93.0	85.0	38.0	24.0	60.0	35.0	33.0	2.0	15.0	21.3
160	94.0	95.0	65.0	40.0	73.5	90.0	87.0	12.0	2.0	47.8
Mean	69.8	63.8	29.5	16.0	44.8	38.8	33.3	3.5	4.3	19.9

SED's

Variety	2.90	VxN	5.70	VxNxPGR	11.4
Nitrogen	4.00	VxPGR	5.70		
PGR	4.00	NxPGR	8.10		

Lodging % crop area at harvest - 1992

Malting site and heavy sites
(Rounded values)

	PIPKIN					PUFFIN					
	Nitrogen rate (kg/ha)										Site
	0	80	120	160	Mean	0	80	120	160	Mean	Mean
Essex	0	20	38	43	25	0	16	20	26	16	20
Cambs	18	37	50	41	37	12	2	9	17	10	23
Humberside	4	17	29	36	22	2	4	7	13	7	14
Midlothian	0	3	19	26	12	0	2	2	2	2	7
Shropshire	0	6	4	27	9	0	0	2	9	3	6
Mean	4	17	28	35	21	3	5	8	13	7	14.

	Growth Regulator treatment (Nos. as method)									
	1	2	3	4		1	2	3	4	
Essex	32	21	31	17	25	15	16	16	15	16
Cambs	40	35	30	41	37	12	17	7	3	10
Humberside	31	20	19	17	22	8	9	5	4	7
Midlothian	28	10	7	3	12	5	1	0	0	2
Shropshire	18	12	4	2	9	5	5	0	1	3
Mean	30	20	18	16	21	9	10	6	5	7

	Growth Regulator treatment (Nos. as method)									
	1	2	3	4		1	2	3	4	
Nitrogen (kg/ha)										
0	3	5	3	7	5	3	8	3	2	4
80	23	18	11	13	16	4	7	5	4	5
120	41	27	26	19	28	10	10	6	6	8
160	52	29	32	26	35	19	19	8	7	13
Mean	30	20	18	16	21	9	11	6	5	8

SED's

Site	2.00	SxV	2.70	SxVxN	5.4
Variety	1.20	SxN	3.80	SxVxPGR	5.4
Nitrogen	1.70	VxN	2.40	SxNxPGR	7.6
PGR	1.70	SxPGR	3.80	VxNxPGR	4.8
		VxPGR	2.40		
		NxPGR	3.40		

Lodging % crop area at harvest - 1993

Malting site and heavy sites
(Rounded values)

	PIPKIN					PUFFIN					
	Nitrogen rate (kg/ha)										Site
	0	80	120	160	Mean	0	80	120	160	Mean	Mean
Essex	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cambs	0.0	23.3	45.8	76.7	36.5	0.0	5.8	16.7	23.3	11.5	24.0
Humberside	8.8	14.8	27.0	23.5	18.5	4.7	11.5	7.0	8.5	7.9	13.2
Midlothian	0.0	0.0	0.0	0.4	0.1	0.0	0.0	0.0	0.4	0.1	0.1
Shropshire	0.0	0.0	0.0	5.4	1.4	0.0	0.0	0.0	0.0	0.0	0.6
Mean	1.8	7.6	14.6	21.2	11.3	0.9	3.5	4.7	6.4	3.9	7.6

	Growth Regulator treatment (Nos. as method)									
	1	2	3	4		1	2	3	4	
Essex	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cambs	50.0	38.3	35.8	21.7	36.5	30.0	14.6	0.4	0.8	11.5
Humberside	23.0	27.7	12.8	10.7	18.6	10.5	11.2	1.7	8.3	7.9
Midlothian	0.4	0.0	0.0	0.0	0.1	0.0	0.4	0.0	0.0	0.1
Shropshire	4.2	1.2	0.0	0.0	1.4	0.0	0.0	0.0	0.0	0.0
Mean	15.5	13.4	9.7	6.5	11.3	8.1	5.2	0.4	1.8	3.9

	Growth Regulator treatment (Nos. as method)									
	1	2	3	4		1	2	3	4	
Nitrogen (kg/ha)										
0	2.7	2.7	0.4	1.3	1.8	1.1	1.3	0.0	1.3	0.9
80	12.7	12.0	4.5	1.1	7.6	5.2	4.9	1.1	2.7	3.5
120	19.7	20.4	11.5	6.7	14.6	10.7	7.0	0.6	0.7	4.8
160	27.0	18.7	22.5	16.5	21.2	15.5	7.7	0.0	2.7	6.5
Mean	15.5	13.5	9.7	6.4	11.3	8.1	5.2	0.4	1.9	3.9

SED's

Site	1.50	SxV	2.13	SxVxN	4.28
Variety	0.96	SxN	3.02	SxVxPGR	4.28
Nitrogen	1.36	VxN	1.92	SxNxPGR	6.06
PGR	1.36	SxPGR	3.02	VxNxPGR	3.84
		VxPGR	1.92		
		NxPGR	2.71		

Grain nitrogen uptake (kg/ha) - 1991

Malting site and heavy sites
(Rounded values)

	PIPKIN					PUFFIN					
	Nitrogen rate (kg/ha)										Site
	0	80	120	160	Mean	0	80	120	160	Mean	Mean
Essex	45.30	74.80	89.90	104.30	78.58	45.90	77.80	94.30	111.20	82.30	80.4
Cambs	60.00	81.60	93.40	100.60	83.90	59.50	85.60	101.50	112.20	89.70	86.8
Humberside	42.70	76.70	93.80	109.30	80.63	49.40	86.00	104.60	120.20	90.05	85.3
Midlothian	46.50	77.60	94.50	115.90	83.63	47.80	80.10	102.00	120.70	87.65	85.6
Shropshire	34.80	60.30	79.80	102.20	69.28	34.20	67.80	83.10	110.90	74.00	71.7
Mean	45.86	74.20	90.28	106.46	79.20	47.36	79.46	97.10	115.04	84.74	81.96

	Growth Regulator treatment (Nos. as method)									
	1	2	3	4		1	2	3	4	
Essex	79.70	75.80	81.40	77.30	78.55	82.60	81.50	83.20	81.80	82.28
Cambs	78.90	81.40	90.40	84.90	83.90	83.70	88.00	92.40	94.70	89.70
Humberside	81.70	78.80	81.10	81.00	80.65	87.70	91.60	90.40	90.40	90.03
Midlothian	82.90	83.50	83.60	84.50	83.63	86.80	89.60	87.20	87.10	87.68
Shropshire	68.70	73.00	66.70	68.80	69.30	76.30	73.20	74.00	72.50	74.00
Mean	78.38	78.50	80.64	79.30	79.21	83.42	84.78	85.44	85.30	84.74

	Growth Regulator treatment (Nos. as method)									
	1	2	3	4		1	2	3	4	
Nitrogen (kg/ha)										
0	46.10	45.30	46.90	45.20	45.88	45.90	49.10	46.40	47.90	47.33
80	71.10	74.90	75.90	74.90	74.20	78.20	78.40	79.80	81.40	79.45
120	89.20	88.90	92.30	90.80	90.30	96.10	95.40	99.30	97.60	97.10
160	107.10	104.90	107.50	106.40	106.48	113.40	116.10	116.30	114.30	115.03
Mean	78.38	78.50	80.65	79.33	79.21	83.40	84.75	85.45	85.30	84.73

SED's

Site	1.76	SxV	1.94	SxVxN	2.76
Variety	0.51	SxN	2.24	SxVxPGR	2.76
Nitrogen	0.72	VxN	1.02	SxNxPGR	3.58
PGR	0.72	SxPGR	2.24	VxNxPGR	2.03
		VxPGR	1.02		
		NxPGR	1.44		

Grain nitrogen uptake (kg/ha) - 1992

Malting site and heavy sites
(Rounded values)

	PIPKIN					PUFFIN					
	Nitrogen rate (kg/ha)										Site
	0	80	120	160	Mean	0	80	120	160	Mean	Mean
Essex	40.80	81.10	95.20	105.50	80.65	43.80	90.10	103.90	118.30	89.03	84.8
Cambs	87.70	107.50	116.00	112.60	105.95	98.00	128.50	139.60	150.40	129.13	117.5
Humberside	53.10	77.20	83.10	91.20	76.15	56.00	80.00	91.60	101.90	82.38	79.2
Midlothian	77.60	110.30	126.70	134.90	112.38	77.10	122.40	142.40	150.20	123.03	117.7
Shropshire	52.80	75.50	88.00	106.60	80.73	62.50	88.20	99.60	127.00	94.33	87.5
Mean	62.40	90.32	101.80	110.16	91.17	67.48	101.84	115.42	129.56	103.58	97.34

	Growth Regulator treatment (Nos. as method)									
	1	2	3	4		1	2	3	4	
Essex	81.00	80.60	81.20	79.80	80.65	86.80	91.30	88.90	89.00	89.00
Cambs	98.20	109.60	107.60	108.40	105.95	126.40	131.00	133.50	125.60	129.13
Humberside	77.10	75.00	76.50	76.00	76.15	82.10	84.80	80.90	81.60	82.35
Midlothian	110.60	110.70	111.50	116.70	112.38	124.00	123.20	127.00	117.80	123.00
Shropshire	78.70	79.20	81.50	83.50	80.73	95.20	93.80	91.90	96.40	94.33
Mean	89.12	91.02	91.66	92.88	91.17	102.90	104.82	104.44	102.08	103.56

	Growth Regulator treatment (Nos. as method)									
	1	2	3	4		1	2	3	4	
Nitrogen (kg/ha)										
0	61.80	59.90	65.60	62.30	62.40	64.10	69.60	70.80	65.40	67.48
80	85.00	89.20	92.30	94.80	90.33	98.60	102.70	105.10	101.00	101.85
120	98.70	105.90	99.10	103.50	101.80	119.40	114.00	113.90	114.30	115.40
160	110.90	109.10	109.70	110.90	110.15	129.50	132.90	128.10	127.70	129.55
Mean	89.10	91.03	91.68	92.88	91.17	102.90	104.80	104.48	102.10	103.57

SED's

Site	2.48	SxV	2.75	SxVxN	4.01
Variety	0.75	SxN	3.22	SxVxPGR	4.01
Nitrogen	1.06	VxN	1.51	SxNxPGR	5.23
PGR	1.06	SxPGR	3.22	VxNxPGR	3.01
		VxPGR	1.51		
		NxPGR	2.13		

Grain nitrogen uptake (kg/ha) - 1993

Malting site and heavy sites
(Rounded values)

	PIPKIN					PUFFIN					
	Nitrogen rate (kg/ha)										Site
	0	80	120	160	Mean	0	80	120	160	Mean	Mean
Essex	38.56	68.94	84.07	96.31	71.97	43.87	76.24	91.42	106.59	79.53	75.75
Cambs	60.58	80.64	89.56	94.54	81.33	72.93	99.07	102.95	108.98	95.98	88.65
Humberside	52.17	77.31	86.29	96.71	78.12	59.18	87.42	99.85	106.05	88.13	83.12
Midlotian	33.21	67.45	73.02	88.62	65.58	35.92	64.13	71.38	91.64	65.77	65.67
Shropshire	28.59	55.21	70.21	91.05	61.27	34.35	64.24	80.72	101.12	70.11	65.69
Mean	42.62	69.91	80.63	93.45	71.65	49.25	78.22	89.26	102.88	79.90	75.78

	Growth Regulator treatment (Nos. as method)									
	1	2	3	4		1	2	3	4	
Essex	71.56	71.89	72.41	72.02	71.97	81.00	79.15	77.82	80.15	79.53
Cambs	78.54	78.39	83.45	84.92	81.33	94.22	91.87	99.67	98.16	95.98
Humberside	75.24	76.88	79.13	81.23	78.12	85.22	86.32	88.42	92.53	88.12
Midlotian	67.93	64.18	67.37	62.82	65.58	66.70	66.58	64.40	65.39	65.77
Shropshire	59.22	61.96	61.46	62.43	61.27	69.62	69.92	70.42	70.47	70.11
Mean	70.50	70.66	72.76	72.68	71.65	79.35	78.77	80.15	81.34	79.90

	Growth Regulator treatment (Nos. as method)									
	1	2	3	4		1	2	3	4	
Nitrogen (kg/ha)										
0	42.26	41.68	42.85	43.71	42.63	49.32	47.94	49.74	50.00	49.25
80	67.09	71.46	71.28	69.81	69.91	78.76	75.58	78.05	80.49	78.22
120	81.81	78.80	80.90	81.02	80.63	89.00	88.23	88.98	90.84	89.26
160	90.84	90.70	96.03	96.21	93.45	100.32	103.33	103.83	104.03	102.88
Mean	70.50	70.66	72.77	72.69	71.65	79.35	78.77	80.15	81.34	79.90

SED's

Site	2.644	SxV	2.770	SxVxN	3.433
Variety	0.524	SxN	3.008	SxVxPGR	3.433
Nitrogen	0.741	VxN	1.047	SxNxPGR	4.156
PGR	0.741	SxPGR	3.008	VxNxPGR	2.094
		VxPGR	1.047		
		NxPGR	1.481		

Sievings - % Grain >2.8mm -1991

Malting site and heavy sites
(Rounded values)

	PIPKIN Nitrogen rate (kg/ha)					PUFFIN					Site
	0	80	120	160	Mean	0	80	120	160	Mean	Mean
Essex	61.00	59.20	58.00	53.00	57.80	81.00	86.00	83.40	80.80	82.80	70.30
Cambs	27.40	22.40	19.80	19.20	22.20	56.20	56.20	55.20	49.00	54.15	38.18
Humberside	50.60	63.60	59.20	54.00	56.85	78.80	80.60	79.00	75.40	78.45	67.65
Midlothian	13.60	20.60	23.80	27.00	21.25	50.00	50.20	56.80	56.80	53.45	37.35
Shropshire	22.40	28.40	32.80	37.00	30.15	38.00	44.60	47.40	56.80	46.70	38.43
Mean	35.00	38.84	38.72	38.04	37.65	60.80	63.52	64.36	63.76	63.11	50.38

	Growth Regulator treatment (Nos. as method)									
	1	2	3	4		1	2	3	4	
Essex	57.00	54.20	61.40	58.60	57.80	84.40	80.60	84.00	82.20	82.80
Cambs	20.20	17.00	25.80	25.60	22.15	55.80	46.80	59.40	54.40	54.10
Humberside	59.00	59.00	57.00	52.60	56.90	81.80	80.60	77.40	74.20	78.50
Midlothian	23.00	18.80	23.80	19.20	21.20	59.40	49.20	54.80	50.40	53.45
Shropshire	29.20	29.20	31.40	30.80	30.15	49.40	47.00	45.60	44.80	46.70
Mean	37.68	35.64	39.88	37.36	37.64	66.16	60.84	64.24	61.20	63.11

	Growth Regulator treatment (Nos. as method)									
	1	2	3	4		1	2	3	4	
Nitrogen (kg/ha)										
0	37.40	35.00	35.20	32.40	35.00	64.60	59.60	61.20	58.00	60.85
80	38.20	35.60	42.80	38.80	38.85	65.60	59.20	65.60	63.60	63.50
120	37.80	36.40	41.60	39.00	38.70	68.20	61.20	65.00	63.00	64.35
160	37.20	35.40	40.00	39.40	38.00	66.20	63.40	65.20	62.02	64.21
Mean	37.65	35.60	39.90	37.40	37.64	66.15	60.85	64.25	61.66	63.23

SED's

Site	0.82	SxV	1.12	SxVxN	2.12
Variety	0.46	SxN	1.52	SxVxPGR	2.12
Nitrogen	0.66	VxN	0.94	SxNxPGR	2.98
PGR	0.66	SxPGR	1.52	VxNxPGR	1.88
		VxPGR	0.94		
		NxPGR	1.32		

Sievings - % Grain >2.8mm -1992

Malting site and heavy sites
(Rounded values)

	PIPKIN					PUFFIN					
	Nitrogen rate (kg/ha)										Site
	0	80	120	160	Mean	0	80	120	160	Mean	Mean
Essex	12.60	22.40	27.20	26.80	22.25	48.20	57.40	55.60	51.00	53.05	37.65
Cambs	40.00	31.40	29.80	31.20	33.10	77.00	74.60	71.80	71.40	73.70	53.40
Humberside	41.40	50.60	53.40	51.60	49.25	76.60	78.00	78.80	76.60	77.50	63.38
Midlothian	49.00	41.20	38.60	36.00	41.20	70.80	79.80	79.40	78.20	77.05	59.13
Shropshire	24.00	23.60	22.00	24.40	23.50	66.40	67.00	64.80	65.00	65.80	44.65
Mean	33.40	33.84	34.20	34.00	33.86	67.80	71.36	70.08	68.44	69.42	51.64

	Growth Regulator treatment (Nos. as method)									
	1	2	3	4		1	2	3	4	
Essex	25.80	18.60	25.80	18.80	22.25	54.20	53.80	52.20	52.20	53.10
Cambs	33.80	30.60	36.80	31.20	33.10	74.20	74.20	74.20	72.20	73.70
Humberside	48.20	43.60	55.20	49.80	49.20	77.20	78.20	79.60	75.20	77.55
Midlothian	40.80	37.40	45.40	41.20	41.20	78.40	75.80	79.20	75.00	77.10
Shropshire	24.60	23.40	23.60	22.60	23.55	64.60	65.60	66.40	66.60	65.80
Mean	34.64	30.72	37.36	32.72	33.86	69.72	69.52	70.32	68.24	69.45

	Growth Regulator treatment (Nos. as method)									
	1	2	3	4		1	2	3	4	
Nitrogen (kg/ha)										
0	37.00	29.80	36.20	30.60	33.40	67.20	68.60	69.80	65.60	67.80
80	34.00	32.00	35.40	33.80	33.80	72.20	70.60	73.00	69.60	71.35
120	35.60	31.00	36.40	34.00	34.25	70.00	70.00	71.20	69.20	70.10
160	32.00	30.00	41.60	32.40	34.00	69.60	68.80	67.20	68.60	68.55
Mean	34.65	30.70	37.40	32.70	33.86	69.75	69.50	70.30	68.25	69.45

SED's

Site	2.74	SxV	2.86	SxVxN	3.50
Variety	0.52	SxN	3.08	SxVxPGR	3.50
Nitrogen	0.74	VxN	1.04	SxNxPGR	4.22
PGR	0.74	SxPGR	3.08	VxNxPGR	2.10
		VxPGR	1.04		
		NxPGR	1.48		

Sievings - % Grain >2.8mm -1993

Malting site and heavy sites
(Rounded values)

	PIPKIN					PUFFIN					
	Nitrogen rate (kg/ha)										Site
	0	80	120	160	Mean	0	80	120	160	Mean	Mean
Essex	45.50	65.20	65.00	63.20	59.73	74.00	80.60	84.30	82.60	80.38	70
Cambs	51.00	51.80	49.40	43.40	48.90	82.50	80.20	76.90	70.80	77.60	63.2
Humberside	71.00	70.20	66.30	62.60	67.53	85.20	83.00	79.90	76.80	81.23	74.3
Midlothian	44.50	55.80	55.60	58.20	53.53	69.40	79.60	80.30	83.00	78.08	65.8
Shropshire	46.00	56.00	55.50	51.90	52.35	73.00	81.60	78.30	81.80	78.68	65.5
Mean	51.60	59.80	58.36	55.86	56.41	76.82	81.00	79.94	79.00	79.19	67.76

	Growth Regulator treatment (Nos. as method)									
	1	2	3	4		1	2	3	4	
Essex	61.10	56.90	60.60	60.40	59.75	81.20	78.90	81.20	80.20	80.38
Cambs	50.40	48.60	48.30	48.10	48.85	73.40	74.20	81.20	81.60	77.60
Humberside	69.90	69.10	66.20	64.60	67.45	85.90	85.40	77.70	75.80	81.20
Midlothian	57.50	54.30	52.40	49.90	53.53	81.50	80.30	74.90	75.60	78.08
Shropshire	49.70	49.90	58.70	51.00	52.33	79.70	79.00	77.00	79.10	78.70
Mean	57.72	55.76	57.24	54.80	56.38	80.34	79.56	78.40	78.46	79.19

	Growth Regulator treatment (Nos. as method)									
	1	2	3	4		1	2	3	4	
Nitrogen (kg/ha)										
0	55.70	50.10	51.20	49.50	51.63	80.30	77.40	74.20	75.40	76.83
80	59.50	60.00	62.70	57.00	59.80	81.40	80.10	81.40	81.10	81.00
120	59.70	56.60	59.40	57.70	58.35	81.60	81.60	78.20	78.30	79.93
160	56.00	56.30	55.70	55.00	55.75	78.00	79.20	79.80	78.90	78.98
Mean	57.73	55.75	57.25	54.80	56.38	80.33	79.58	78.40	78.43	79.18

SED's

Site	1.09	SxV	1.36	SxVxN	2.41
Variety	0.51	SxN	1.78	SxVxPGR	2.41
Nitrogen	0.73	VxN	1.03	SxNxPGR	3.33
PGR	0.73	SxPGR	1.78	VxNxPGR	2.05
		VxPGR	1.03		
		NxPGR	1.45		

Sievings - % Grain 2.8-2.5mm - 1991

Malting site and heavy sites
(Rounded values)

	PIPKIN					PUFFIN					
	Nitrogen rate (kg/ha)										Site
	0	80	120	160	Mean	0	80	120	160	Mean	Mean
Essex	31.00	34.00	33.20	34.60	33.20	14.60	11.20	13.00	14.80	13.40	23.30
Cambs	52.80	47.60	46.00	44.20	47.65	35.80	35.80	33.60	34.60	34.95	41.30
Humberside	38.80	30.20	32.80	35.20	34.25	16.40	14.00	14.60	16.00	15.25	24.75
Midlothian	58.00	59.20	56.40	53.40	56.75	39.80	39.60	34.40	34.00	36.95	46.85
Shropshire	48.20	54.00	51.80	49.20	50.80	42.40	42.80	41.60	34.40	40.30	45.55
Mean	45.76	45.00	44.04	43.32	44.53	29.80	28.68	27.44	26.76	28.17	36.35

	Growth Regulator treatment (Nos. as method)									
	1	2	3	4		1	2	3	4	
Essex	33.40	36.40	30.60	32.60	33.25	12.40	15.60	11.80	14.00	13.45
Cambs	47.40	46.40	45.40	51.60	47.70	34.60	40.00	30.20	34.80	34.90
Humberside	33.20	32.20	34.40	37.40	34.30	13.00	13.80	15.40	18.80	15.25
Midlothian	57.80	57.60	55.80	56.00	56.80	32.60	40.40	36.00	38.80	36.95
Shropshire	51.60	51.20	50.20	50.20	50.80	38.40	39.80	41.00	41.80	40.25
Mean	44.68	44.76	43.28	45.56	44.57	26.20	29.92	26.88	29.64	28.16

	Growth Regulator treatment (Nos. as method)									
	1	2	3	4		1	2	3	4	
Nitrogen (kg/ha)										
0	46.00	45.20	45.40	46.40	45.75	27.00	31.20	29.20	32.00	29.85
80	43.80	45.80	44.00	46.40	45.00	27.40	32.00	27.00	28.40	28.70
120	45.20	43.60	42.00	45.60	44.10	24.80	30.20	26.20	28.60	27.45
160	43.80	44.40	41.60	43.80	43.40	25.60	26.40	25.20	29.80	26.75
Mean	44.70	44.75	43.25	45.55	44.56	26.20	29.95	26.90	29.70	28.19

SED's

Site	0.68	SxV	0.88	SxVxN	1.66
Variety	0.36	SxN	1.2	SxVxPGR	1.86
Nitrogen	0.5	VxN	0.72	SxNxPGR	2.3
PGR	0.5	SxPGR	1.2	VxNxPGR	1.44
		VxPGR	0.72		
		NxPGR	1.02		

Sievings - % Grain 2.8-2.5mm - 1992

Malting site and heavy sites
(Rounded values)

	PIPKIN					PUFFIN					
Nitrogen rate (kg/ha)											Site
	0	80	120	160	Mean	0	80	120	160	Mean	Mean
Essex	62.20	51.60	44.60	39.80	49.55	42.20	34.20	32.20	30.40	34.75	42.15
Cambs	47.00	38.40	37.80	36.20	39.85	18.80	20.00	22.20	22.20	20.80	30.33
Humberside	40.80	36.60	33.40	34.80	36.40	17.20	16.40	15.80	17.20	16.65	26.53
Midlothian	39.00	43.00	43.20	44.80	42.50	23.00	15.80	16.20	16.60	17.90	30.20
Shropshire	42.00	44.40	43.20	41.00	42.65	25.40	26.20	27.20	26.40	26.30	34.48
Mean	46.20	42.80	40.44	39.32	42.19	25.32	22.52	22.72	22.56	23.28	32.74

	Growth Regulator treatment (Nos. as method)									
	1	2	3	4		1	2	3	4	
Essex	50.00	49.20	49.20	49.80	49.55	34.40	35.20	33.00	36.60	34.80
Cambs	41.00	39.60	38.40	40.80	39.95	21.00	20.20	20.00	22.00	20.80
Humberside	37.60	38.80	33.80	35.60	36.45	17.40	16.60	14.80	17.80	16.65
Midlothian	41.80	42.40	42.60	43.00	42.45	17.40	18.80	15.80	19.40	17.85
Shropshire	41.60	40.80	44.20	44.00	42.65	27.40	26.80	25.60	25.40	26.30
Mean	42.40	42.16	41.64	42.64	42.21	23.52	23.52	21.84	24.24	23.28

	Growth Regulator treatment (Nos. as method)									
	1	2	3	4		1	2	3	4	
Nitrogen (kg/ha)										
0	45.60	47.20	44.60	47.40	46.20	26.00	25.00	23.20	27.00	25.30
80	43.20	41.80	43.40	43.20	42.90	22.40	23.60	20.80	23.40	22.55
120	41.20	39.80	40.40	40.40	40.45	23.00	22.80	21.60	23.40	22.70
160	39.80	39.80	38.20	39.60	39.35	22.80	22.80	21.60	23.20	22.60
Mean	42.45	42.15	41.65	42.65	42.23	23.55	23.55	21.80	24.25	23.29

SED's

Site	1.40	SxV	1.50	SxVxN	2.02
Variety	0.34	SxN	1.68	SxVxPGR	2.02
Nitrogen	0.48	VxN	0.70	SxNxPGR	2.54
PGR	0.48	SxPGR	1.68	VxNxPGR	1.38
		VxPGR	0.70		
		NxPGR	0.98		

Sievings - % Grain 2.8-2.5mm - 1993

Malting site and heavy sites
(Rounded values)

	PIPKIN					PUFFIN					
	Nitrogen rate (kg/ha)										Site
	0	80	120	160	Mean	0	80	120	160	Mean	Mean
Essex	42.20	29.30	28.20	28.60	32.08	20.60	14.60	13.60	13.80	15.65	23.9
Cambs	38.10	31.60	30.90	32.20	33.20	13.00	14.60	15.90	18.00	15.38	24.3
Humberside	21.00	20.70	21.60	23.30	21.65	9.80	10.70	11.70	13.60	11.45	16.6
Midlothian	40.90	35.00	35.00	32.60	35.88	22.20	15.10	14.70	12.60	16.15	26
Shropshire	18.30	17.50	17.20	17.10	17.53	10.10	7.40	8.60	7.00	8.28	12.9
Mean	32.10	26.82	26.58	26.76	28.07	15.14	12.48	12.90	13.00	13.38	20.74

	Growth Regulator treatment (Nos. as method)									
	1	2	3	4		1	2	3	4	
Essex	31.30	34.60	31.10	31.30	32.08	15.40	15.80	15.10	16.40	15.68
Cambs	31.20	34.00	34.00	33.80	33.25	17.40	17.00	13.70	13.50	15.40
Humberside	20.20	21.30	21.80	23.20	21.63	8.60	9.30	13.50	14.40	11.45
Midlothian	32.50	35.60	37.00	38.40	35.88	14.00	14.40	18.00	18.30	16.18
Shropshire	18.30	18.20	15.40	18.20	17.53	7.90	8.30	9.00	7.90	8.28
Mean	26.70	28.74	27.86	28.98	28.07	12.66	12.96	13.86	14.10	13.40

	Growth Regulator treatment (Nos. as method)									
	1	2	3	4		1	2	3	4	
Nitrogen (kg/ha)										
0	29.20	33.30	32.80	33.20	32.13	13.20	15.20	16.60	15.60	15.15
80	26.70	26.60	25.40	28.70	26.85	12.30	12.80	12.50	12.40	12.50
120	24.80	28.40	26.30	26.90	26.60	11.80	11.50	13.50	14.90	12.93
160	26.20	26.70	27.00	27.20	26.78	13.30	12.30	12.90	13.50	13.00
Mean	26.73	28.75	27.88	29.00	28.09	12.65	12.95	13.88	14.10	13.39

SED's

Site	0.77	SxV	0.9	SxVxN	1.43
Variety	0.29	SxN	1.1	SxVxPGR	1.43
Nitrogen	0.41	VxN	0.58	SxNxPGR	1.93
PGR	0.41	SxPGR	1.1	VxNxPGR	1.16
		VxPGR	0.58		
		NxPGR	0.82		

Sievings - % Grain 2.5-2.2mm - 1991

Malting site and heavy sites
(Rounded values)

	PIPKIN					PUFFIN					
	Nitrogen rate (kg/ha)										Site
	0	80	120	160	Mean	0	80	120	160	Mean	Mean
Essex	6.40	5.60	7.00	9.40	7.10	3.20	2.20	2.80	3.40	2.90	5.00
Cambs	15.80	22.60	23.60	25.00	21.75	6.40	6.40	8.60	11.00	8.10	14.93
Humberside	8.20	6.40	5.40	7.40	6.85	3.60	3.80	4.60	5.20	4.30	5.58
Midlothian	23.00	16.40	15.60	15.60	17.65	7.80	8.00	6.80	7.40	7.50	12.58
Shropshire	22.20	14.00	11.60	10.00	14.45	14.40	9.60	8.80	6.80	9.90	12.18
Mean	15.12	13.00	12.64	13.48	13.56	7.08	6.00	6.32	6.76	6.54	10.05
	Growth Regulator treatment (Nos. as method)										
	1	2	3	4		1	2	3	4		
Essex	7.80	7.40	6.20	7.00	7.10	2.40	2.80	3.00	3.20	2.85	
Cambs	22.60	25.00	20.80	18.60	21.75	7.40	9.40	7.20	8.20	8.05	
Humberside	5.60	8.00	6.20	7.40	6.80	3.60	3.80	4.60	5.00	4.25	
Midlothian	15.20	18.80	16.20	20.20	17.60	6.20	8.20	7.00	8.60	7.50	
Shropshire	15.00	15.20	13.40	13.80	14.35	9.60	10.20	10.00	10.00	9.95	
Mean	13.24	14.88	12.56	13.40	13.52	5.84	6.88	6.36	7.00	6.52	
	Growth Regulator treatment (Nos. as method)										
	1	2	3	4		1	2	3	4		
Nitrogen (kg/ha)											
0	13.00	15.20	15.20	16.80	15.05	6.20	7.00	7.20	7.60	7.00	
80	13.40	16.00	10.40	12.20	13.00	5.40	6.80	5.80	6.20	6.05	
120	12.40	14.00	12.00	12.00	12.60	5.40	6.80	6.20	6.80	6.30	
160	14.00	14.40	12.80	12.60	13.45	6.40	7.00	6.20	7.40	6.75	
Mean	13.20	14.90	12.60	13.40	13.53	5.85	6.90	6.35	7.00	6.53	

SED's

Site	0.28	SxV	0.42	SxVxN	0.88	
Variety	0.20	SxN	0.60	SxVxPGR	0.88	
Nitrogen	0.28	VxN	0.40	SxNxPGR	1.24	
PGR	0.28	SxPGR	0.60	VxNxPGR	0.78	
		VxPGR	0.40			
		NxPGR	0.56			

Sievings - % Grain 2.5-2.2mm - 1992

Malting site and heavy sites
(Rounded values)

	PIPKIN					PUFFIN					
	Nitrogen rate (kg/ha)										Site
	0	80	120	160	Mean	0	80	120	160	Mean	Mean
Essex	21.80	20.40	20.40	22.40	21.25	7.80	6.20	9.60	10.60	8.55	14.90
Cambs	10.80	20.60	22.60	22.40	19.10	3.40	4.40	4.60	5.00	4.35	11.73
Humberside	14.00	10.20	9.80	10.40	11.10	4.00	4.00	3.40	4.00	3.85	7.48
Midlothian	10.60	12.20	14.60	15.60	13.25	4.60	3.20	3.20	3.40	3.60	8.43
Shropshire	23.80	22.80	23.40	22.20	23.05	6.00	5.00	6.00	6.00	5.75	14.40
Mean	16.20	17.24	18.16	18.60	17.55	5.16	4.56	5.36	5.80	5.22	11.39

	Growth Regulator treatment (No. as method)									
	1	2	3	4		1	2	3	4	
Essex	18.40	23.80	19.60	23.20	21.25	9.00	8.60	8.40	8.40	8.60
Cambs	18.20	19.80	18.00	20.40	19.10	4.00	4.40	4.80	4.20	4.35
Humberside	11.00	13.60	8.80	11.00	11.10	3.60	3.40	3.60	4.80	3.85
Midlothian	14.80	14.80	11.20	12.20	13.25	3.20	3.80	3.20	4.20	3.60
Shropshire	22.80	24.00	22.40	22.80	23.00	6.00	5.60	5.60	5.80	5.75
Mean	17.04	19.20	16.00	17.92	17.54	5.16	5.16	5.12	5.48	5.23

	Growth Regulator treatment (No. as method)									
	1	2	3	4		1	2	3	4	
Nitrogen (kg/ha)										
0	14.60	18.00	15.20	17.20	16.25	5.40	4.60	5.00	5.60	5.15
80	17.20	18.00	16.00	17.00	17.05	4.20	4.40	4.80	4.80	4.55
120	17.40	20.40	16.80	18.20	18.20	5.40	5.40	5.20	5.40	5.35
160	19.00	20.60	15.60	19.40	18.65	5.80	6.20	5.40	6.00	5.85
Mean	17.05	19.25	15.90	17.95	17.54	5.20	5.15	5.10	5.45	5.23

SED's

Site	1.16	SxV	1.20	SxVxN	1.46
Variety	0.22	SxN	1.30	SxVxPGR	1.46
Nitrogen	0.30	VxN	0.44	SxNxPGR	1.76
PGR	0.30	SxPGR	1.30	VxNxPGR	0.86
		VxPGR	0.44		
		NxPGR	0.62		

Sievings - % Grain 2.5-2.2mm - 1993

Malting site and heavy sites
(Rounded values)

	PIPKIN					PUFFIN					
	Nitrogen rate (kg/ha)										Site
	0	80	120	160	Mean	0	80	120	160	Mean	Mean
Essex	10.40	4.50	5.50	6.60	6.75	4.10	2.40	2.10	2.80	2.85	7.5
Cambs	8.40	12.00	14.00	16.00	12.60	3.10	3.80	5.00	7.20	4.78	5.9
Humberside	5.20	5.40	7.00	8.00	6.40	3.30	4.10	5.40	5.90	4.68	3.7
Midlothian	11.80	6.90	7.00	6.90	8.15	5.80	3.00	3.10	2.50	3.60	4.2
Shropshire	8.70	4.50	5.00	6.90	6.28	3.40	1.80	2.20	2.00	2.35	7.2
Mean	8.90	6.66	7.70	8.88	8.04	3.94	3.02	3.56	4.08	3.65	5.70

	Growth Regulator treatment (Nos. as method)									
	1	2	3	4		1	2	3	4	
Essex	6.30	6.90	7.00	6.90	6.78	2.60	2.70	2.80	3.30	2.85
Cambs	12.70	12.20	12.80	12.70	12.60	6.40	5.80	3.50	3.40	4.78
Humberside	6.00	5.50	7.10	6.90	6.38	3.40	3.40	5.50	6.40	4.68
Midlothian	7.50	7.90	8.10	9.10	8.15	2.90	3.10	4.40	3.90	3.58
Shropshire	6.80	6.80	5.20	6.30	6.28	2.20	2.20	2.50	2.50	2.35
Mean	7.86	7.86	8.04	8.38	8.04	3.50	3.44	3.74	3.90	3.65

	Growth Regulator treatment (Nos. as method)									
	1	2	3	4		1	2	3	4	
Nitrogen (kg/ha)										
0	8.1	8.7	9.2	9.7	8.93	3.20	3.70	4.60	4.30	3.95
80	6.9	6.5	6.3	7	6.68	2.80	2.80	3.00	3.50	3.03
120	7.6	7.7	7.7	7.9	7.73	3.50	3.30	3.60	3.90	3.58
160	8.9	8.6	9.1	8.9	8.88	4.60	4.00	3.80	4.00	4.10
Mean	7.88	7.88	8.08	8.38	8.05	3.53	3.45	3.75	3.93	3.66

SED's

Site	0.27	SxV	0.36	SxVxN	0.69
Variety	0.15	SxN	0.49	SxVxPGR	0.69
Nitrogen	0.21	VxN	0.30	SxNxPGR	0.97
PGR	0.21	SxPGR	0.49	VxNxPGR	0.61
		VxPGR	0.30		
		NxPGR	0.43		

Sievings - % Grain <2.2mm -1991

Malting site and heavy sites
(Rounded values)

	PIPKIN					PUFFIN					
	Nitrogen rate (kg/ha)										Site
	0	80	120	160	Mean	0	80	120	160	Mean	Mean
Essex	1.40	1.20	1.60	2.40	1.65	1.00	0.80	1.20	1.20	1.05	1.35
Cambs	4.20	7.60	11.40	11.60	8.70	1.60	1.80	3.00	3.80	2.55	5.63
Humberside	1.80	1.40	2.20	3.00	2.10	1.20	1.40	1.80	3.00	1.85	1.98
Midlothian	5.40	4.20	4.20	4.00	4.45	2.40	2.20	2.00	2.00	2.15	3.30
Shropshire	7.20	3.80	3.40	3.80	4.55	5.20	2.60	2.40	2.00	3.05	3.80
Mean	4.00	3.64	4.56	4.96	4.29	2.28	1.76	2.08	2.40	2.13	3.21

	Growth Regulator treatment (Nos. as method)									
	1	2	3	4		1	2	3	4	
Essex	1.80	1.60	1.60	1.80	1.70	0.80	0.80	1.20	1.20	1.00
Cambs	10.00	11.60	8.00	5.20	8.70	2.20	3.40	2.20	2.40	2.55
Humberside	1.60	2.00	2.20	2.40	2.05	1.40	1.60	2.40	1.80	1.80
Midlothian	4.00	4.80	4.20	4.80	4.45	1.80	2.20	2.20	2.20	2.10
Shropshire	4.20	4.20	4.80	4.80	4.50	2.80	3.00	3.40	3.20	3.10
Mean	4.32	4.84	4.16	3.80	4.28	1.80	2.20	2.28	2.16	2.11

	Growth Regulator treatment (Nos. as method)									
	1	2	3	4		1	2	3	4	
Nitrogen (kg/ha)										
0	3.40	4.20	4.20	4.40	4.05	2.00	2.20	2.40	2.40	2.25
80	4.40	4.20	2.80	3.00	3.60	1.60	1.80	1.80	1.80	1.75
120	4.40	5.80	4.20	3.80	4.55	1.60	2.20	2.20	2.00	2.00
160	5.00	5.20	5.60	4.20	5.00	1.80	2.60	2.80	2.40	2.40
Mean	4.30	4.85	4.20	3.85	4.30	1.75	2.20	2.30	2.15	2.10

SED's

Site	0.28	SxV	0.32	SxVxN	0.50
Variety	0.10	SxN	0.40	SxVxPGR	0.50
Nitrogen	0.14	VxN	0.20	SxNxPGR	0.68
PGR	0.14	SxPGR	0.40	VxNxPGR	0.40
		VxPGR	0.20		
		NxPGR	0.28		

Sievings - % Grain <2.2mm -1992

Malting site and heavy sites
(Rounded values)

	PIPKIN					PUFFIN					
Nitrogen rate (kg/ha)										Site	
	0	80	120	160	Mean	0	80	120	160	Mean	Mean
Essex	3.40	5.40	7.80	10.60	6.80	1.80	1.40	2.60	3.40	2.30	4.55
Cambs	2.60	7.60	9.80	10.40	7.60	1.20	1.40	1.20	1.20	1.25	4.42
Humberside	3.00	2.60	2.60	3.40	2.90	2.60	2.20	2.20	2.40	2.35	2.62
Midlothian	2.80	4.00	3.60	5.20	3.90	1.40	1.00	1.20	1.80	1.35	2.62
Shropshire	10.20	9.20	11.60	12.40	10.85	2.20	1.80	2.20	2.40	2.15	6.50
Mean	4.40	5.76	7.08	8.40	6.41	1.84	1.56	1.88	2.24	1.88	4.14

	Growth Regulator treatment (Nos. as method)									
	1	2	3	4		1	2	3	4	
Essex	5.40	8.40	5.20	8.00	6.75	2.40	2.40	2.20	2.20	2.30
Cambs	7.00	8.00	7.00	8.20	7.55	1.40	1.20	1.40	1.20	1.30
Humberside	3.00	3.00	2.80	2.80	2.90	2.40	2.00	2.20	2.60	2.30
Midlothian	3.80	5.20	2.80	3.80	3.90	1.20	1.60	1.60	1.20	1.40
Shropshire	10.80	11.80	9.80	10.60	10.75	2.00	2.00	2.40	2.20	2.15
Mean	6.00	7.28	5.52	6.68	6.37	1.88	1.84	1.96	1.88	1.89

	Growth Regulator treatment (Nos. as method)									
	1	2	3	4		1	2	3	4	
Nitrogen (kg/ha)										
0	3.60	4.80	4.60	4.40	4.35	1.80	1.60	1.80	2.00	1.80
80	5.40	6.40	5.20	6.00	5.75	1.60	1.40	1.80	1.60	1.60
120	6.40	8.60	6.40	7.20	7.15	1.80	2.00	2.00	1.80	1.90
160	8.80	9.40	6.00	9.40	8.40	2.40	2.20	2.20	2.20	2.25
Mean	6.05	7.30	5.55	6.75	6.41	1.90	1.80	1.95	1.90	1.89

SED's

Site	0.58	SxV	0.62	SxVxN	0.82
Variety	0.14	SxN	0.7	SxVxPGR	0.82
Nitrogen	0.20	VxN	0.28	SxNxPGR	1.04
PGR	0.20	SxPGR	0.7	VxNxPGR	0.56
		VxPGR	0.28		
		NxPGR	0.4		

Sievings - % Grain <2.2mm -1993

Malting site and heavy sites
(Rounded values)

	PIPKIN					PUFFIN					
	Nitrogen rate (kg/ha)										Site
	0	80	120	160	Mean	0	80	120	160	Mean	Mea
Essex	1.50	0.80	1.00	1.40	1.18	1.10	0.60	0.70	0.80	0.80	2.3
Cambs	2.30	4.60	5.60	7.90	5.10	1.20	1.20	2.00	3.70	2.03	2.2
Humberside	2.80	3.80	5.10	6.50	4.55	1.70	2.30	2.90	3.80	2.68	1.3
Midlothian	2.80	2.30	2.40	2.40	2.48	2.70	2.10	1.90	1.80	2.13	1.3
Shropshire	27.00	22.00	22.20	24.00	23.80	13.50	9.20	10.80	9.10	10.65	3.2
Mean	7.28	6.70	7.26	8.44	7.42	4.04	3.08	3.66	3.84	3.66	2.06

	Growth Regulator treatment (Nos. as method)									
	1	2	3	4		1	2	3	4	
Essex	1.10	1.10	1.20	1.30	1.18	0.70	0.70	0.80	1.00	0.80
Cambs	5.60	5.40	4.80	4.60	5.10	2.70	2.80	1.40	1.10	2.00
Humberside	3.90	4.00	4.90	5.30	4.53	2.00	1.90	3.30	3.40	2.65
Midlothian	2.40	2.30	2.50	2.50	2.43	1.90	2.00	2.60	2.10	2.15
Shropshire	25.10	25.00	20.70	24.50	23.83	10.20	10.50	11.50	10.50	10.68
Mean	7.62	7.56	6.82	7.64	7.41	3.50	3.58	3.92	3.62	3.66

	Growth Regulator treatment (Nos. as method)									
	1	2	3	4		1	2	3	4	
Nitrogen (kg/ha)										
0	7.00	7.70	6.80	7.50	7.25	3.30	3.70	4.50	4.60	4.03
80	6.90	6.90	5.60	7.30	6.68	3.50	2.70	3.00	3.10	3.08
120	7.90	7.50	6.60	7.10	7.28	3.10	3.50	4.70	3.40	3.68
160	8.70	8.30	8.20	8.60	8.45	4.10	4.30	3.50	3.40	3.83
Mean	7.63	7.60	6.80	7.63	7.41	3.50	3.55	3.93	3.63	3.65

SED's

Site	0.23	SxV	0.35	SxVxN	0.74	
Variety	0.17	SxN	0.52	SxVxPGR	0.74	
Nitrogen	0.24	VxN	0.34	SxNxPGR	1.06	
PGR	0.24	SxPGR	0.52	VxNxPGR	0.28	
		VxPGR	0.34			
		NxPGR	0.48			

Pipkin

1991

Site	N/PGR treatment	H_20 (%)	HWE2 (lokg-1)	HWE7 (lokg-1)	C/F (lokg-1)	Colour (EBC)	TSN (%)	TN (%)	SNR (%)	FAN (mg l-1)	pH	Ferm (%)	Visc (mPa)	Friab (%)
Little Oakley, Essex	80/Nil	4.4	313	310	3	2.1	0.49	1.22	40	116	5.92	79	1.51	92
	80/CCC	4.3	313	312	1	2.4	0.52	1.33	39	121	5.92	79	1.54	92
	80/Seq	4.2	314	310	4	2.4	0.49	1.29	38	114	5.95	79	1.54	91
Hardwick, Cambs.	80/Nil	4.2	310	307	3	2.4	0.53	1.44	37	123	5.99	78	1.54	90
	80/Terp	4.6	306	303	3	2.4	0.56	1.58	35	128	5.99	78	1.57	84
	80/Seq	4	309	306	3	2.5	0.56	1.48	38	128	5.99	78	1.56	85
Goole, Humberside	80/Nil	4.7	311	308	3	2.1	0.51	1.42	36	114	6.02	79	1.62	84
	80/CCC	4.6	312	309	3	2.5	0.52	1.51	34	113	5.99	79	1.65	83
	80/Seq	4.3	311	307	4	2.3	0.55	1.52	36	113	5.93	79	1.58	81
Much Wenlock, Shrops	80/CCC	4.4	308	305	3	2.1	0.53	1.39	38	125	5.94	79	1.53	89
	80/Terp	4.1	309	305	4	2.1	0.53	1.48	36	126	5.95	79	1.56	84
	80/Seq	4.4	309	306	3	2.5	0.54	1.43	38	129	5.96	79	1.57	86
Penicuick, Midlothian	80/CCC	4.3	312	310	2	2.6	0.52	1.34	39	127	5.98	78	1.56	91
	80/Terp	4.3	310	307	3	2.6	0.51	1.27	40	125	5.92	79	1.54	91
	80/Seq	4.1	308	305	3	2.6	0.5	1.24	40	119	5.91	79	1.56	90

Pipkin

1992

	N/PGR treatment	H_20 (%)	HWE2 (lokg-1)	HWE7 (lokg-1)	C/F (lokg-1)	Colour (EBC)	TSN (%)	TN (%)	SNR (%)	FAN (mg l-1)	pH	Ferm (%)	Visc (mPa)	Friab (%)
Little Oakley, Essex	80/Nil	4.7	315	312	3	2	0.46	1.22	38	102	5.95	78	1.51	96
	80/CCC	5.2	314	312	2	2.1	0.51	1.33	38	112	5.95	78	1.51	94
	80/Terp	4.9	315	313	2	2.1	0.48	1.19	40	104	5.93	78	1.49	98
	80/Seq	4.4	312	310	2	2.1	0.57	1.39	41	127	5.89	78	1.53	91
	120/Seq	4.6	312	310	3	2	0.54	1.38	39	118	5.92	78	1.56	93
Hardwick, Cambs.	80/Nil	4.5	311	309	2	2	0.59	1.59	37	118	5.97	79	1.64	84
	80/CCC	4.6	307	304	3	2.1	0.62	1.77	35	124	6	76	1.55	87
	80/Terp	4.6	305	305	0	2	0.62	1.64	38	125	5.98	79	1.54	84
	80/Seq	4.8	307	300	7	2.1	0.68	1.84	37	139	5.93	79	1.54	82
	120/Seq	4.8	317	304	13	2.1	0.65	1.74	37	134	5.96	79	1.54	84
Penicuick, Midlothian	80/Nil	4.7	309	304	5	2.2	0.52	1.55	34	111	6.01	76	1.8	78
	80/CCC	4.9	311	303	8	2.1	0.51	1.5	34	111	6.03	76	1.74	81
	80/Terp	5.1	312	305	7	2.2	0.52	1.49	35	117	6.02	77	1.67	84
	80/Seq	4.9	307	299	8	2.2	0.53	1.67	32	116	6.02	76	1.79	72
	120/Terp	5.2	309	301	8	2.2	0.56	1.59	35	124	6.04	76	1.69	77

Pipkin

1993

	N/PGR treatment	H_20 (%)	HWE2 (lokg-1)	HWE7 (lokg-1)	C/F (lokg-1)	Colour (EBC)	TSN (%)	TN (%)	SNR (%)	FAN (mg l-1)	pH	Ferm (%)	Visc (mPa)	Friab (%)
Little Oakley, Essex	80/Nil	3.9	313	311	2	-	0.53	1.29	41	0.11	5.95	75	1.53	83
	80/CCC	4.1	312	310	2	-	0.56	1.39	40	0.11	5.92	75	1.52	83
	80/Terp	3.9	311	310	1	-	0.52	1.29	40	0.1	5.98	76	1.52	
	80/Seq	3.6	313	311	2	-	0.53	1.26	42	0.11	5.93	76	1.53	89
	120/Terp	3.9	311	308	3	-	0.59	1.5	39	0.12	5.94	75	1.56	75
						-								
Hardwick, Cambs.	80/Nil	5.8	311	304	7	-	0.64	1.67	38	0.12	6.02	76	1.51	82
	80/CCC	5.6	308	303	5	-	0.63	1.66	38	0.12	6.04	76	1.55	83
	80/Terp	5.9	306	303	3	-	0.64	1.7	38	0.11	6.06	75	1.55	79
	80/Seq	5.4	306	303	3	-	0.64	1.75	37	0.11	6.05	76	1.55	84
	120/CCC	5.6	304	298	6	-	0.63	1.83	34	0.11	6.09	75	1.59	75
Much Wenlock, Shrops	80/Nil	4.3	309	306	3	-	0.5	1.34	37	0.09	5.98	79	1.49	90
	80/CCC	4.5	310	308	2	-	0.48	1.26	38	0.08	6	78	151	90
	80/Terp	4.5	309	308	1	-	0.47	1.28	37	0.09	6.01	78	1.52	90
	80/Seq	4.5	310	308	2	-	0.45	1.23	37	0.09	5.98	78	1.51	92
	120/Nil	4.7	309	305	4	-	0.51	1.36	38	0.1	5.98	79	1.48	90
						-								
Penicuick, Midlothian	80/Terp	4.2	308	302	6	-	0.54	1.35	40	0.1	5.98	75	1.71	74
	80/Seq	4.1	307	301	6	-	0.5	1.32	38	0.09	6.01	76	1.76	78
	120/Seq	4.2	307	299	6	-	0.48	1.36	35	0.09	6.03	76	1.79	73
	120/Terp	4.4	308	300	8	-	0.52	1.35	39	0.09	5.99	75	1.79	75
	120/CCC	4.9	308	299	9	-	0.47	1.34	35	0.08	6.05	75	1.87	70

Puffin

1991

	N/PGR treatment	H_20 (%)	HWE2 (lokg-1)	HWE7 (lokg-1)	C/F (lokg-1)	Colour (EBC)	TSN (%)	TN (%)	SNR (%)	FAN (mg l-1)	pH	Ferm (%)	Visc (mPa)	Friab (%)
Little Oakley, Essex	80/Nil	4.6	314	310	4	2.1	0.58	1.42	41	124	6	78	1.53	89
	80/CCC	5.1	313	309	4	2.1	0.55	1.48	37	115	6	78	1.53	84
	80/Seq	5.1	311	307	4	2.1	0.58	1.52	38	123	5.94	78	1.55	86
Hardwick, Cambs.	80/Nil	4.5	311	307	4	2.1	0.62	1.56	40	138	5.96	79	1.57	89
	80/Terp	4.6	308	306	2	2.1	0.6	1.6	38	130	5.97	77	1.58	88
	80/Seq	4.5	310	306	4	2.1	0.59	1.61	37	130	5.93	78	1.61	84
Goole, Humberside	80/Nil	3.8	308	303	5	2.3	0.59	1.59	37	124	5.94	76	1.59	74
	80/CCC	4.4	308	302	6	2.3	0.59	1.6	37	126	5.94	75	1.59	76
	80/Seq	4.1	308	304	4	2.3	0.64	1.66	39	131	5.97	75	1.63	73
Much Wenlock, Shrops	80/CCC	4.5	307	304	3	2.1	0.63	1.63	39	142	6.02	78	1.57	82
	80/Terp	4.8	307	303	4	2.1	0.6	1.6	38	134	6.02	78	1.55	80
	80/Seq	4.5	306	304	2	2.1	0.6	1.66	36	128	6.03	78	1.56	82
Penicuick, Midlothian	80/CCC	3.8	312	307	5	2.4	0.55	1.36	40	124	5.96	78	1.6	87
	80/Terp	4.1	314	311	3	2.3	0.55	1.35	41	124	5.96	78	1.58	89
	80/Seq	4	313	308	5	2.3	0.54	1.34	40	123	5.94	77	1.59	88

Puffin

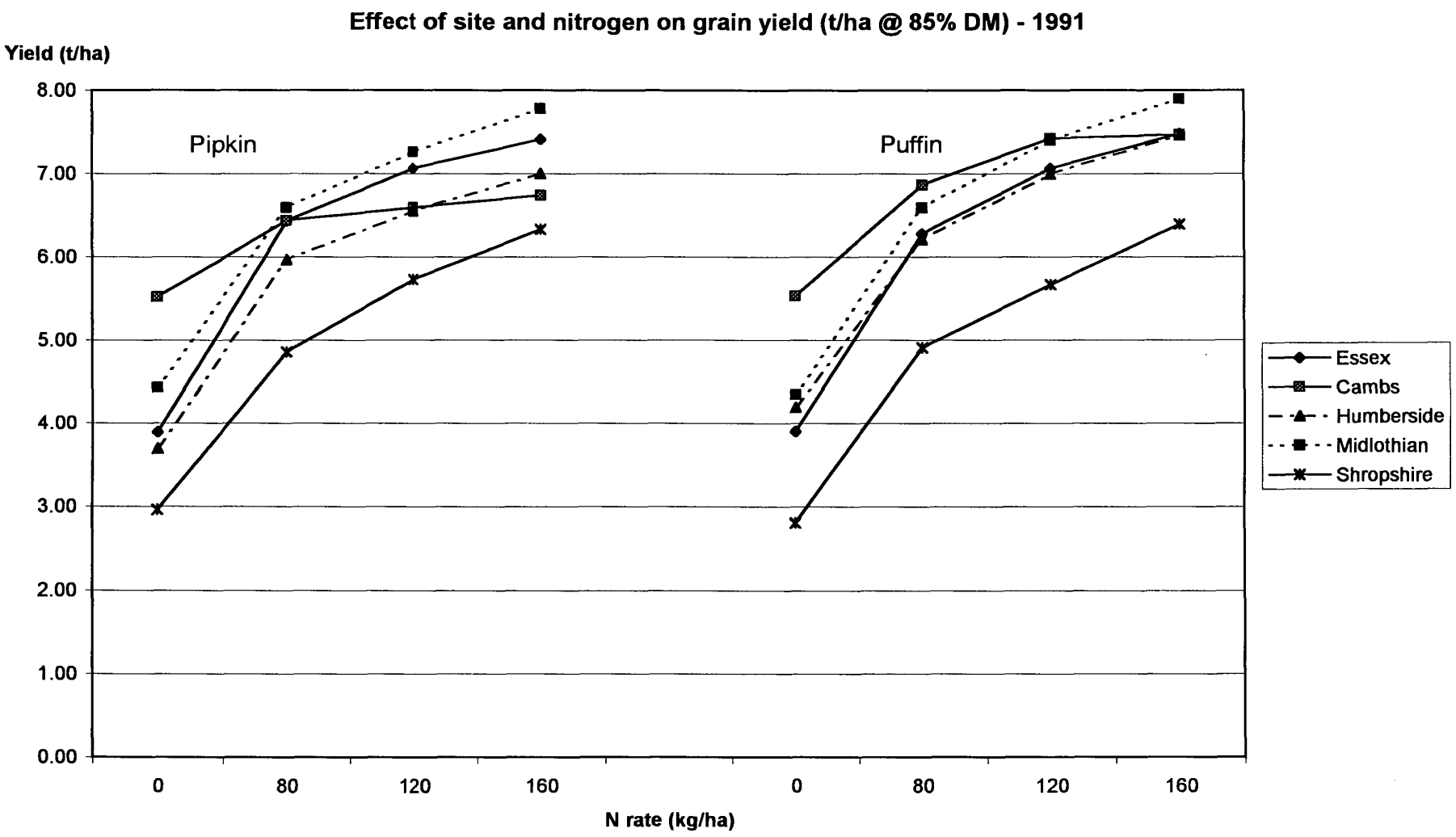
1992

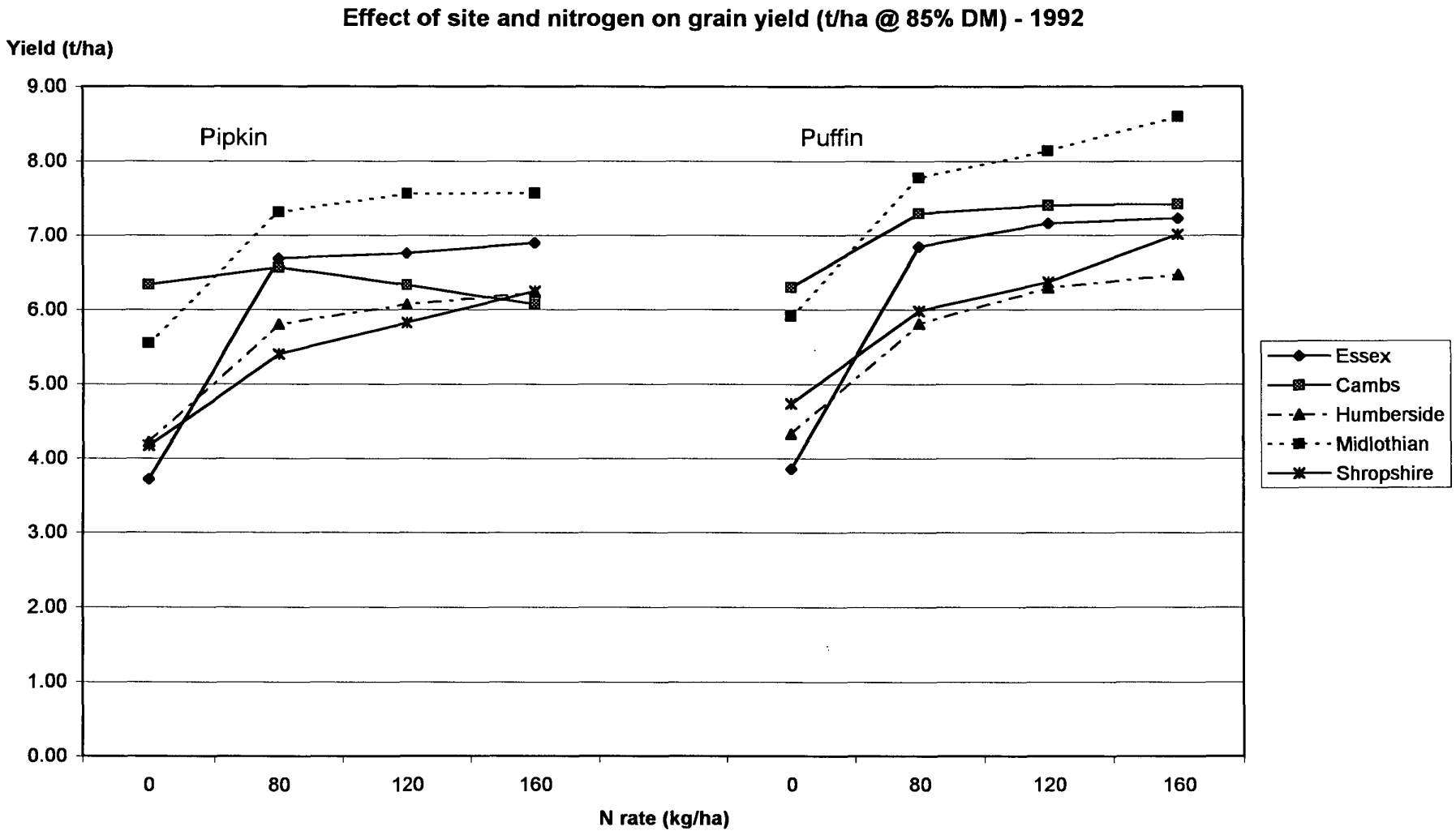
	N/PGR treatment	H_20 (%)	HWE2 (lokg-1)	HWE7 (lokg-1)	C/F (lokg-1)	Colour (EBC)	TSN (%)	TN (%)	SNR (%)	FAN (mg l-1)	pH	Ferm (%)	Visc (mPa)	Friab (%)
Little Oakley, Essex	80/Nil	4.7	317	312	5	2	0.53	1.28	41	121	5.96	78	1.55	93
	80/CCC	4.2	315	311	4	2.1	0.6	1.39	43	138	5.9	78	1.57	90
	80/Terp	4.4	317	315	2	2.1	0.54	1.32	41	121	5.96	77	1.57	96
	80/Seq	4.8	313	309	4	2	0.6	1.53	39	134	5.92	78	1.55	87
	120/Seq	4.7	313	310	3	2	0.64	1.57	41	141	5.89	78	1.55	87
Hardwick, Cambs.	80/Nil	5.1	314	308	6	1.8	0.67	1.82	37	138	5.97	78	1.65	76.1
	80/CCC	4.4	312	304	8	1.8	0.69	1.98	35	136	5.91	77	1.69	73.1
	80/Terp	4.3	311	307	4	1.8	0.68	1.8	38	138	5.97	78	1.69	76.4
	80/Seq	4.6	308	302	6	1.8	0.7	1.89	37	139	5.94	77	1.68	73.9
	120/Seq	3.8	311	305	6	1.9	0.7	1.83	38	146	5.97	77	1.66	75..0
Penicuick, Midlothian	80/Nil	5.5	310	301	9	1.9	0.64	1.65	39	118	5.98	74	1.63	75
	80/CCC	4.5	313	304	9	2	0.6	1.65	36	114	5.95	75	1.65	75
	80/Terp	4.8	311	303	8	2	0.66	1.64	40	129	5.92	75	1.63	76
	80/Seq	4.6	310	301	9	1.9	0.62	1.64	38	116	5.95	-	1.72	73
	120/Terp	4.2	308	300	8	2	0.64	1.68	38	117	5.93	-	1.69	73

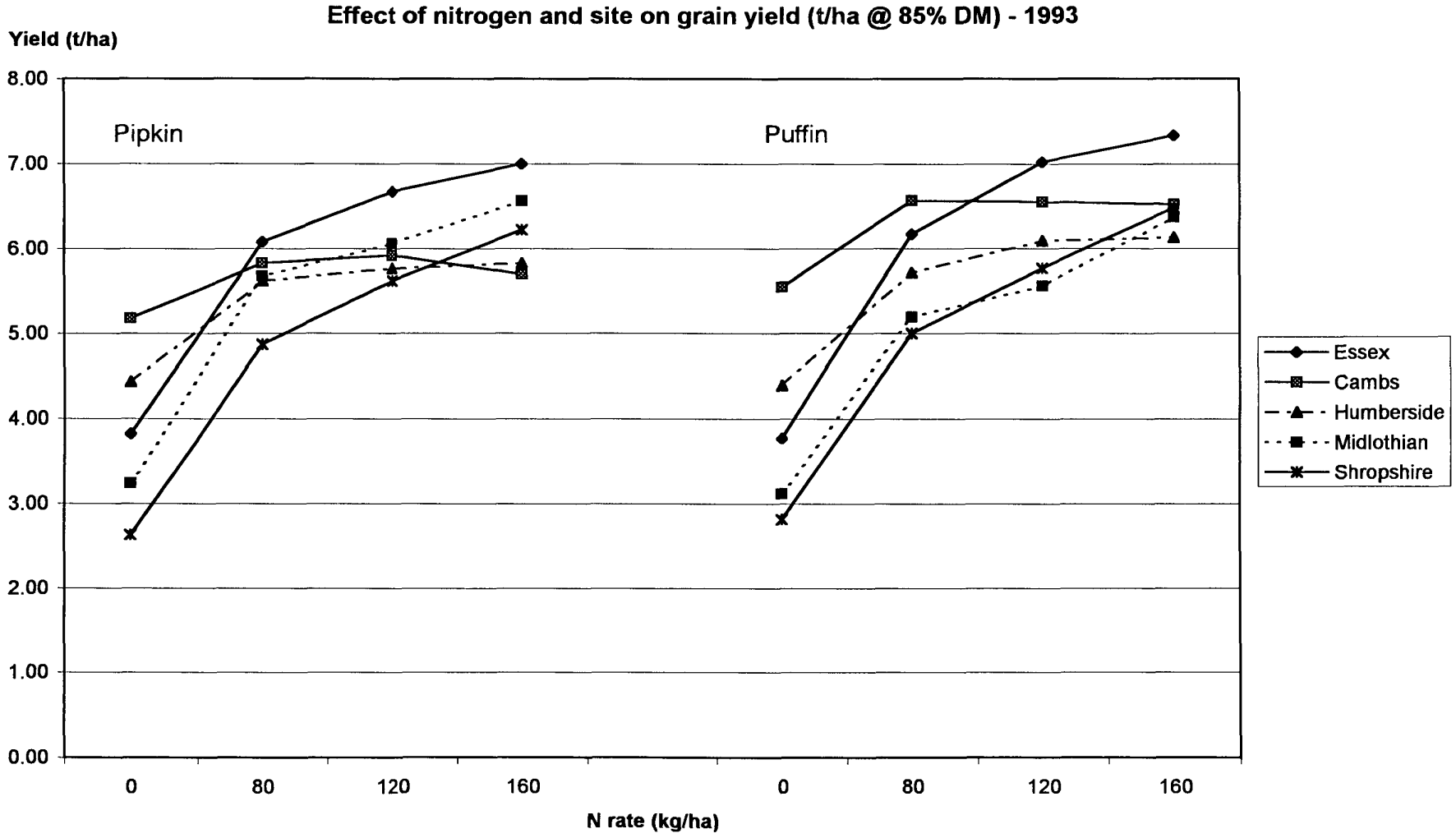
Puffin

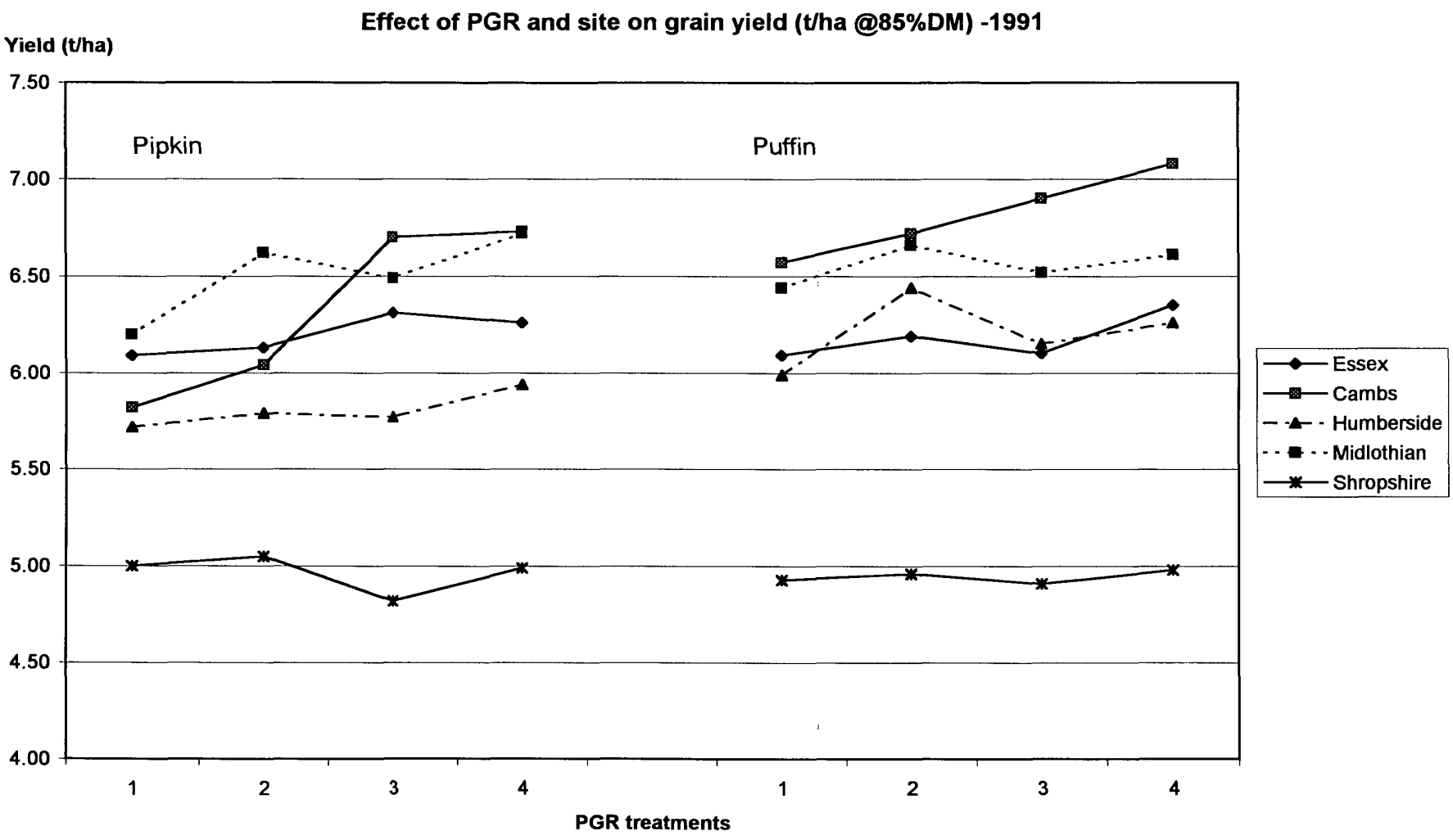
1993

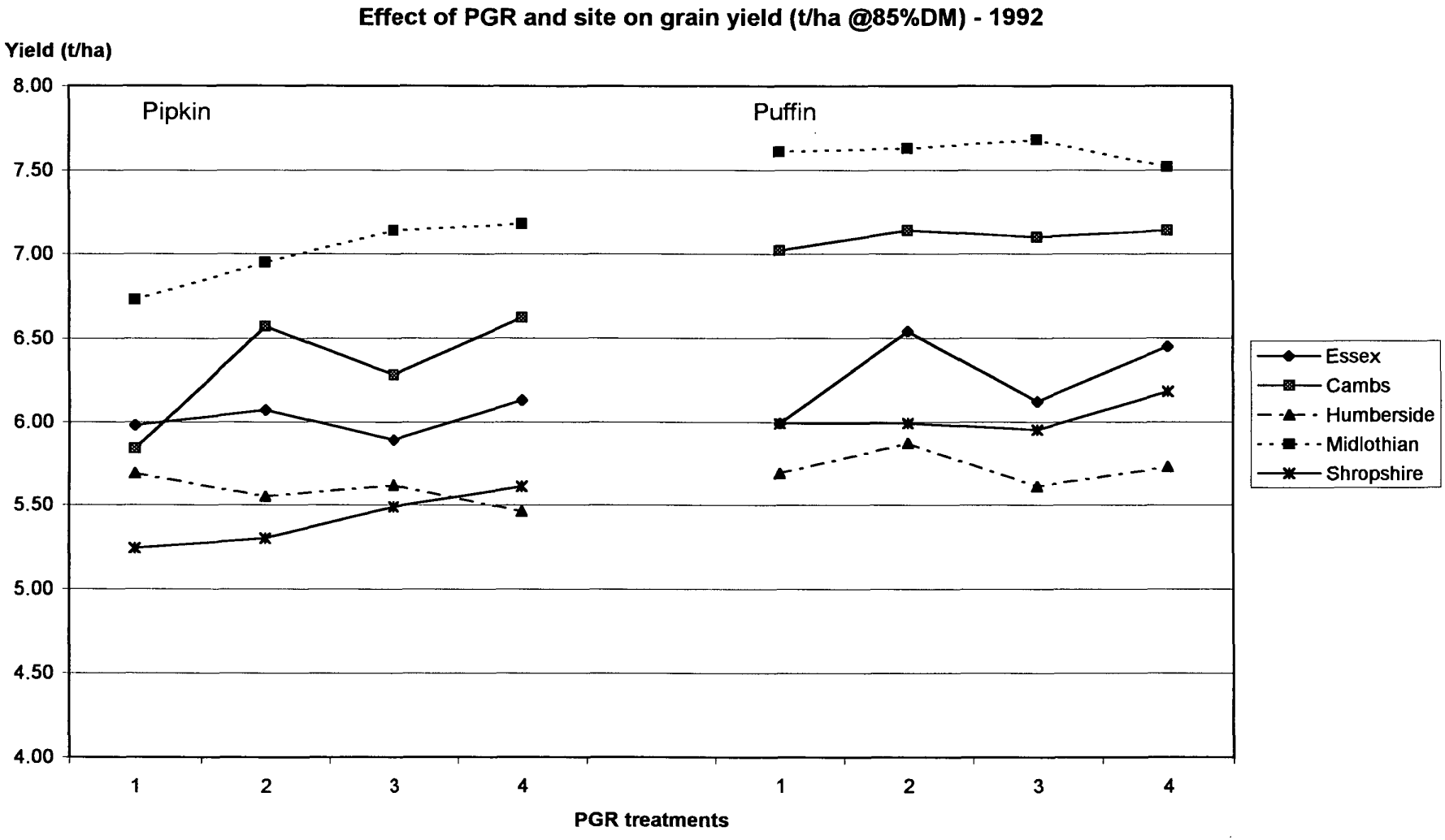
	N/PGR treatment	H_20 (%)	HWE2 (lokg-1)	HWE7 (lokg-1)	C/F (lokg-1)	Colour (EBC)	TSN (%)	TN (%)	SNR (%)	FAN (mg l-1)	pH	Ferm (%)	Visc (mPa)	Friab (%)
Little Oakley, Essex	80/Nil	4.1	313	309	4	-	0.59	1.42	42	0.11	5.99	75	1.53	80
	80/CCC	3.5	313	309	4	-	0.61	1.42	43	1.1	5.98	74	1.53	81
	80/Terp	3.5	312	308	4	-	0.57	1.37	42	0.1	6.01	74	1.53	83
	80/Seq	3.6	312	308	4	-	0.58	1.39	42	0.1	6	74	1.54	84
	120/Terp	3.4	311	306	5	-	0.6	1.46	41	0.1	6	73	1.56	79
						-								
Hardwick, Cambs.	80/Nil	5.9	309	307	2	-	0.73	1.82	40	0.12	6.05	76	1.58	75
	80/CCC	5.1	307	301	6	-	0.74	1.92	39	0.12	6	75	1.6	70
	80/Terp	5.5	308	304	4	-	0.65	1.82	36	0.1	6.05	75	1.59	74
	80/Seq	5.5	308	301	7	-	0.68	1.86	37	0.11	6.07	76	1.65	73
	120/CCC	5.2	303	302	1	-	0.68	1.85	37	0.11	6.06	75	1.61	74
Much Wenlock, Shrops	80/Nil	4.8	315	311	4	-	0.63	1.39	45	0.12	5.96	78	1.5	91
	80/CCC	4.2	314	311	3	-	0.59	1.4	42	0.11	5.95	77	1.53	89
	80/Terp	4.2	313	310	3	-	0.62	1.41	44	0.11	5.98	77	1.52	89
	80/Seq	4.4	315	311	4	-	0.62	1.43	43	0.11	5.98	77	1.56	89
	120/Nil	4.1	313	308	5	-	0.66	1.52	43	0.12	5.92	76	1.53	87
						-								
Penicuick, Midlothian	80/Terp	4.6	311	306	5	-	0.56	1.47	38	0.1	5.96	73	1.68	78
	80/Seq	3.9	310	304	6	-	0.56	1.4	40	0.1	5.95	73	1.66	77
	120/Seq	4.1	310	301	9	-	0.53	1.4	38	0.09	5.96	73	1.75	75
	120/Terp	4.4	309	300	9	-	0.57	1.52	38	0.1	5.87	72	1.78	70
	120/CCC	3.6	308	300	8	-	0.57	1.49	38	0.1	5.89	72	1.75	74

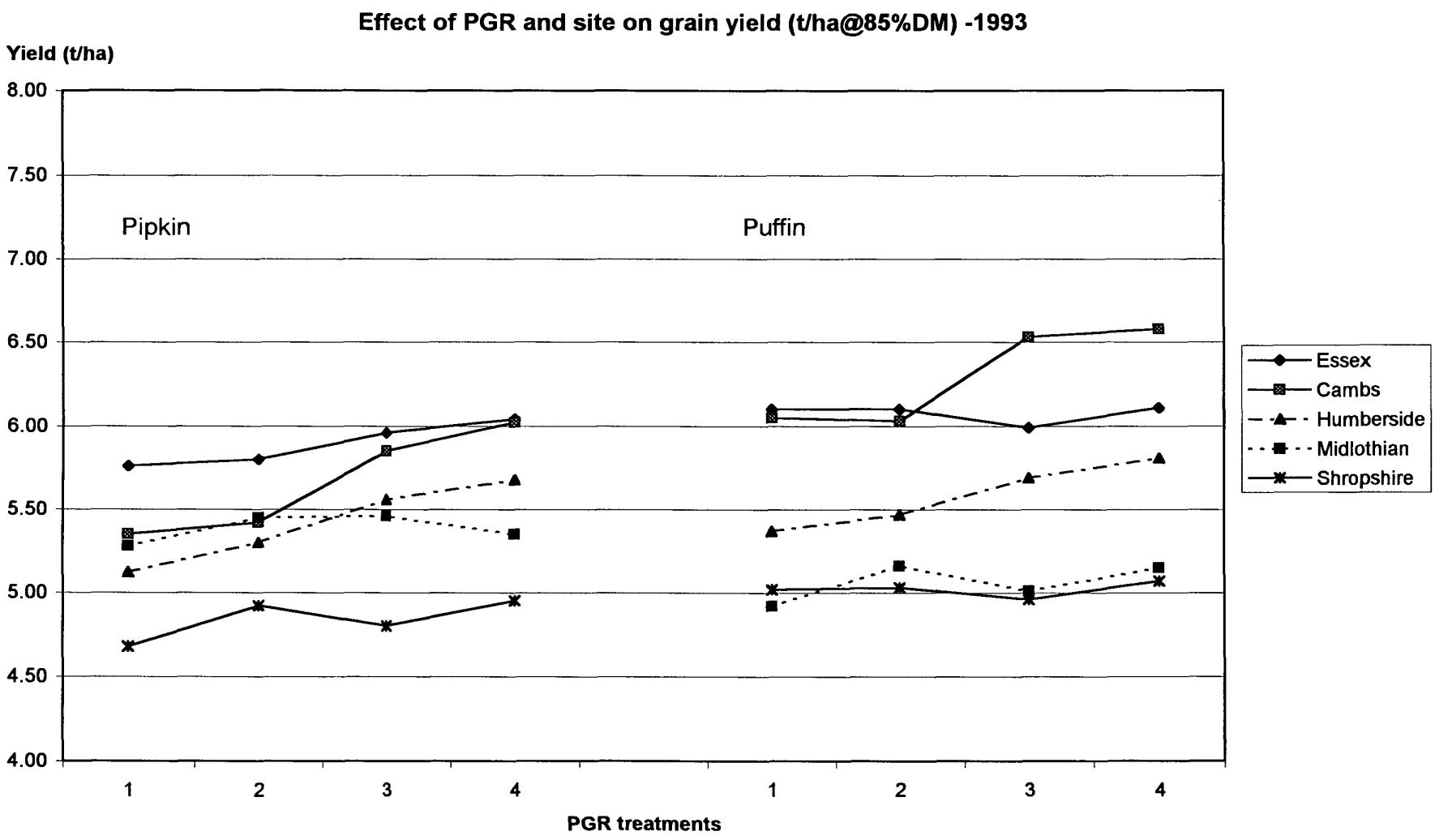

Effect of site and nitrogen on grain yield (t/ha @ 85% DM) - 1991
Yield (t/ha)
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
Pipkin
Puffin
0
80
120
160
0
80
120
160
N rate (kg/ha)
Essex
Cambs
Humberside
Midlothian
Shropshire

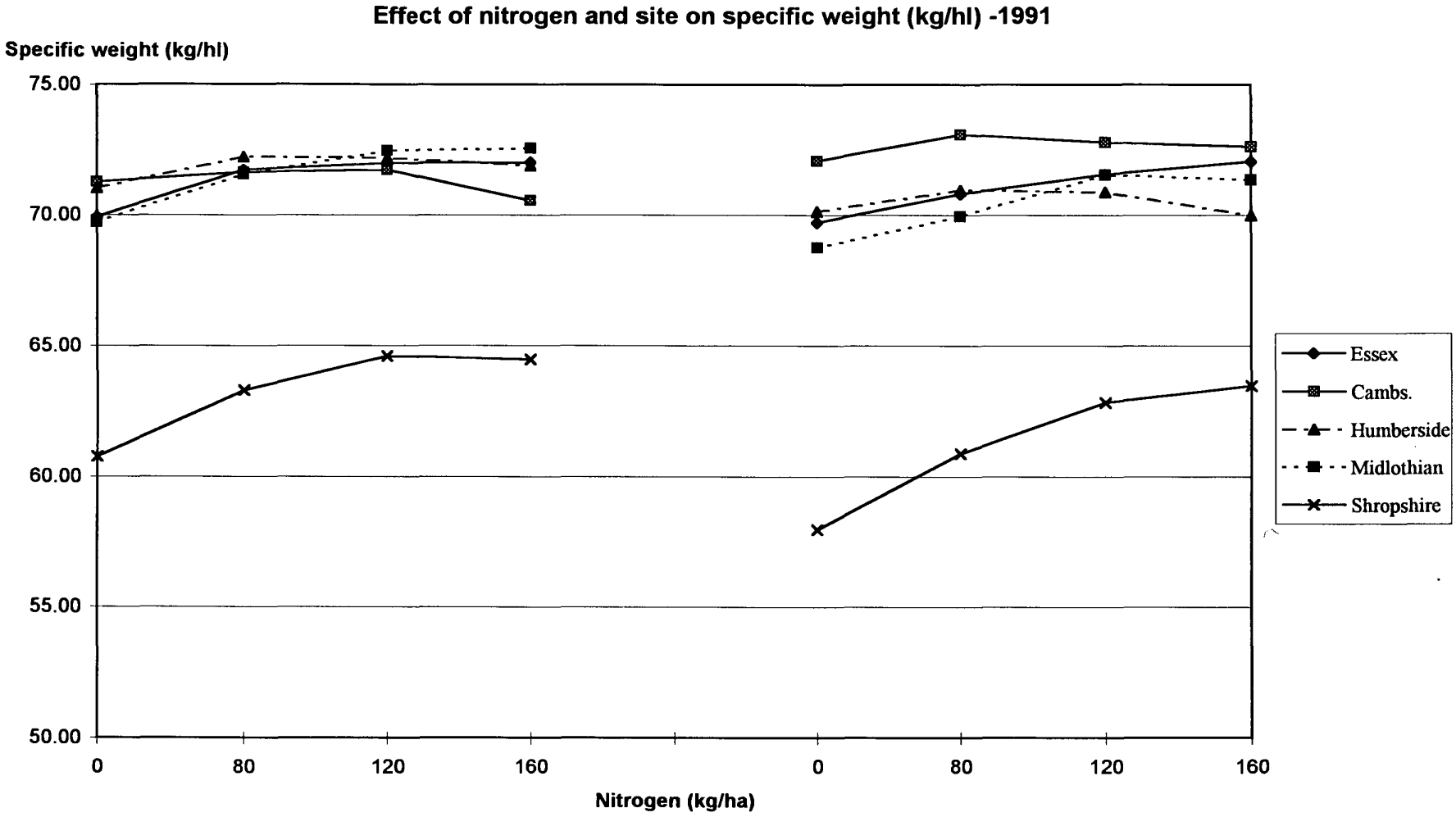

Effect of site and nitrogen on grain yield (t/ha @ 85% DM) - 1992
Yield (t/ha)
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
Pipkin
Puffin
0
80
120
160
0
80
120
160
N rate (kg/ha)
Essex
Cambs
Humberside
Midlothian
Shropshire

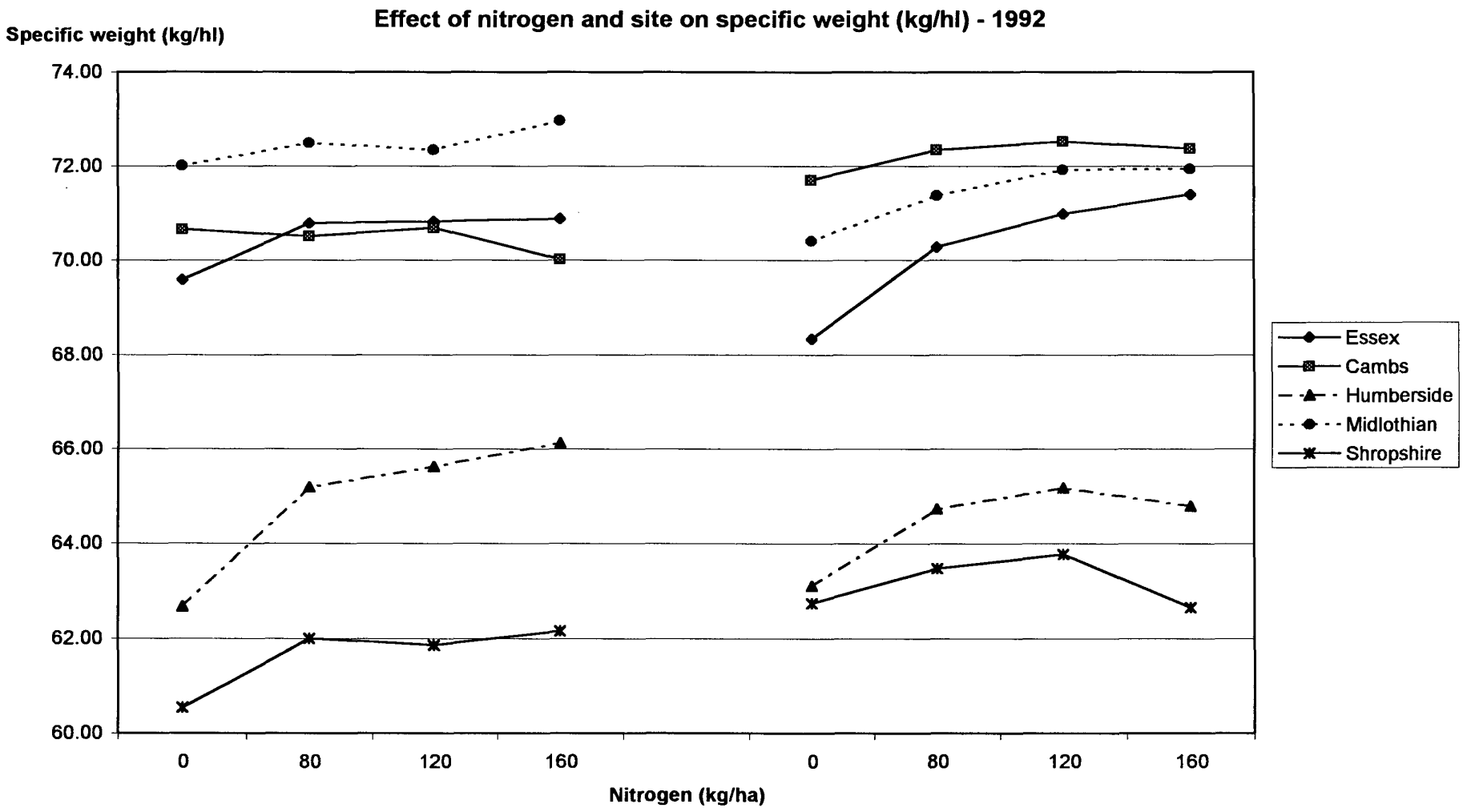

Effect of nitrogen and site on grain yield (t/ha @ 85% DM) - 1993
Yield (t/ha)
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
Pipkin
Puffin
0
80
120
160
0
80
120
160
N rate (kg/ha)
Essex
Cambs
Humberside
Midlothian
Shropshire

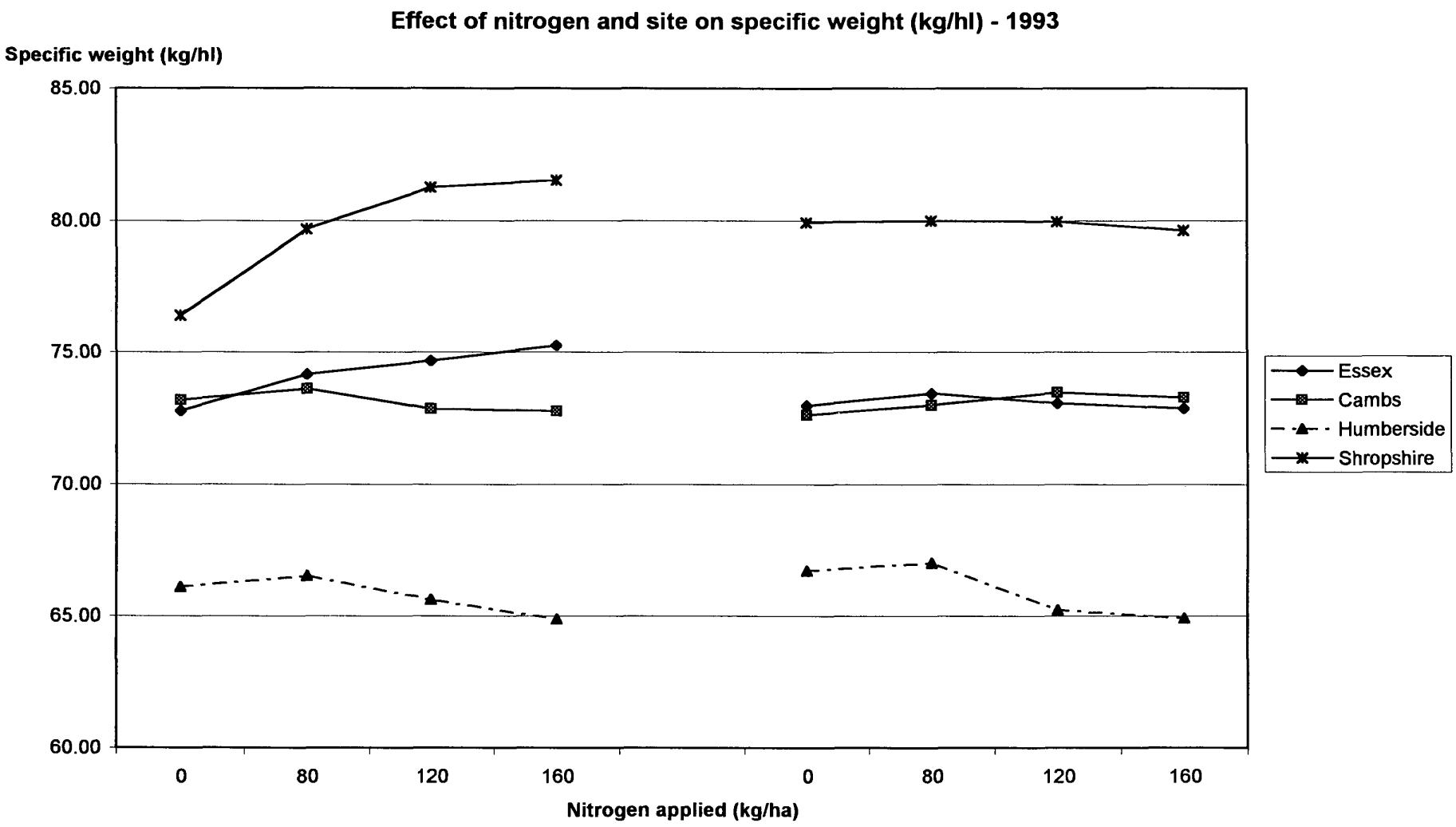

Effect of PGR and site on grain yield (t/ha @85%DM) -1991
Yield (t/ha)
7.50
7.00
6.50
6.00
5.50
5.00
4.50
4.00
Pipkin
Puffin
1
2
3
4
1
2
3
4
PGR treatments
Essex
Cambs
Humberside
Midlothian
Shropshire

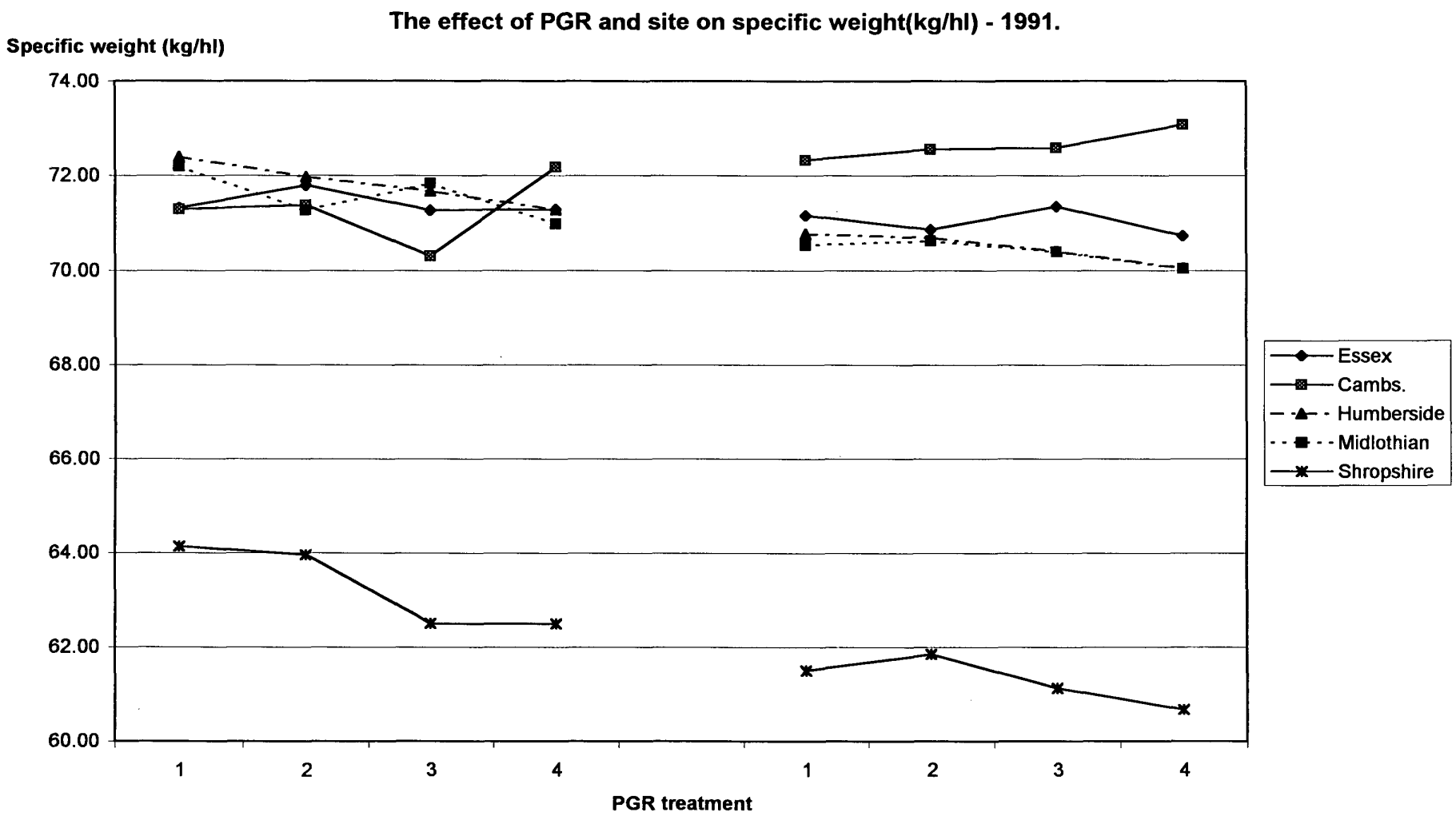

Effect of PGR and site on grain yield (t/ha @85%DM) - 1992
Yield (t/ha)
8.00
7.50
7.00
6.50
6.00
5.50
5.00
4.50
4.00
Pipkin
Puffin
1
2
3
4
1
2
3
4
PGR treatments
Essex
Cambs
Humberside
Midlothian
Shropshire

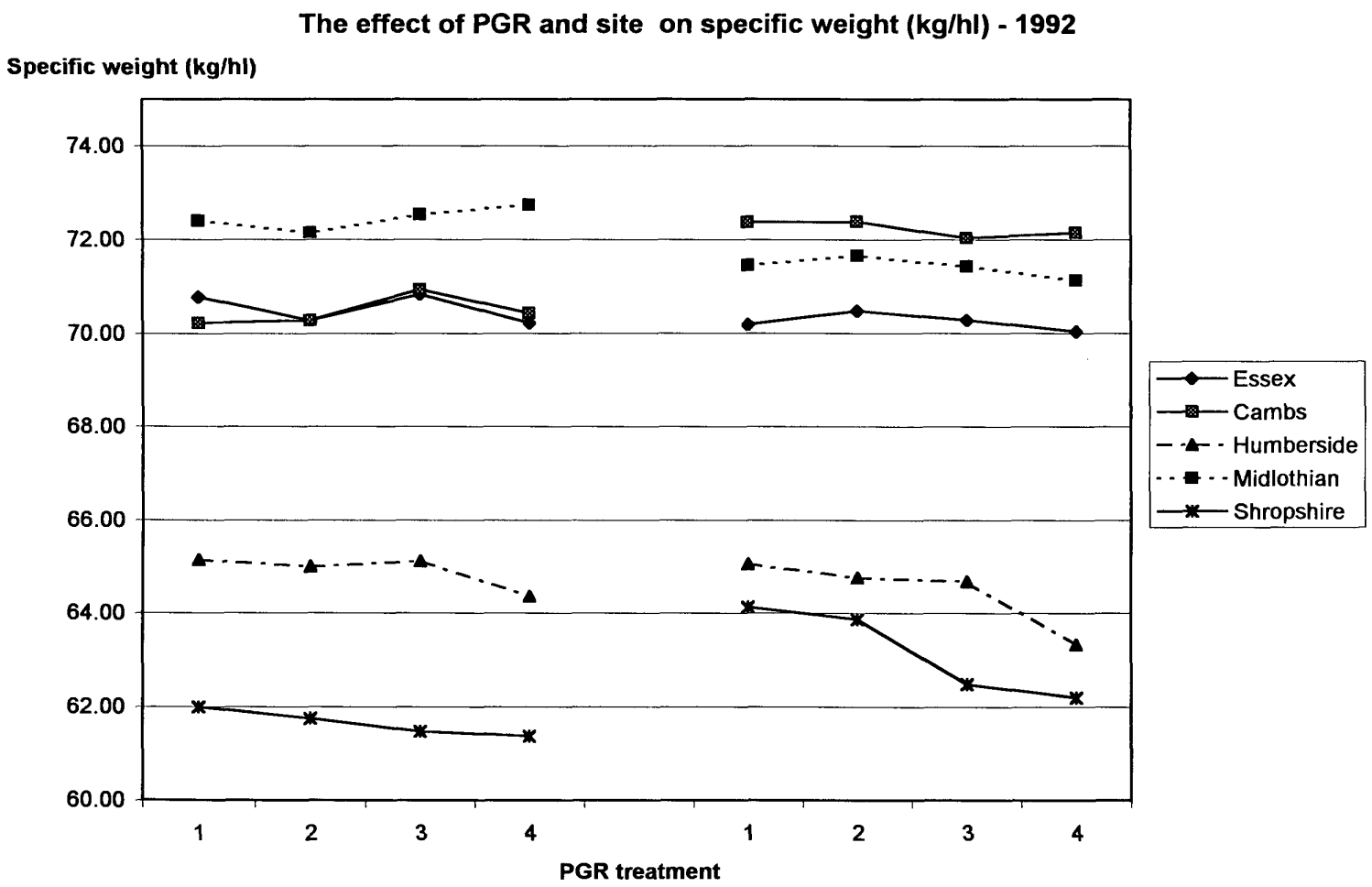

Effect of PGR and site on grain yield (t/ha@85%DM) -1993
Yield (t/ha)
8.00
7.50
7.00
6.50
6.00
5.50
5.00
4.50
4.00
Pipkin
Puffin
1
2
3
4
1
2
3
4
PGR treatments
Essex
Cambs
Humberside
Midlothian
Shropshire

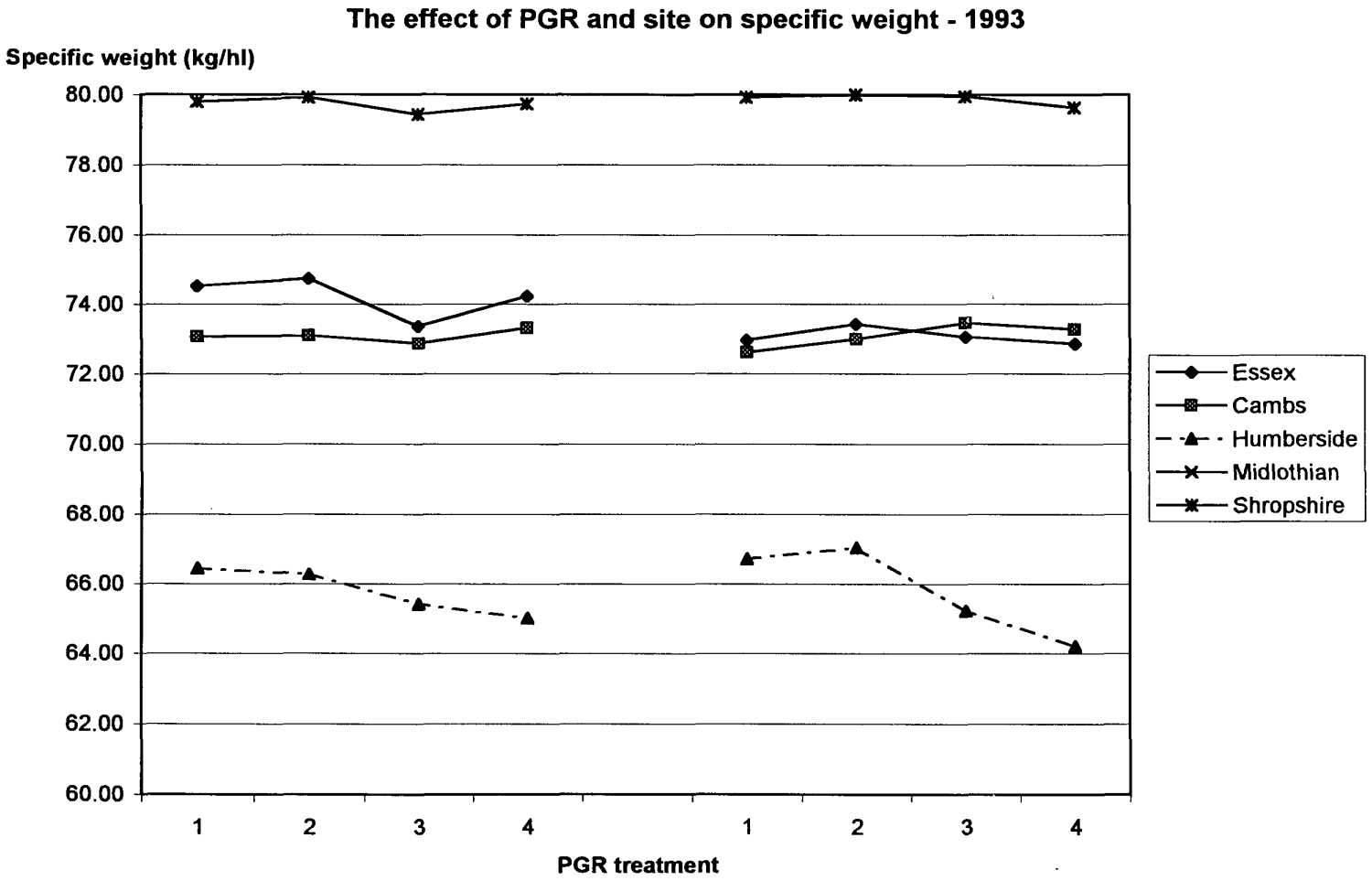

Effect of nitrogen and site on specific weight (kg/hl) -1991
Specific weight (kg/hl)
75.00
70.00
65.00
60.00
55.00
50.00
0
80
120
160
0
80
120
160
Nitrogen (kg/ha)
Essex
Cambs.
Humberside
Midlothian
Shropshire

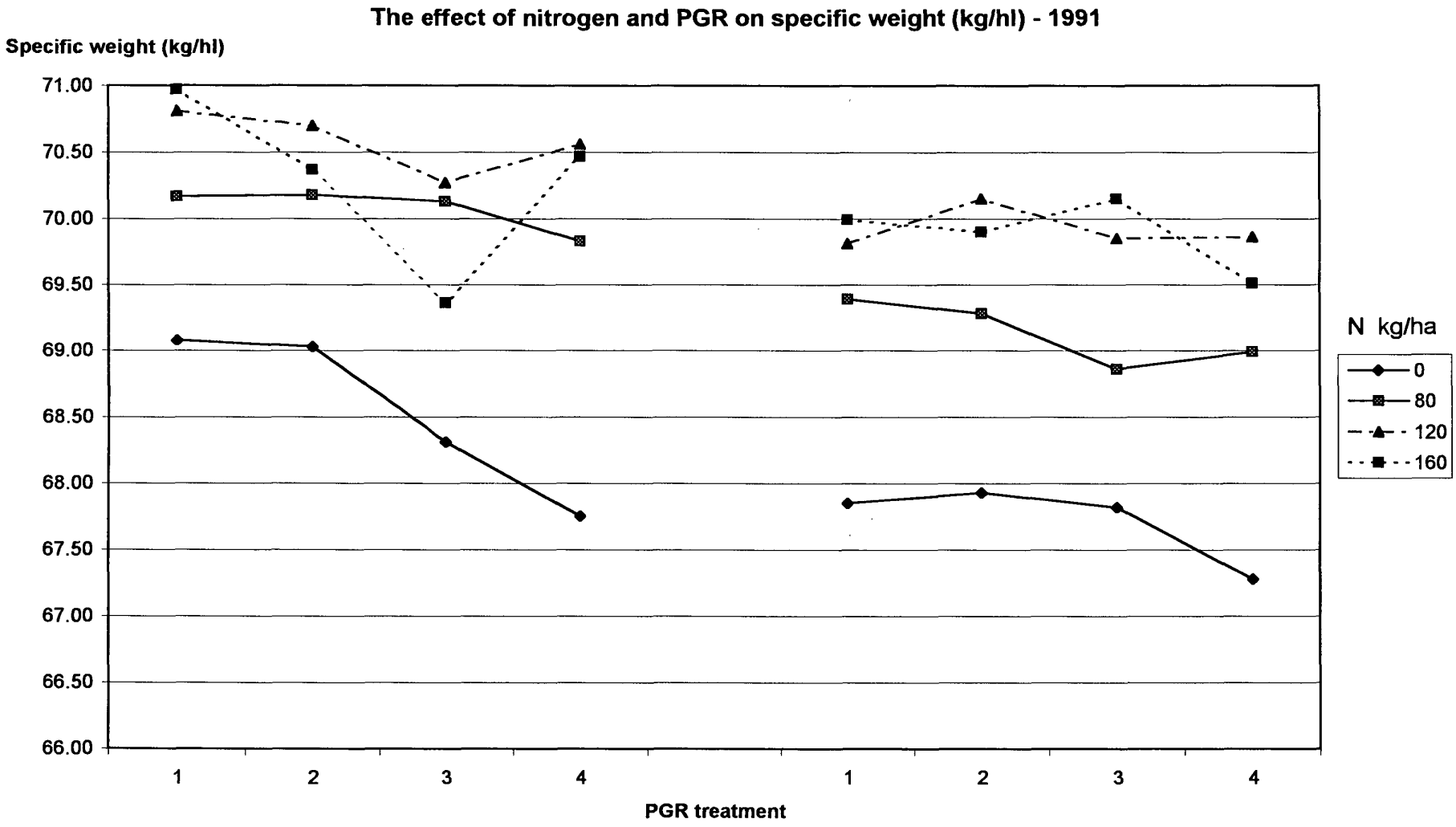

Effect of nitrogen and site on specific weight (kg/hl) - 1992
Specific weight (kg/hl)
74.00
72.00
70.00
68.00
66.00
64.00
62.00
60.00
0
80
120
160
0
80
120
160
Nitrogen (kg/ha)
Essex
Cambs
Humberside
Midlothian
Shropshire

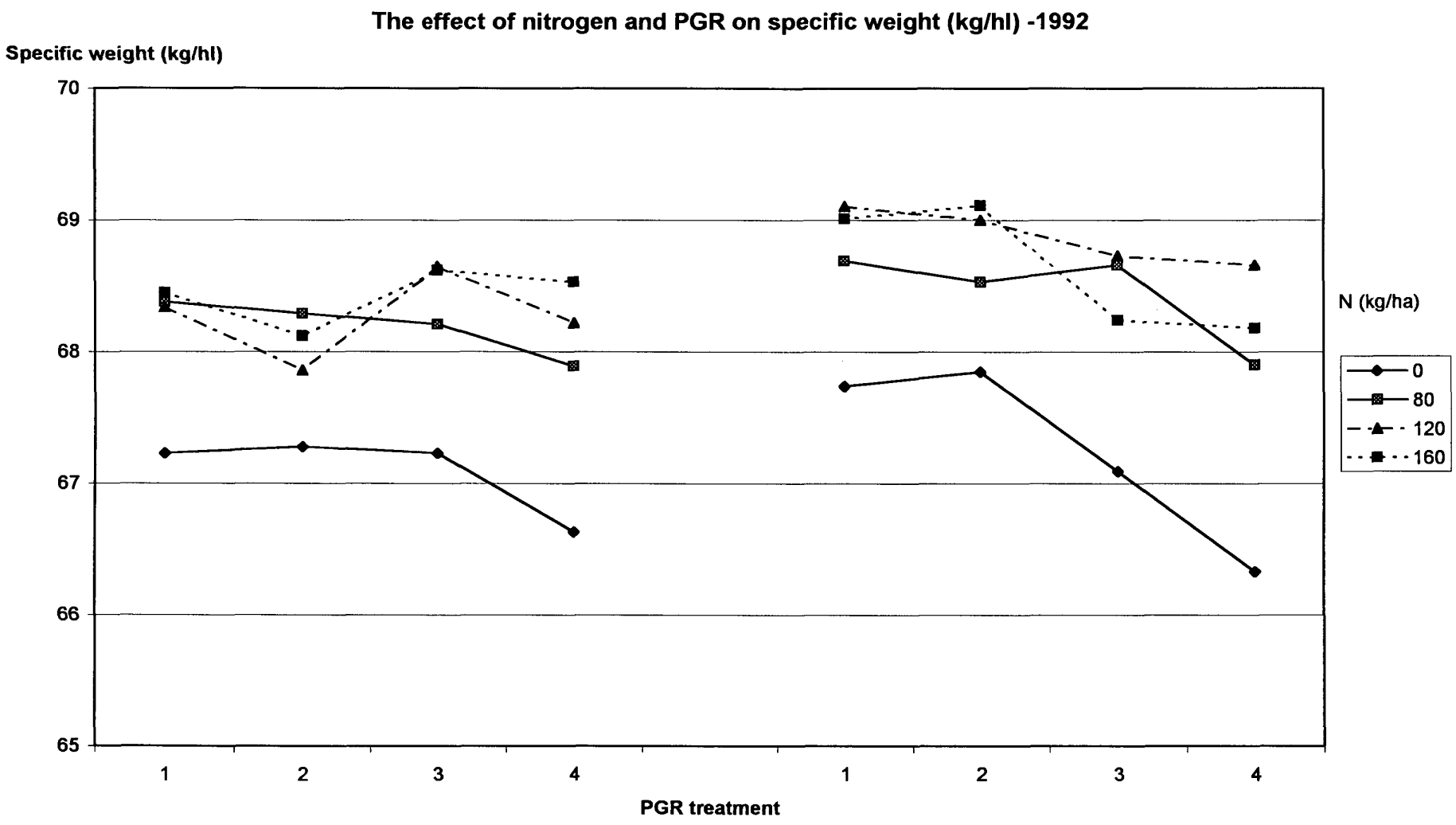

Effect of nitrogen and site on specific weight (kg/hl) - 1993
Specific weight (kg/hl)
85.00
80.00
75.00
70.00
65.00
60.00
0
80
120
160
0
80
120
160
Nitrogen applied (kg/ha)
Essex
Cambs
Humberside
Shropshire

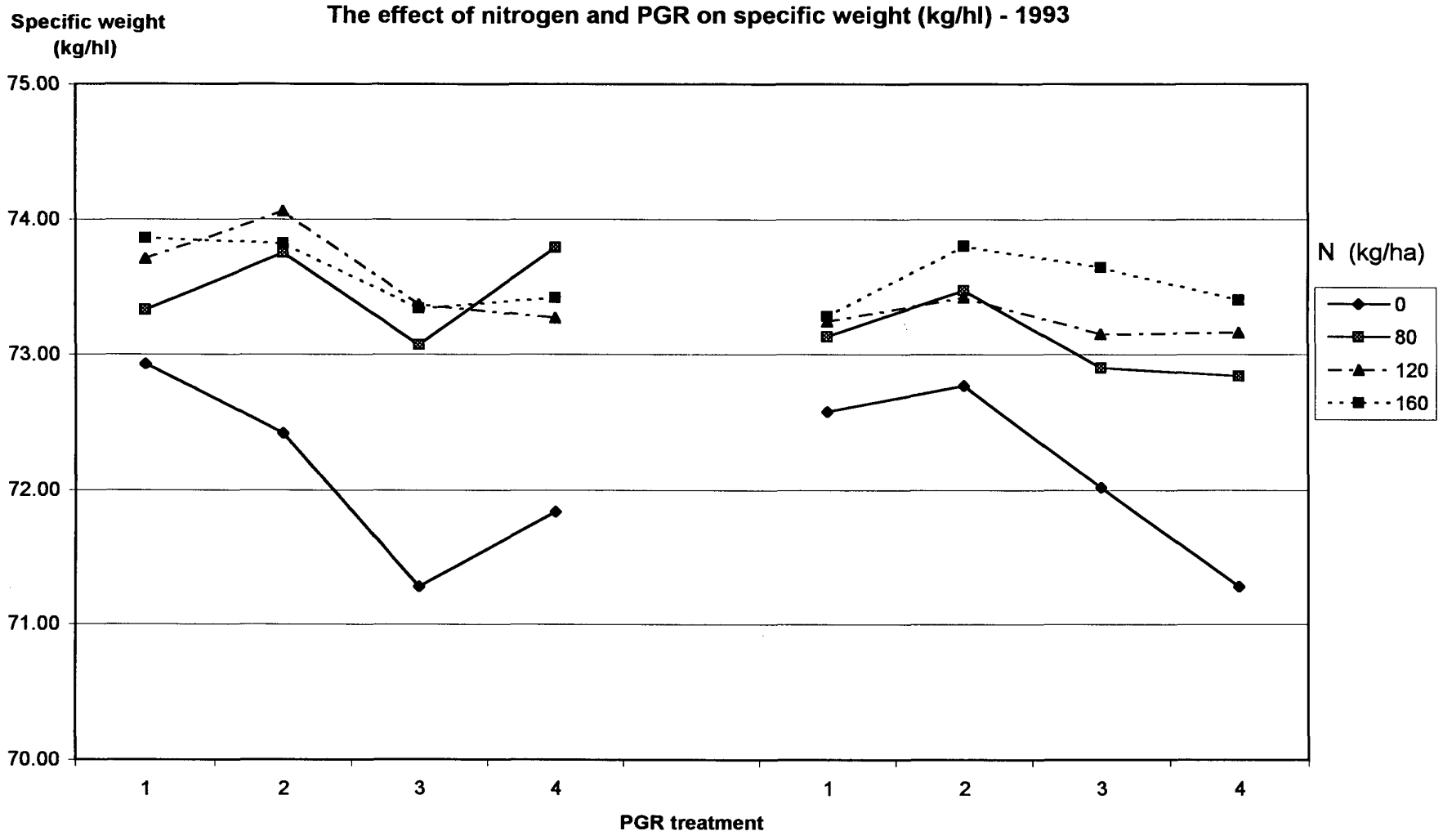

The effect of PGR and site on specific weight(kg/hl) - 1991.
Specific weight (kg/hl)
74.00
72.00
70.00
68.00
66.00
64.00
62.00
60.00
1
2
3
4
1
2
3
4
PGR treatment
Essex
Cambs.
Humberside
Midlothian
Shropshire

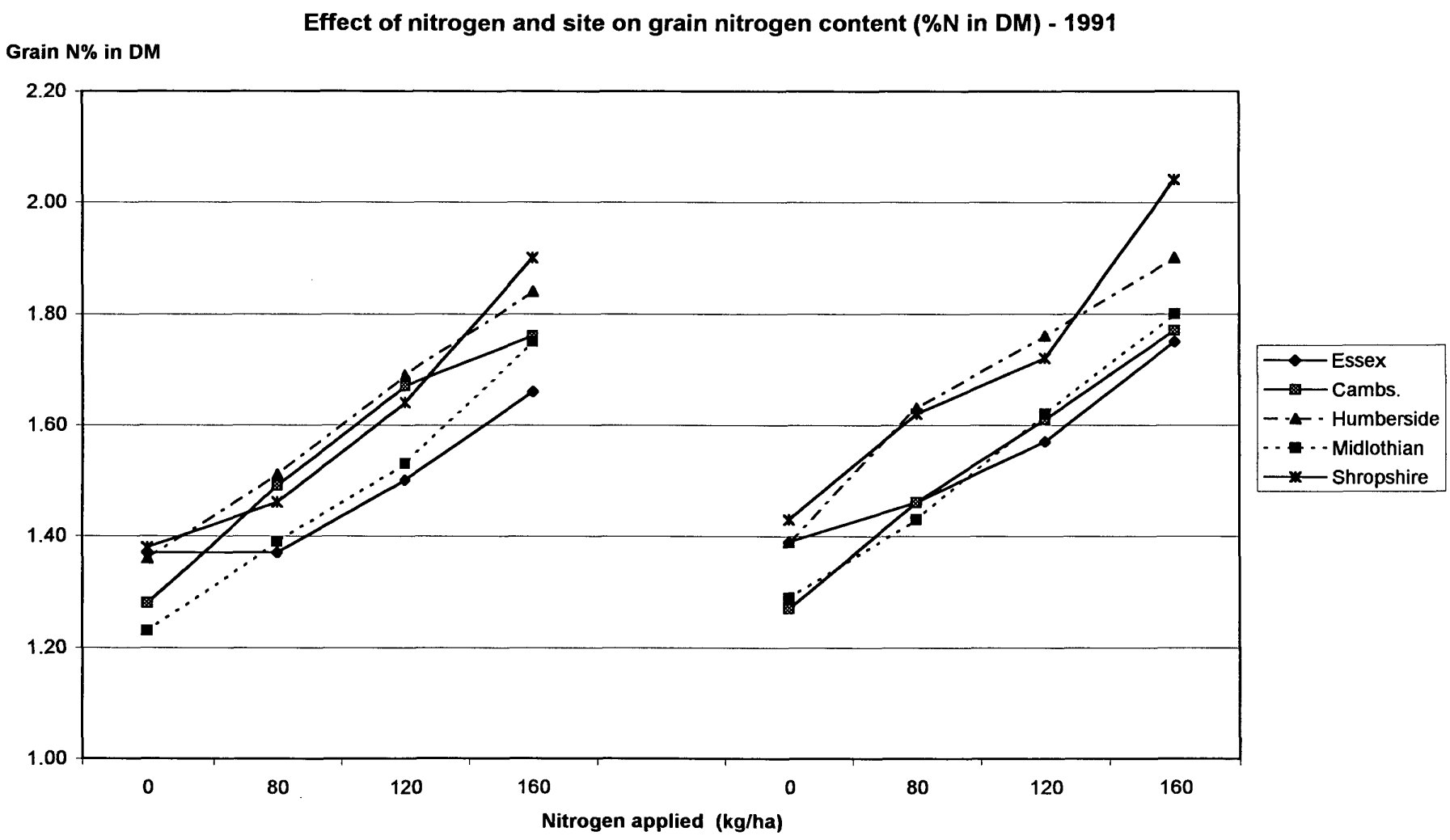

The effect of PGR and site on specific weight (kg/hl) - 1992
Specific weight (kg/hl)
74.00
72.00
70.00
68.00
66.00
64.00
62.00
60.00
1
2
3
4
1
2
3
4
PGR treatment
Essex
Cambs
Humberside
Midlothian
Shropshire

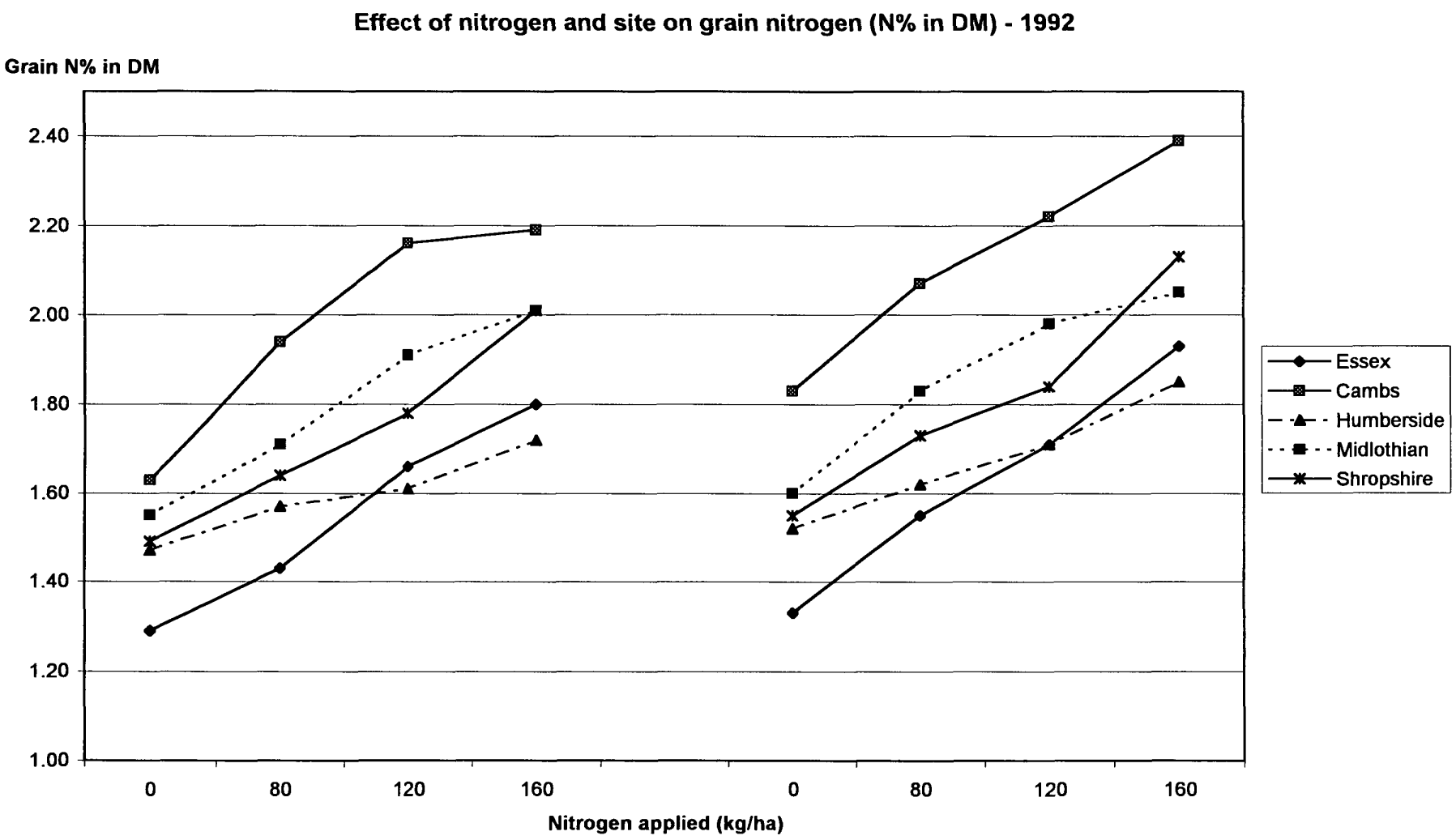

The effect of PGR and site on specific weight - 1993
Specific weight (kg/hl)
80.00
78.00
76.00
74.00
72.00
70.00
68.00
66.00
64.00
62.00
60.00
1
2
3
4
1
2
3
4
PGR treatment
Essex
Cambs
Humberside
Midlothian
Shropshire

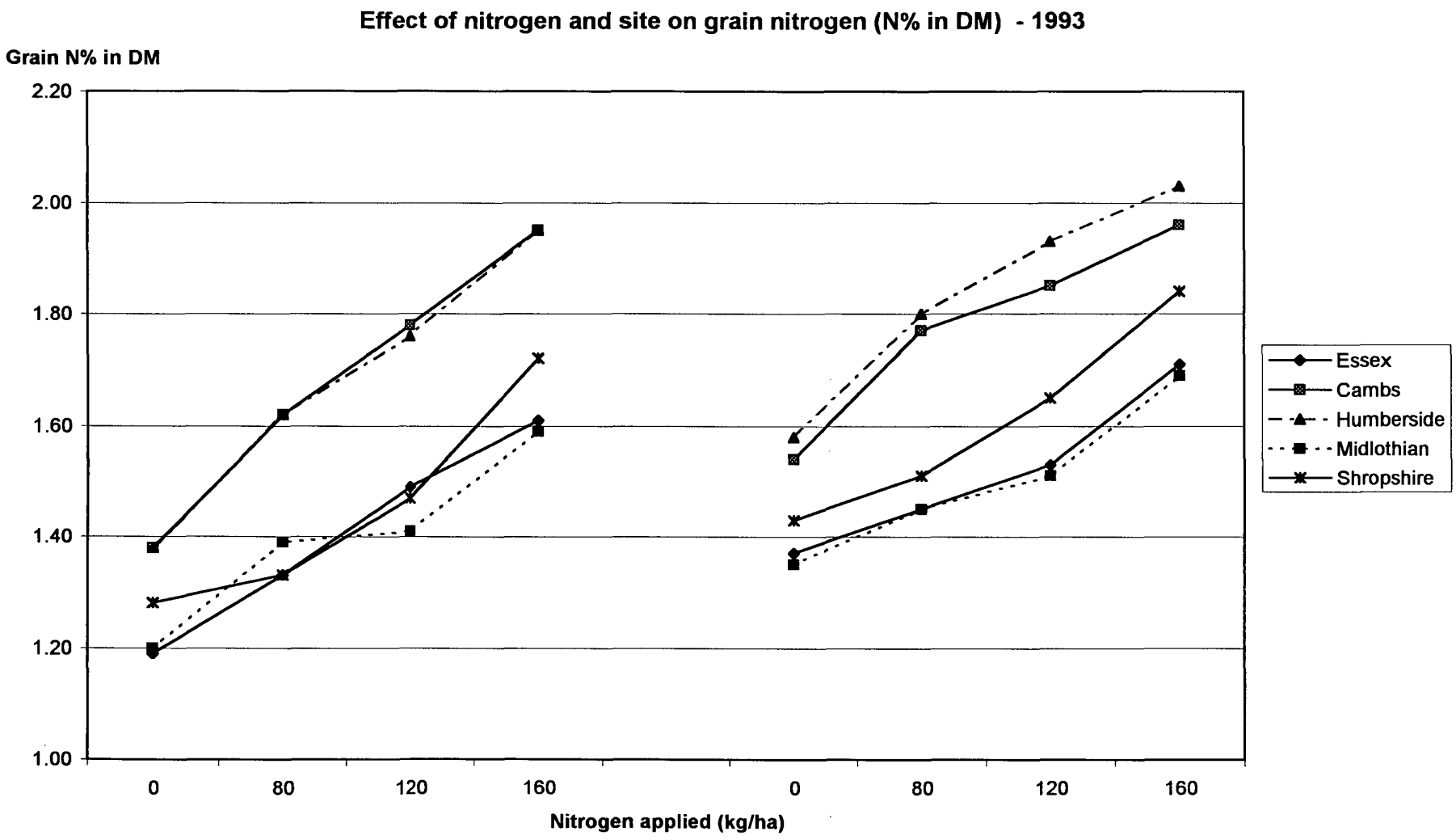

The effect of nitrogen and PGR on specific weight (kg/hl) - 1991
Specific weight (kg/hl)
71.00
70.50
70.00
69.50
69.00
68.50
68.00
67.50
67.00
66.50
66.00
1
2
3
4
1
2
3
4
PGR treatment
N kg/ha
0
80
120
160

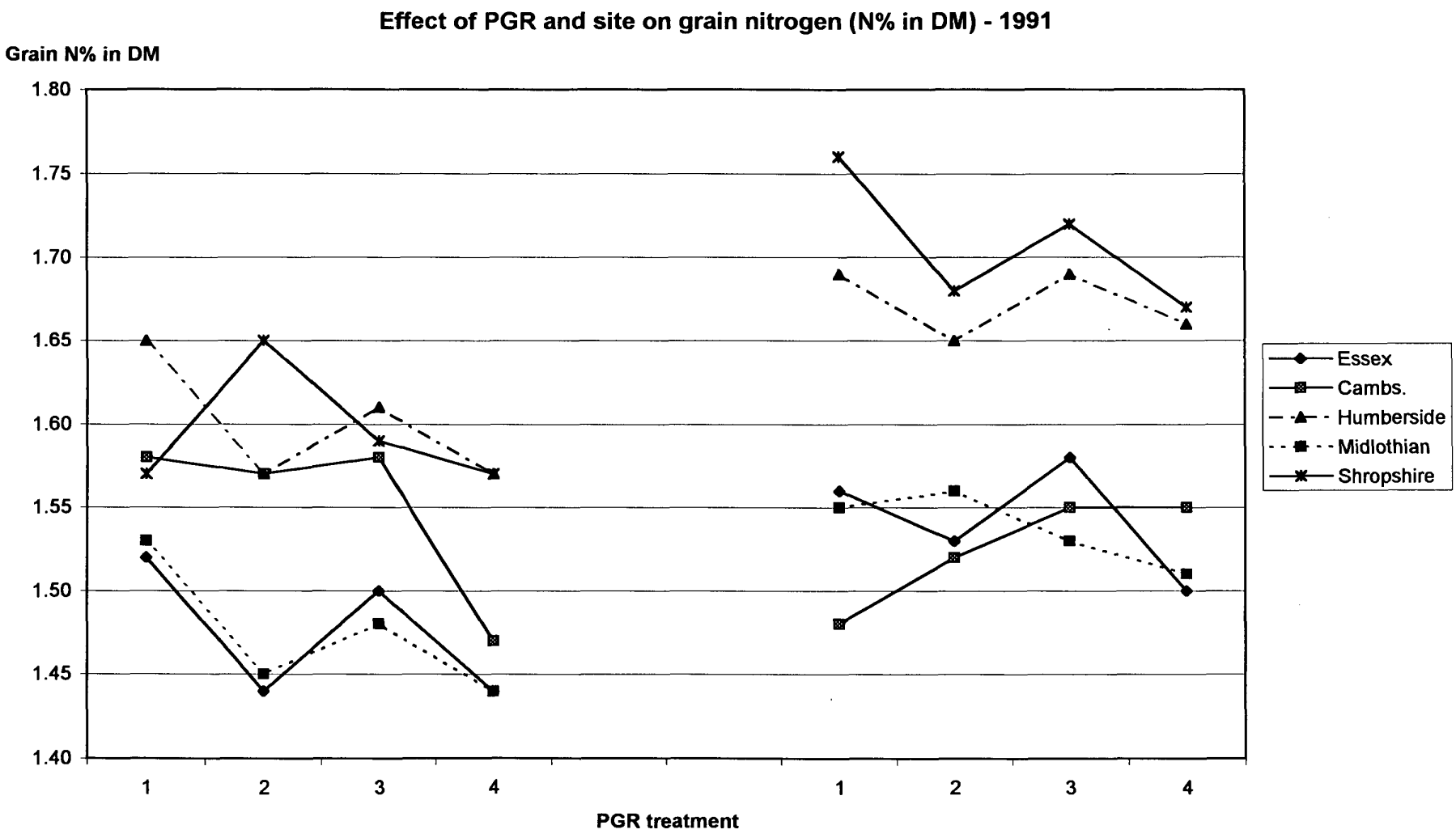

The effect of nitrogen and PGR on specific weight (kg/hl) -1992
Specific weight (kg/hl)
70
69
68
67
66
65
1
2
3
4
1
2
3
4
PGR treatment
N (kg/ha)
0
80
120
160

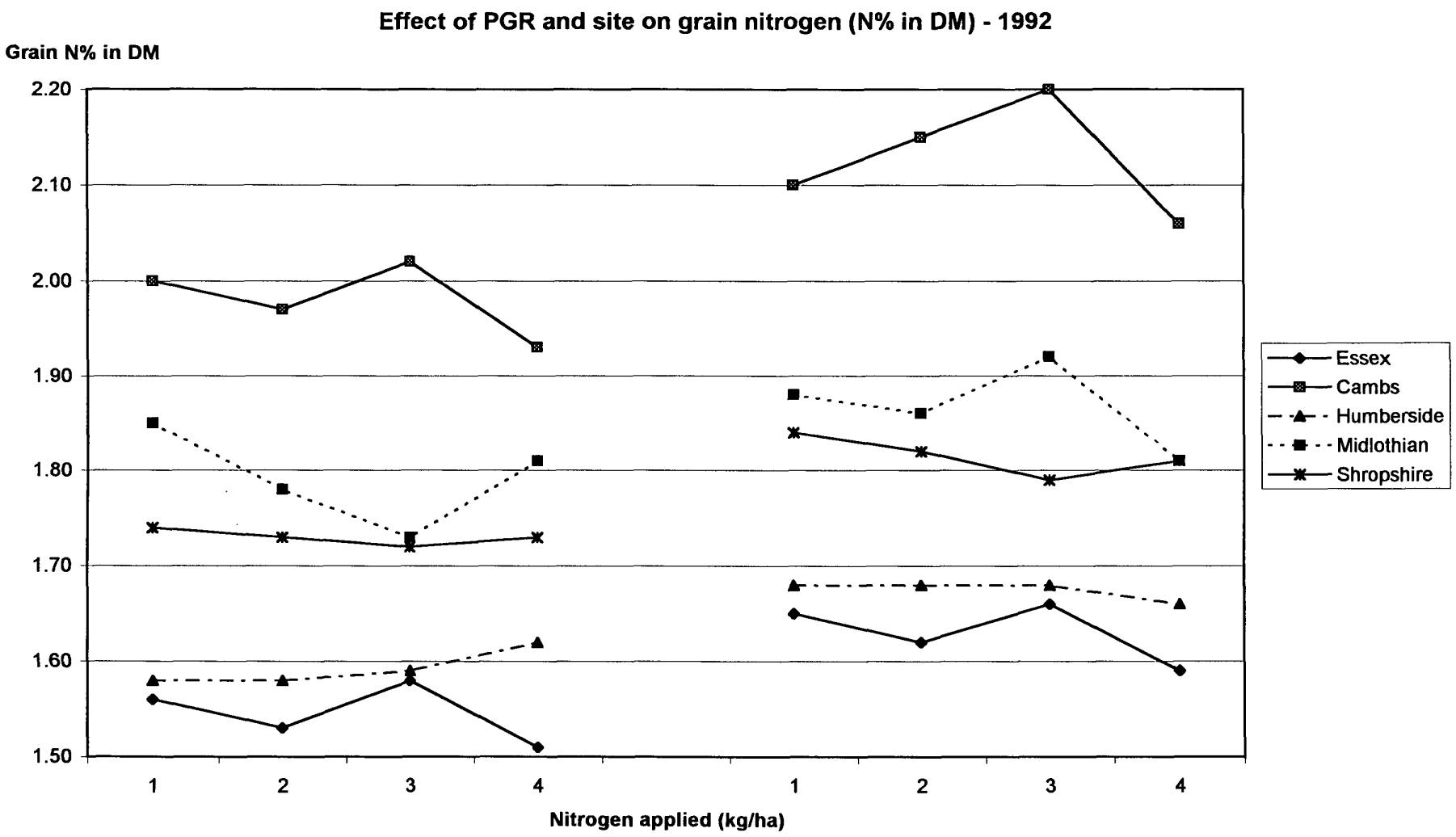

The effect of nitrogen and PGR on specific weight (kg/hl) - 1993
Specific weight (kg/hl)
75.00
74.00
73.00
72.00
71.00
70.00
1
2
3
4
1
2
3
4
PGR treatment
N (kg/ha)
0
80
120
160

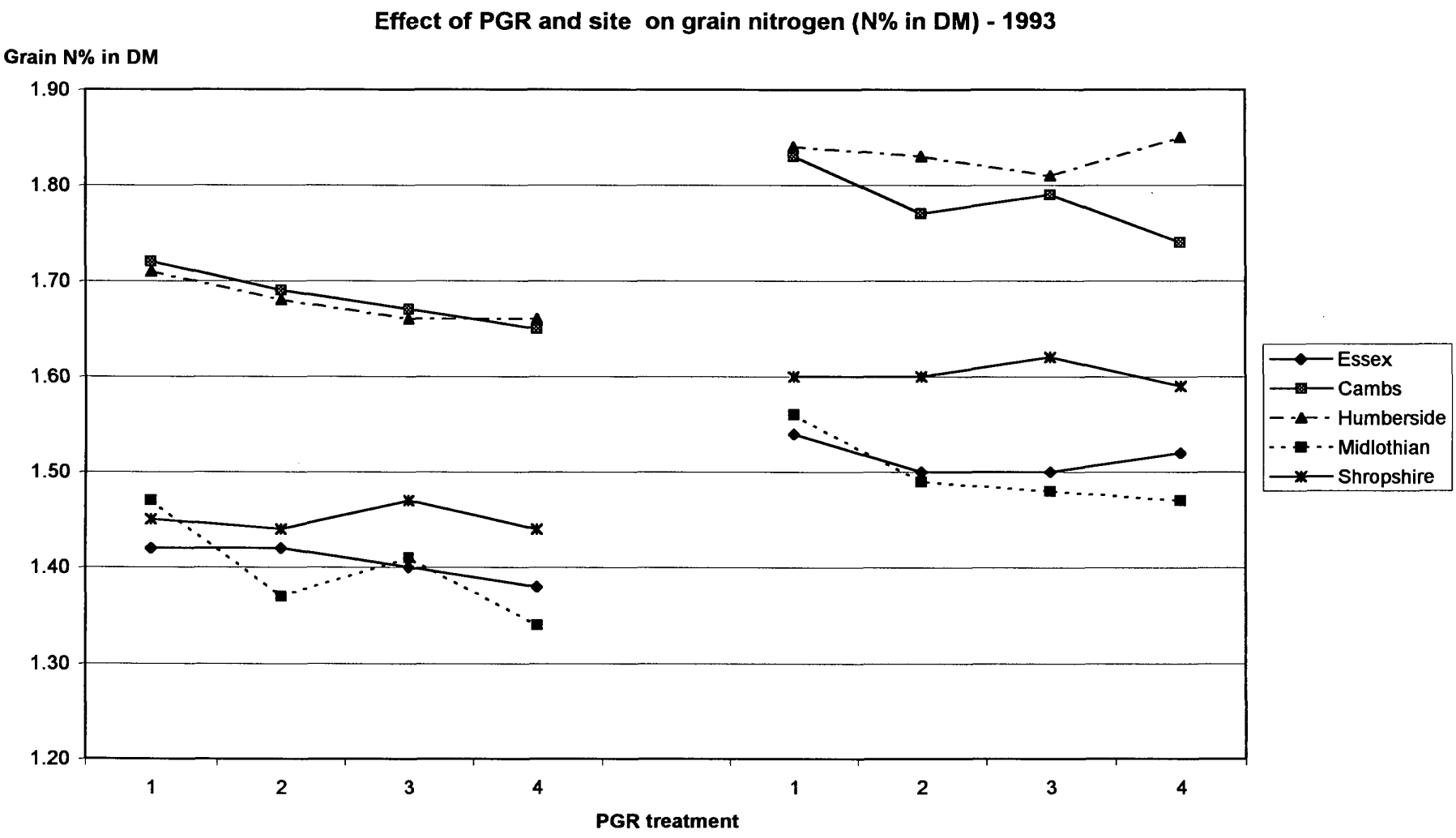

Effect of nitrogen and site on grain nitrogen content (%N in DM) - 1991
Grain N% in DM
2.20
2.00
1.80
1.60
1.40
1.20
1.00
0
80
120
160
0
80
120
160
Nitrogen applied (kg/ha)
Essex
Cambs.
Humberside
Midlothian
Shropshire

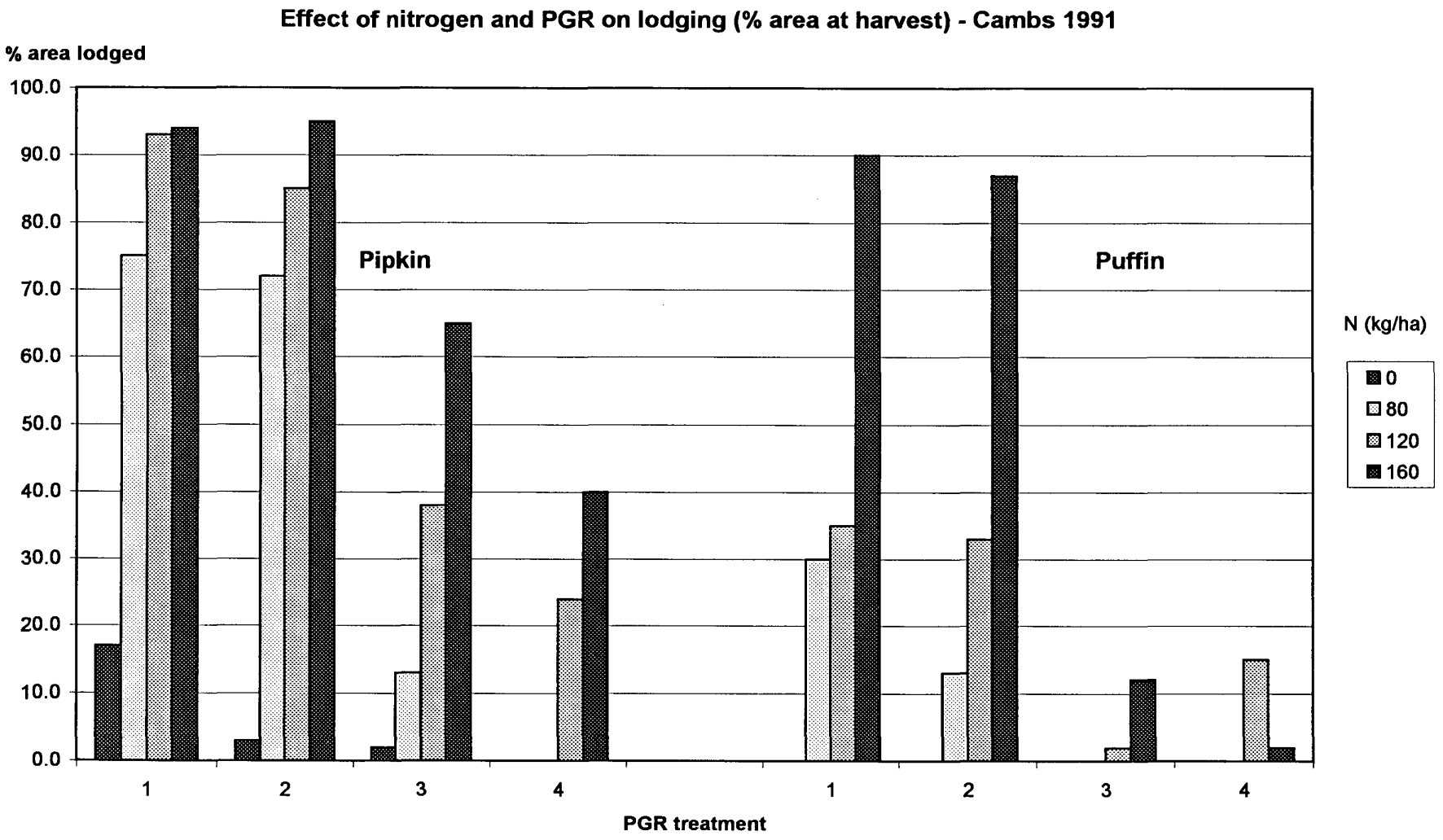

Effect of nitrogen and site on grain nitrogen (N% in DM) - 1992
Grain N% in DM
2.40
2.20
2.00
1.80
1.60
1.40
1.20
1.00
0
80
120
160
0
80
120
160
Nitrogen applied (kg/ha)
Essex
Cambs
Humberside
Midlothian
Shropshire

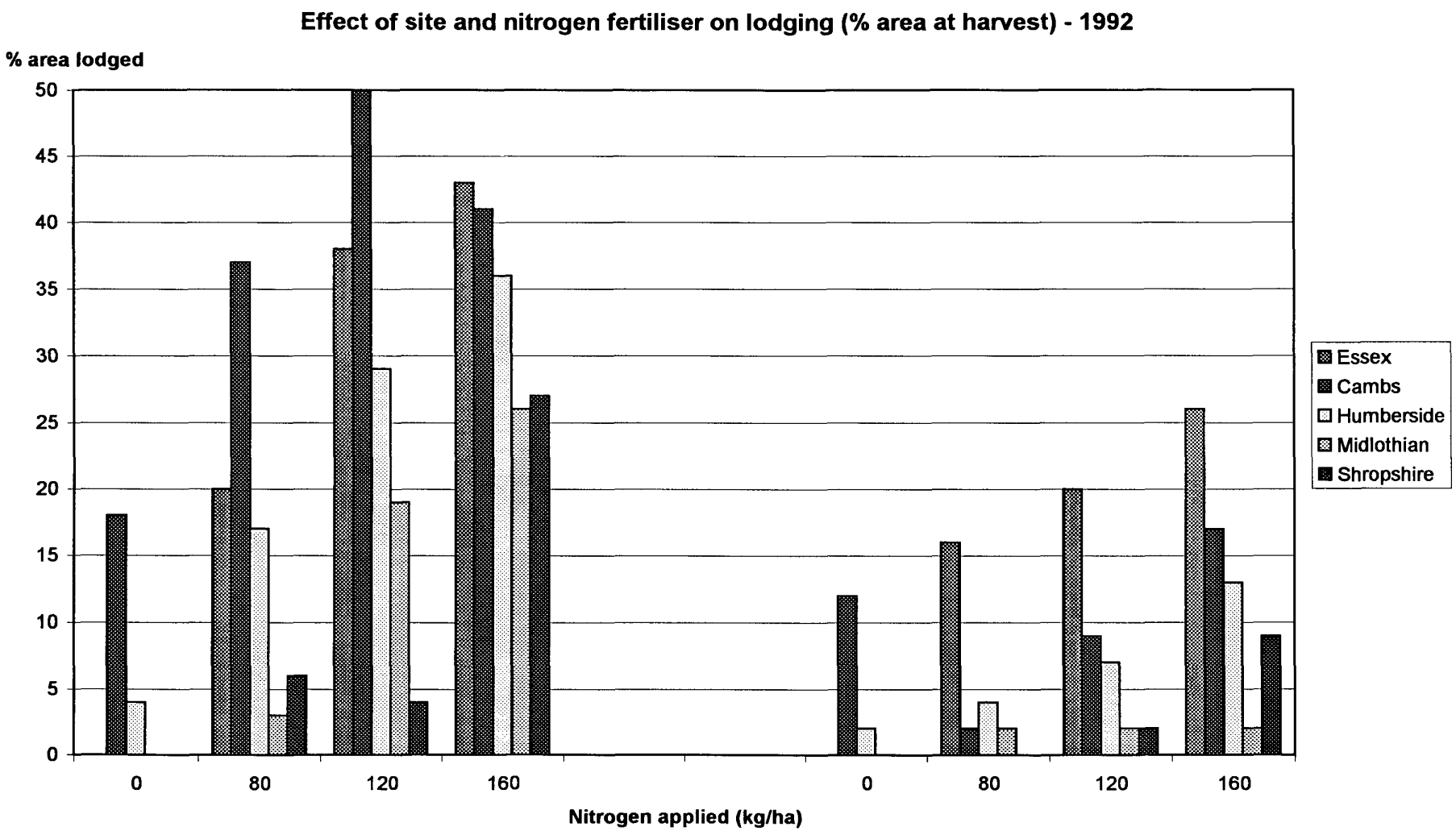

Effect of nitrogen and site on grain nitrogen (N% in DM) - 1993
Grain N% in DM
2.20
2.00
1.80
1.60
1.40
1.20
1.00
0
80
120
160
0
80
120
160
Nitrogen applied (kg/ha)
Essex
Cambs
Humberside
Midlothian
Shropshire

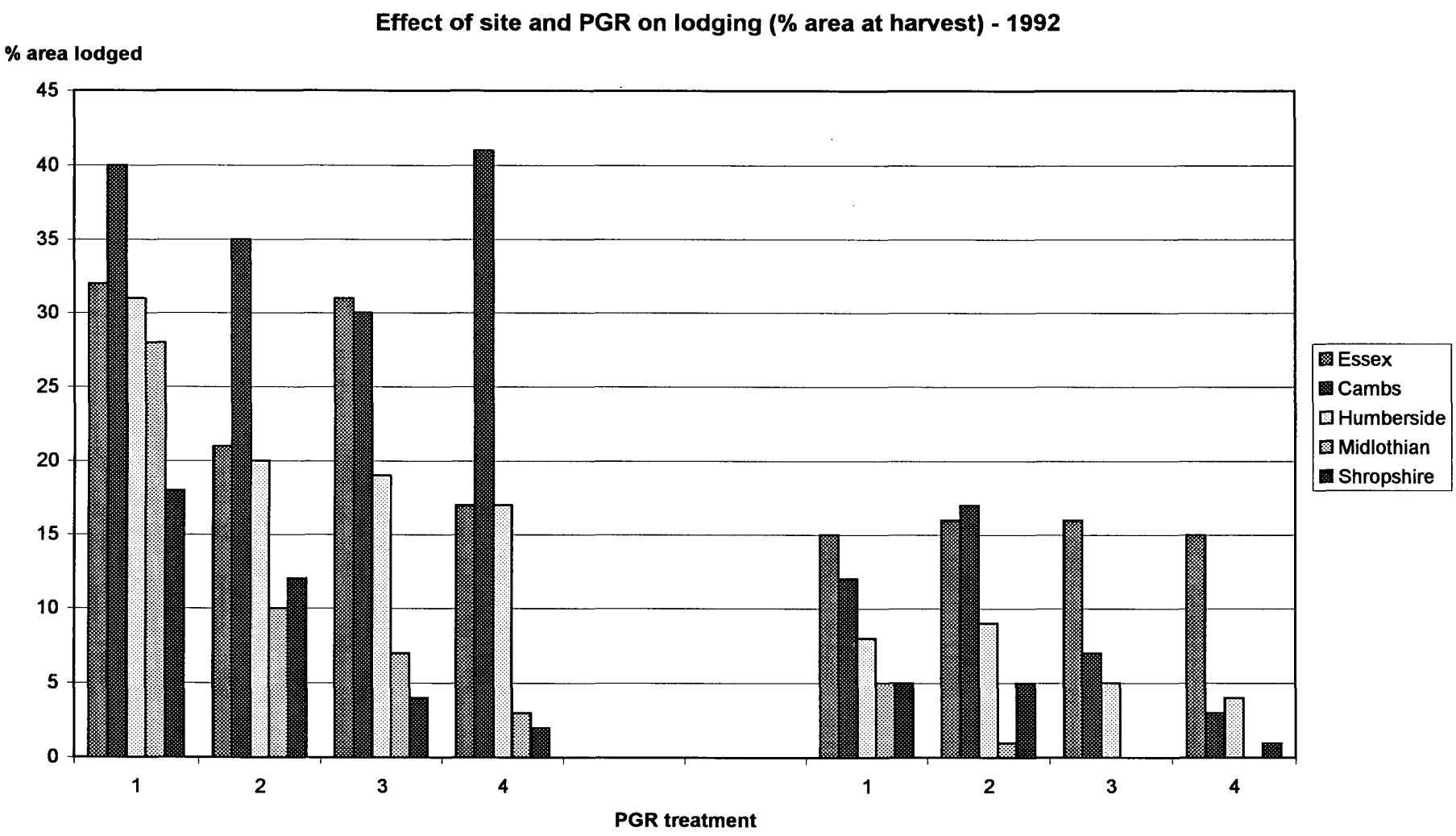

Effect of PGR and site on grain nitrogen (N% in DM) - 1991
Grain N% in DM
1.80
1.75
1.70
1.65
1.60
1.55
1.50
1.45
1.40
1
2
3
4
1
2
3
4
PGR treatment
Essex
Cambs.
Humberside
Midlothian
Shropshire

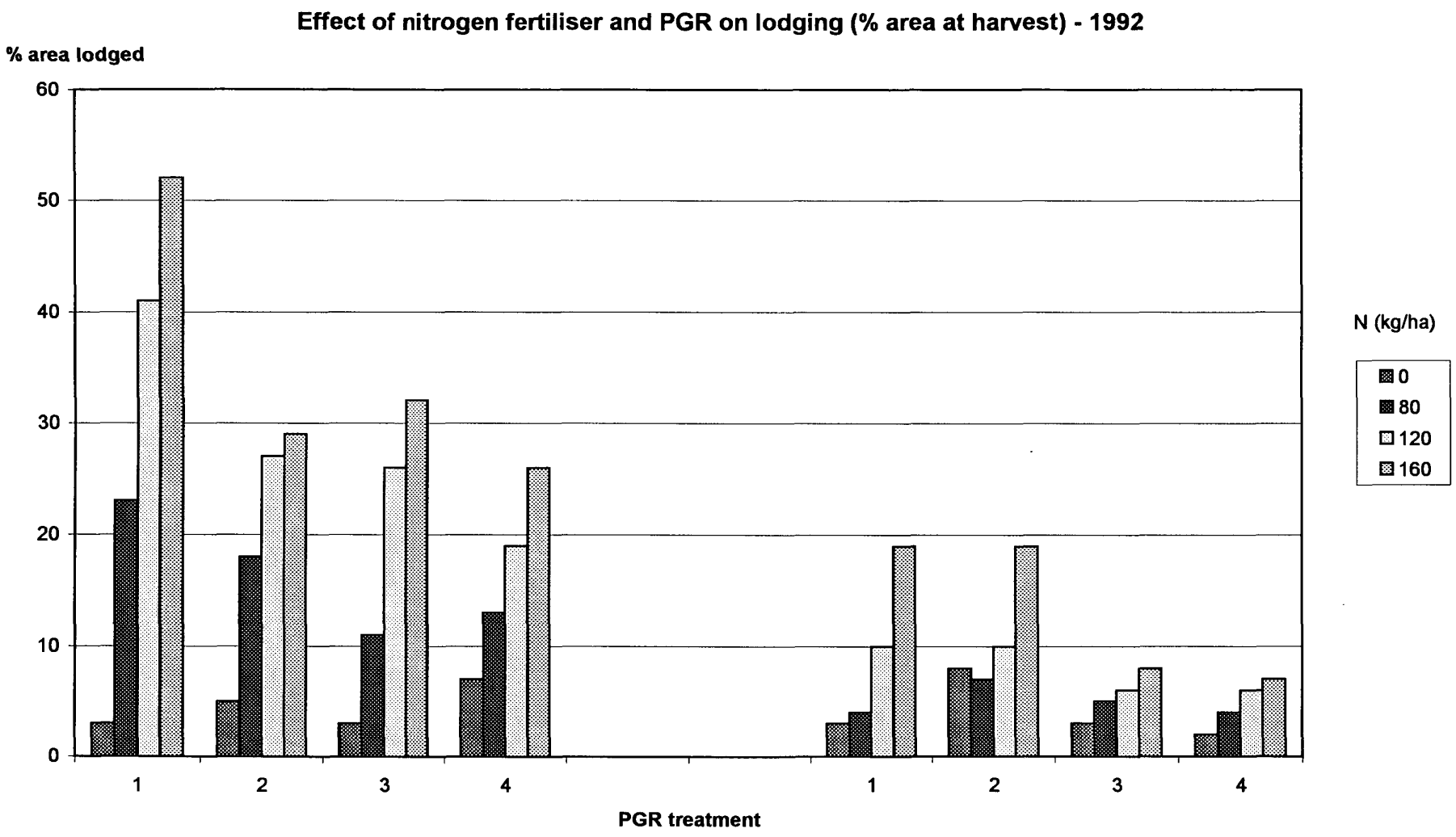

Effect of PGR and site on grain nitrogen (N% in DM) - 1992
Grain N% in DM
2.20
2.10
2.00
1.90
1.80
1.70
1.60
1.50
1
2
3
4
1
2
3
4
Nitrogen applied (kg/ha)
Essex
Cambs
Humberside
Midlothian
Shropshire

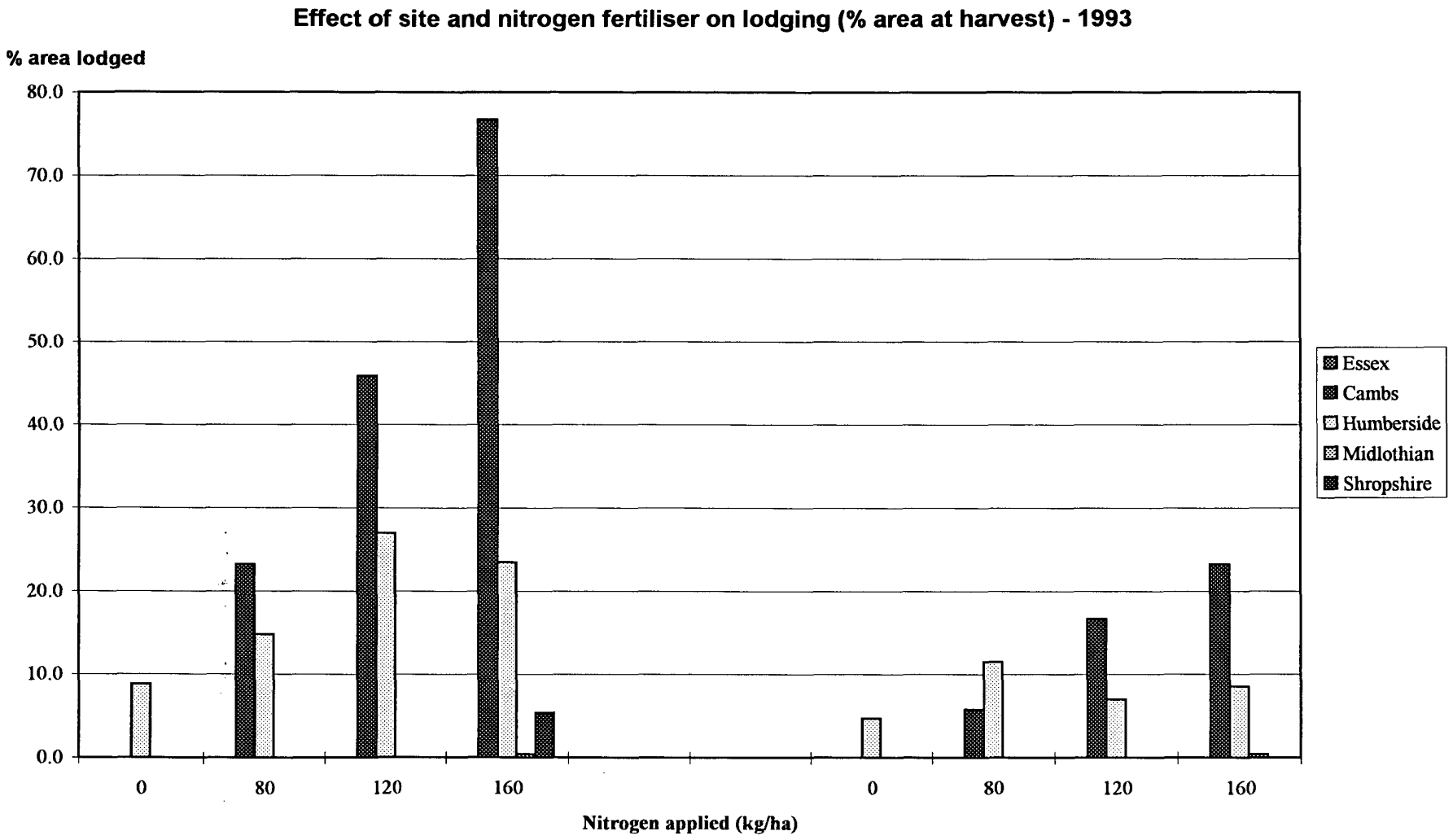

Effect of PGR and site on grain nitrogen (N% in DM) - 1993
Grain N% in DM
1.90
1.80
1.70
1.60
1.50
1.40
1.30
1.20
1
2
3
4
1
2
3
4
PGR treatment
Essex
Cambs
Humberside
Midlothian
Shropshire

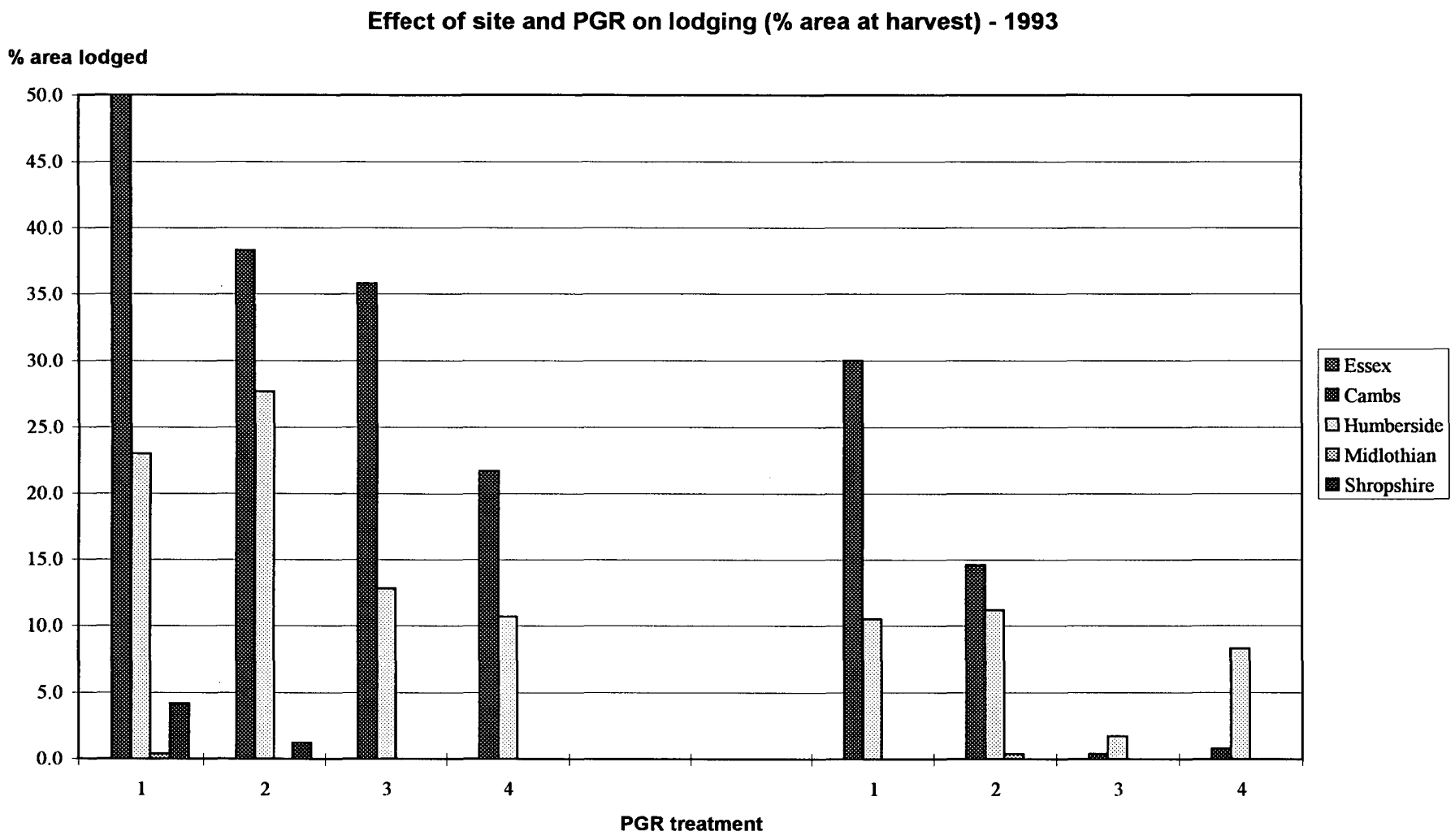

Effect of nitrogen and PGR on lodging (% area at harvest) - Cambs 1991
% area lodged
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Pipkin
Puffin
1
2
3
4
1
2
3
4
PGR treatment
N (kg/ha)
0
80
120
160

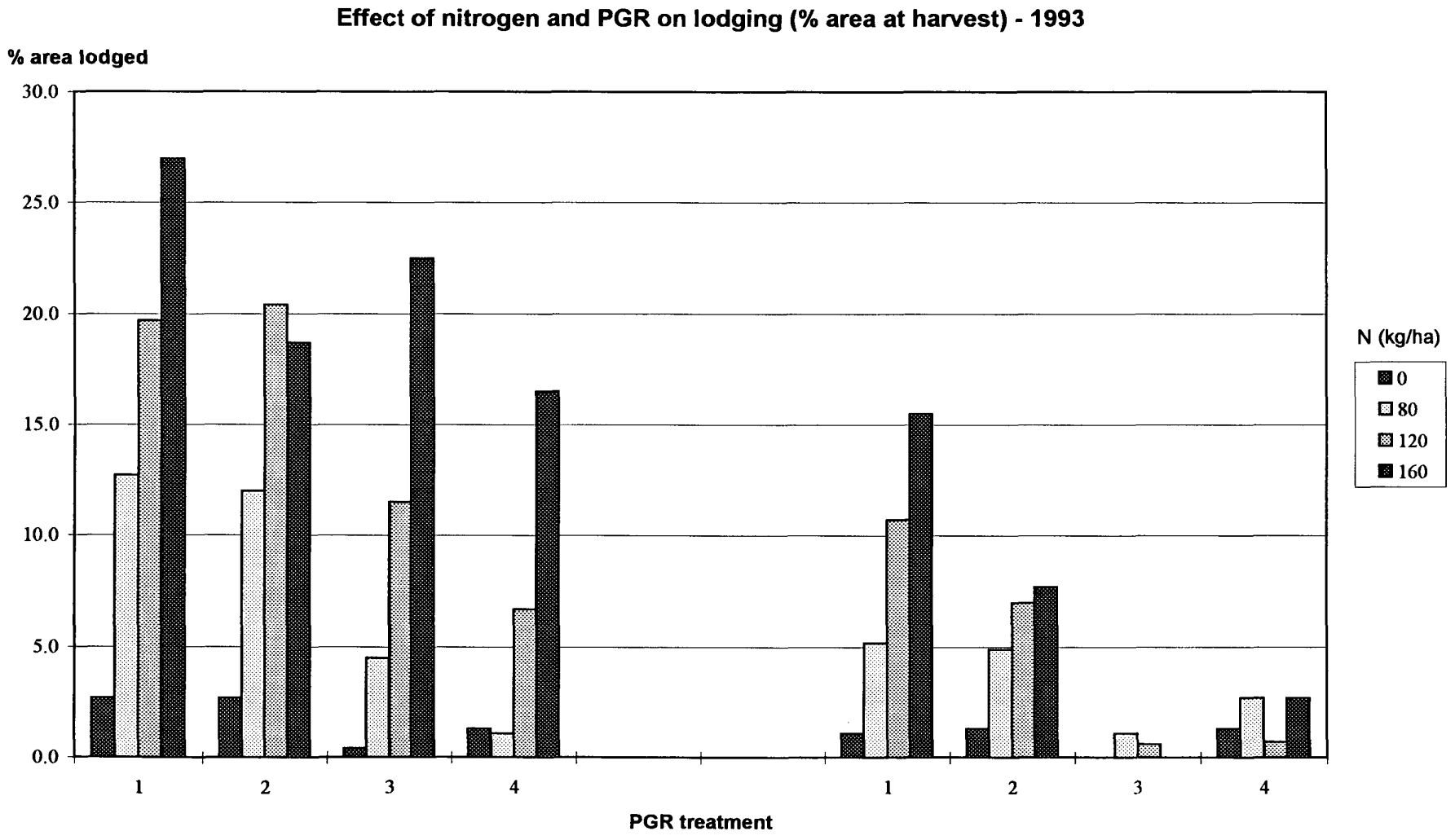

Effect of site and nitrogen fertiliser on lodging (% area at harvest) - 1992
% area lodged
50
45
40
35
30
25
20
15
10
5
0
0
80
120
160
0
80
120
160
Nitrogen applied (kg/ha)
Essex
Cambs
Humberside
Midlothian
Shropshire

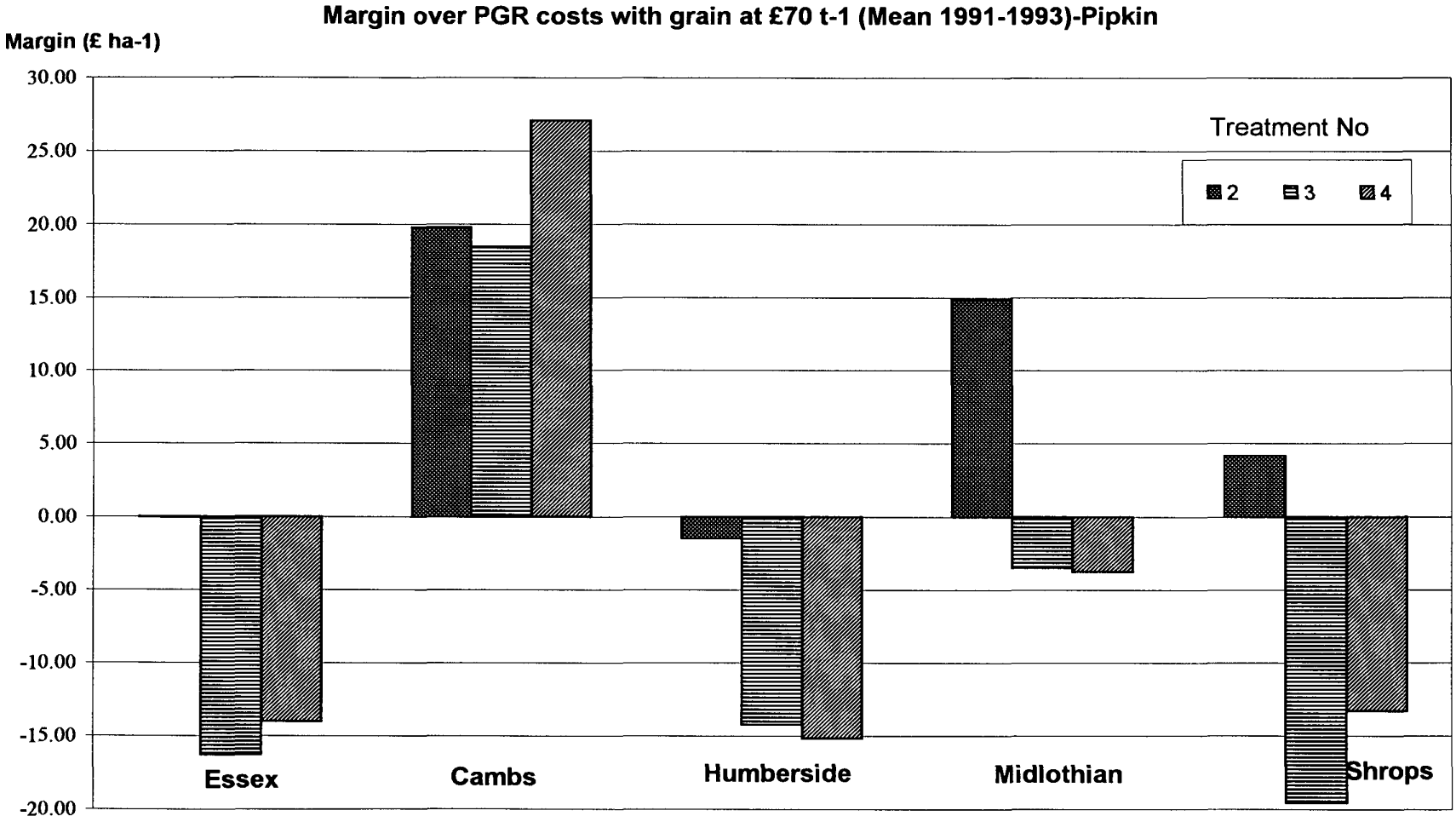

Effect of site and PGR on lodging (% area at harvest) - 1992
% area lodged
45
40
35
30
25
20
15
10
5
0
1
2
3
4
1
2
3
4
PGR treatment
Essex
Cambs
Humberside
Midlothian
Shropshire

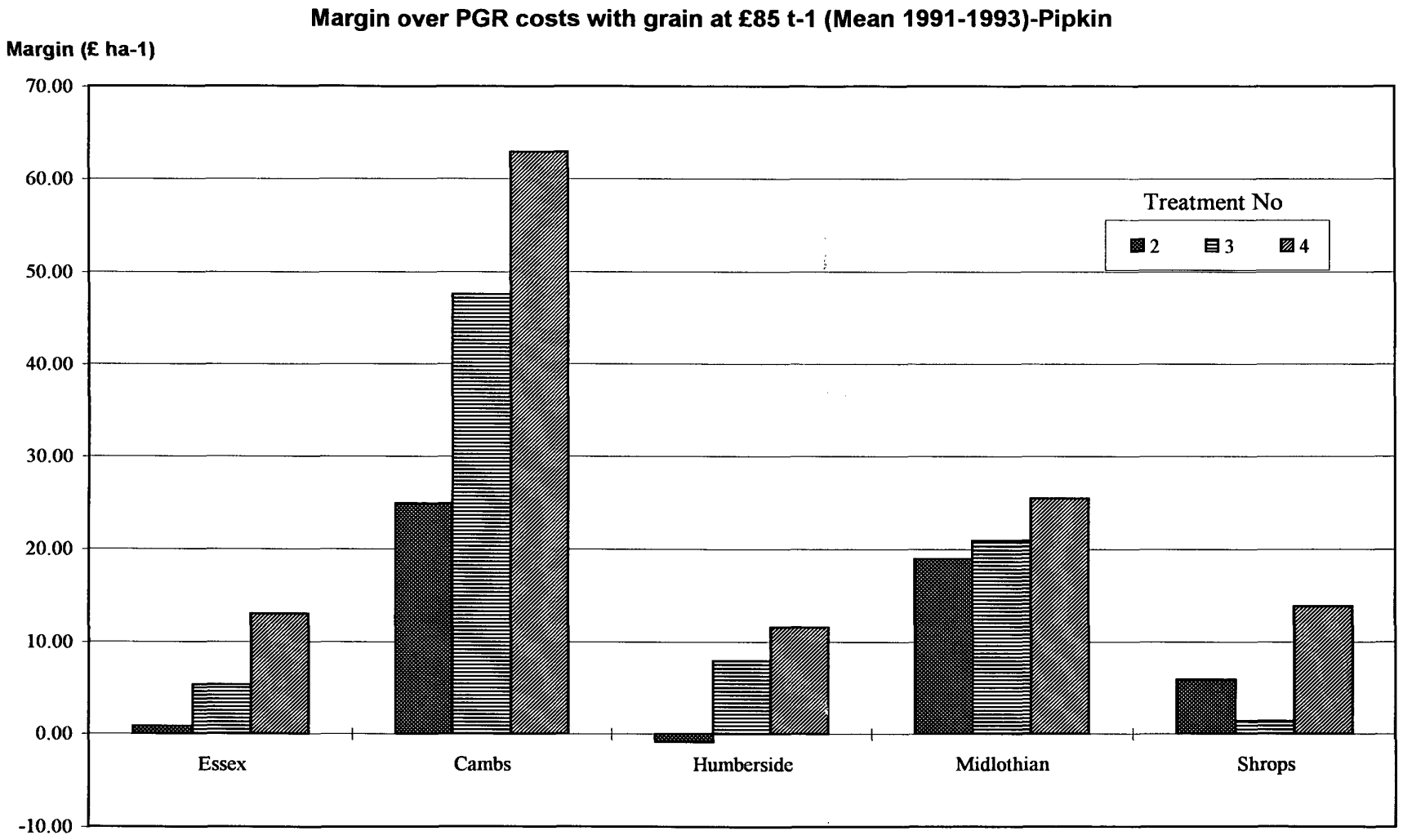

Effect of nitrogen fertiliser and PGR on lodging (% area at harvest) - 1992
% area lodged
60
50
40
30
20
10
0
1
2
3
4
1
2
3
4
PGR treatment
N (kg/ha)
0
80
120
160

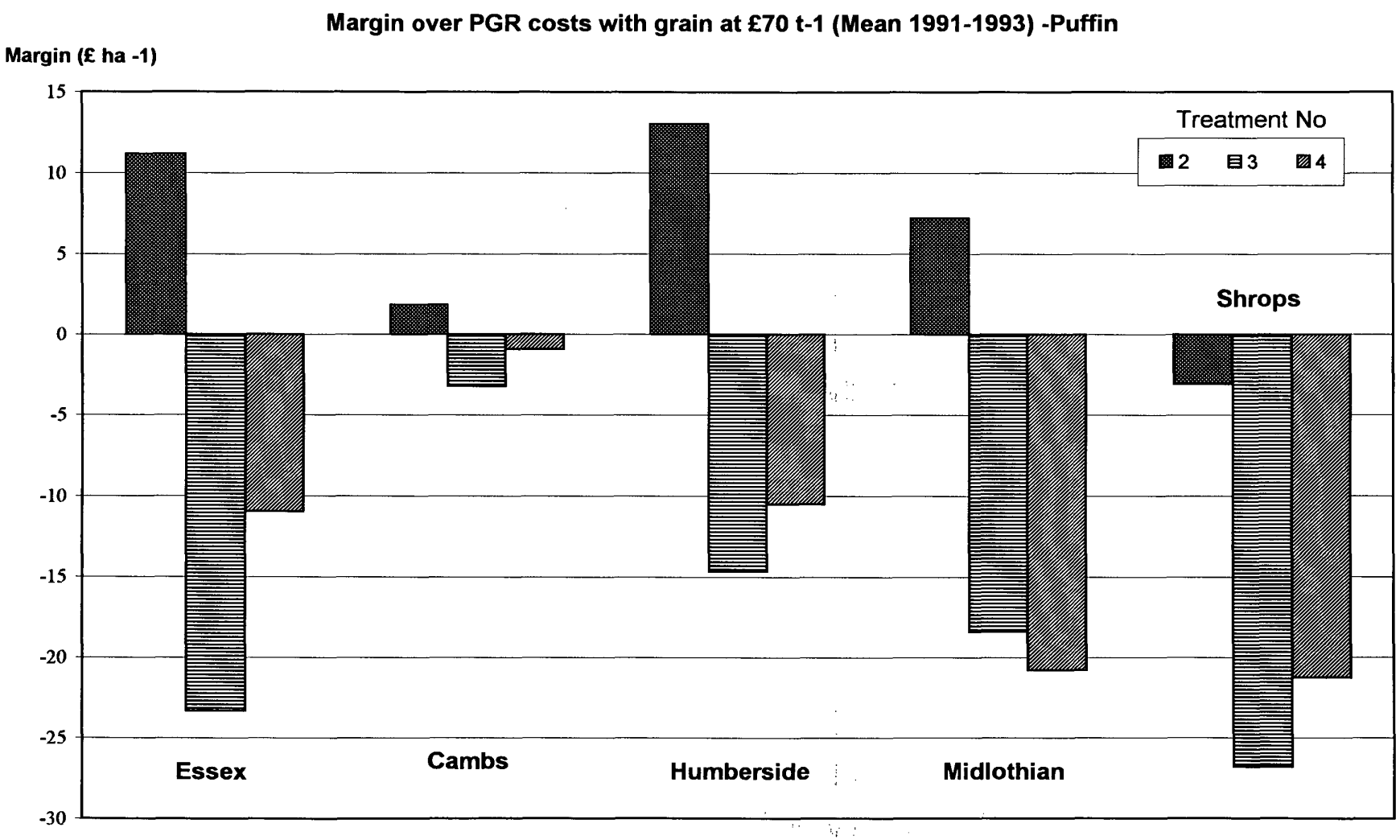

Effect of site and nitrogen fertiliser on lodging (% area at harvest) - 1993
% area lodged
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
80
120
160
0
80
120
160
Nitrogen applied (kg/ha)
Essex
Cambs
Humberside
Midlothian
Shropshire

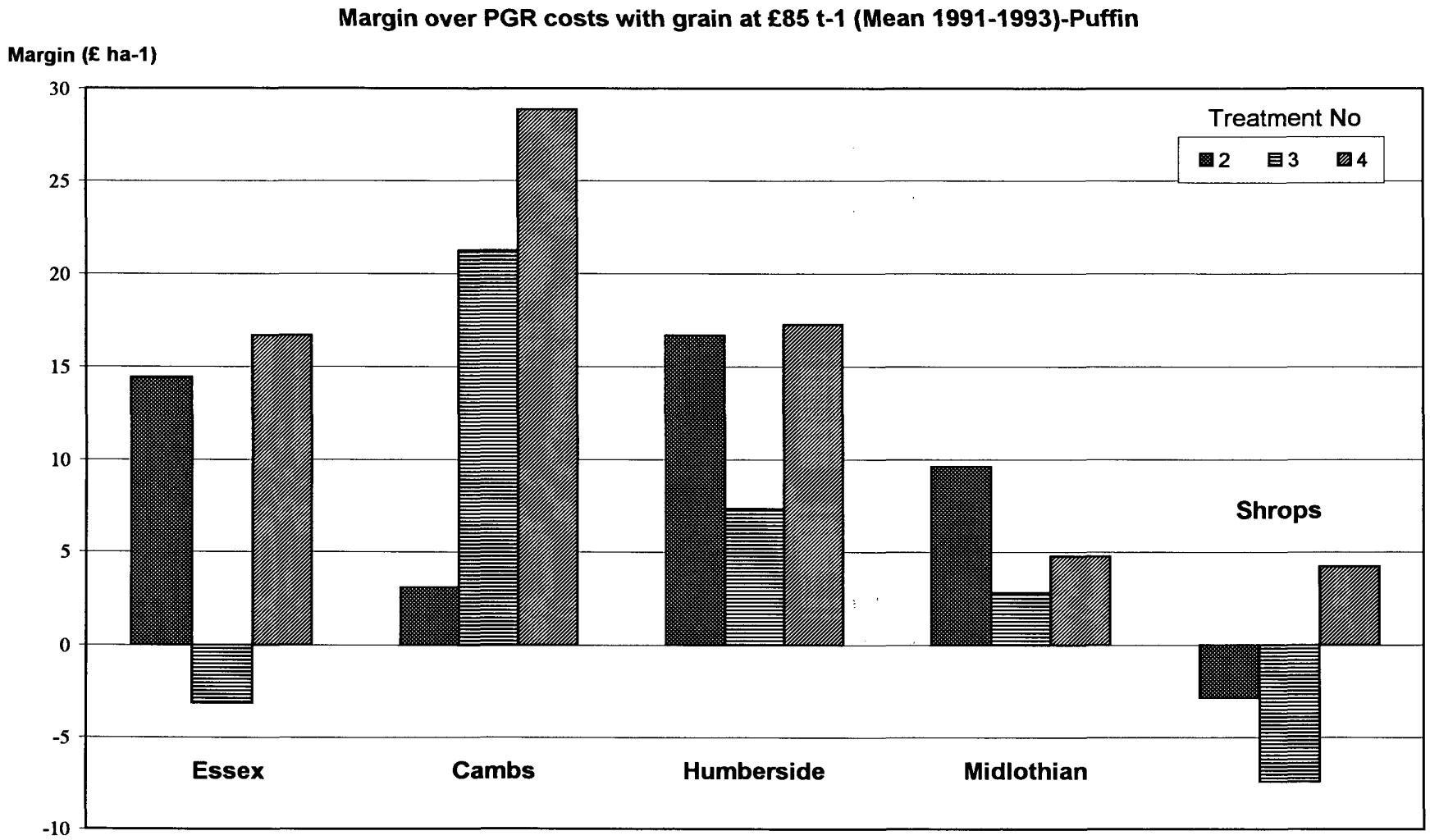

Effect of site and PGR on lodging (% area at harvest) - 1993
% area lodged
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
1
2
3
4
1
2
3
4
PGR treatment
Essex
Cambs
Humberside
Midlothian
Shropshire

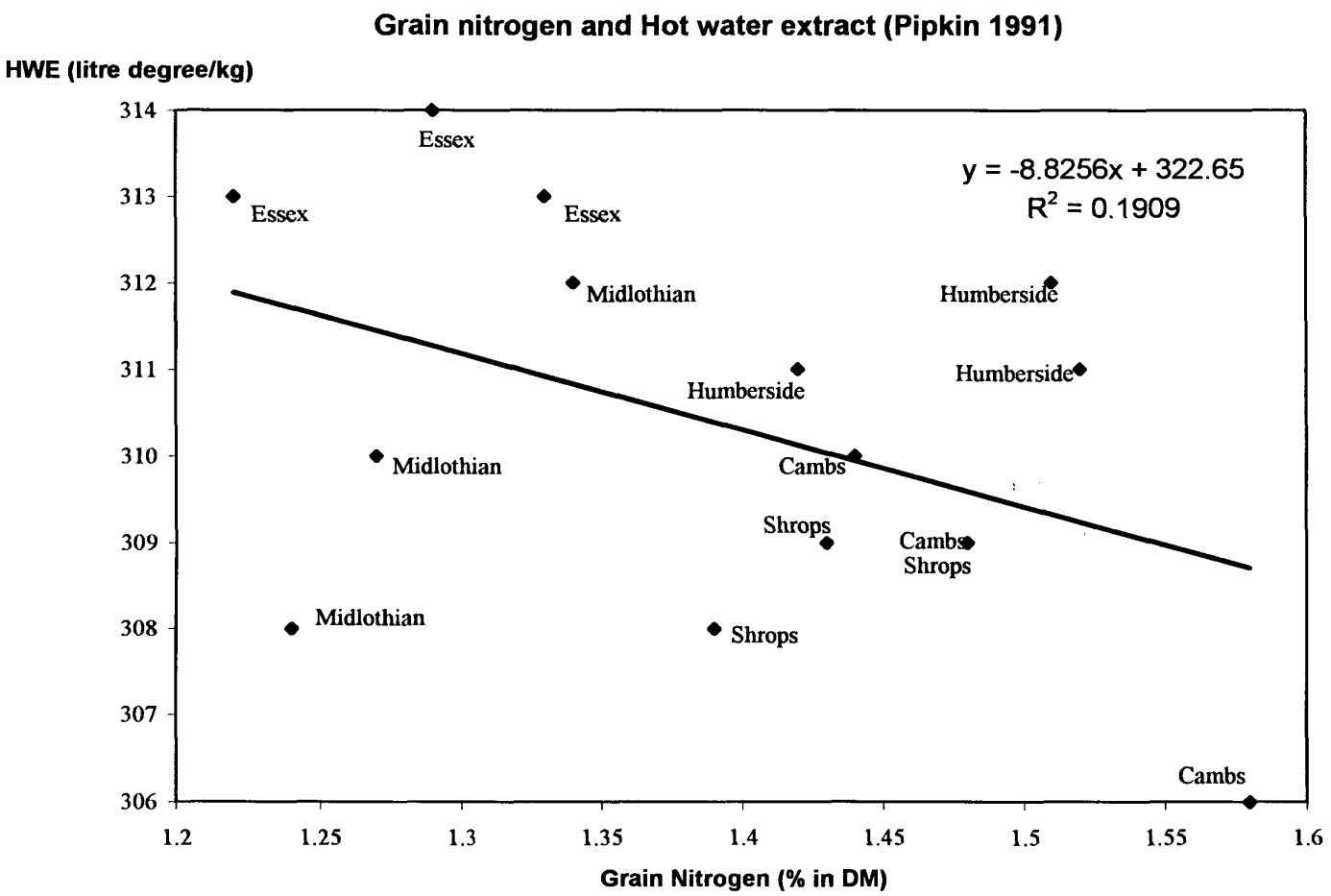

Effect of nitrogen and PGR on lodging (% area at harvest) - 1993
% area lodged
30.0
25.0
20.0
15.0
10.0
5.0
0.0
1
2
3
4
1
2
3
4
PGR treatment
N (kg/ha)
0
80
120
160

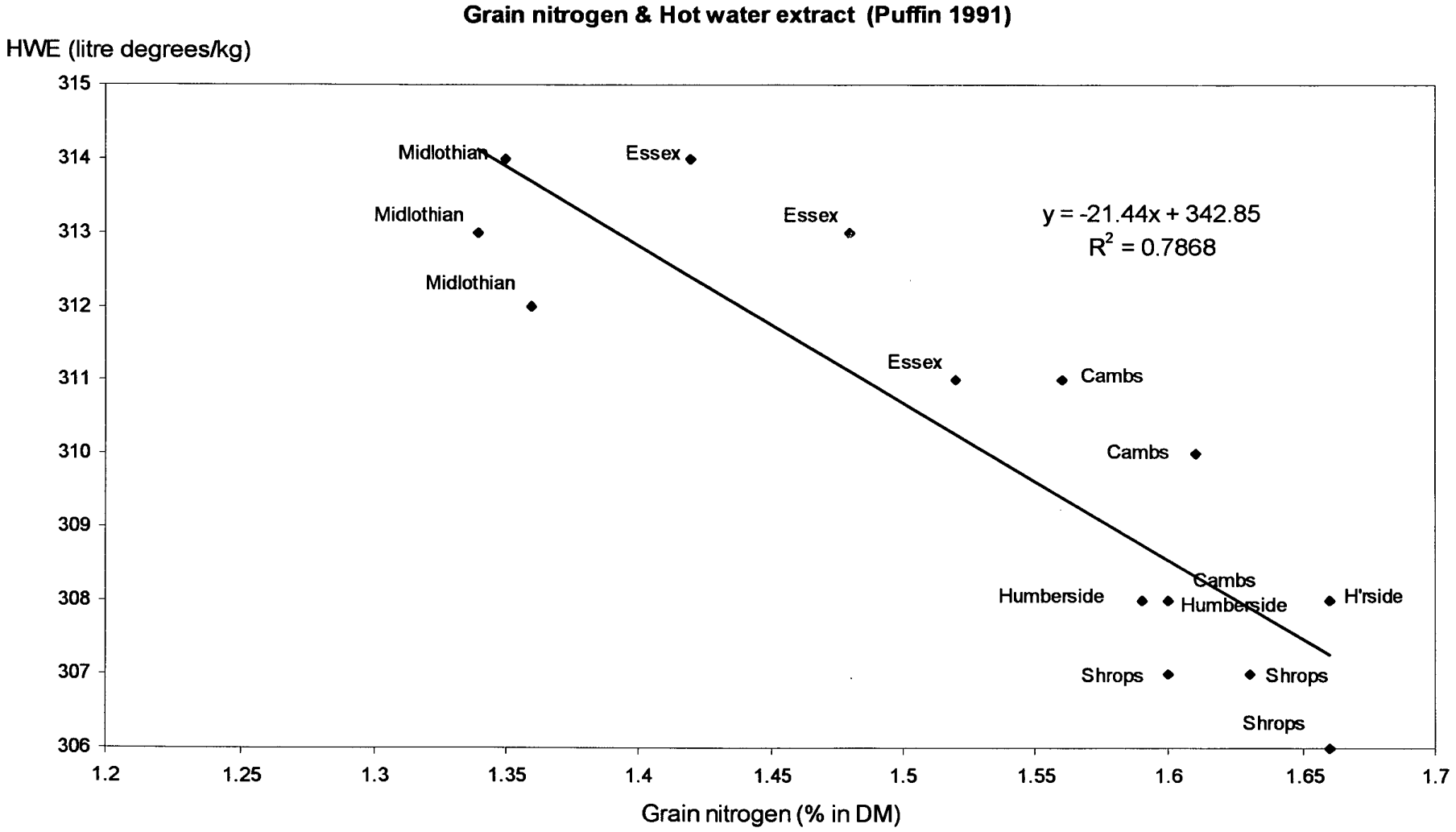

Margin over PGR costs with grain at £70 t-1 (Mean 1991-1993)-Pipkin
Margin (£ ha-1)
30.00
25.00
20.00
15.00
10.00
5.00
0.00
-5.00
-10.00
-15.00
-20.00
Treatment No
2
3
4
Essex
Cambs
Humberside
Midlothian
Shrops

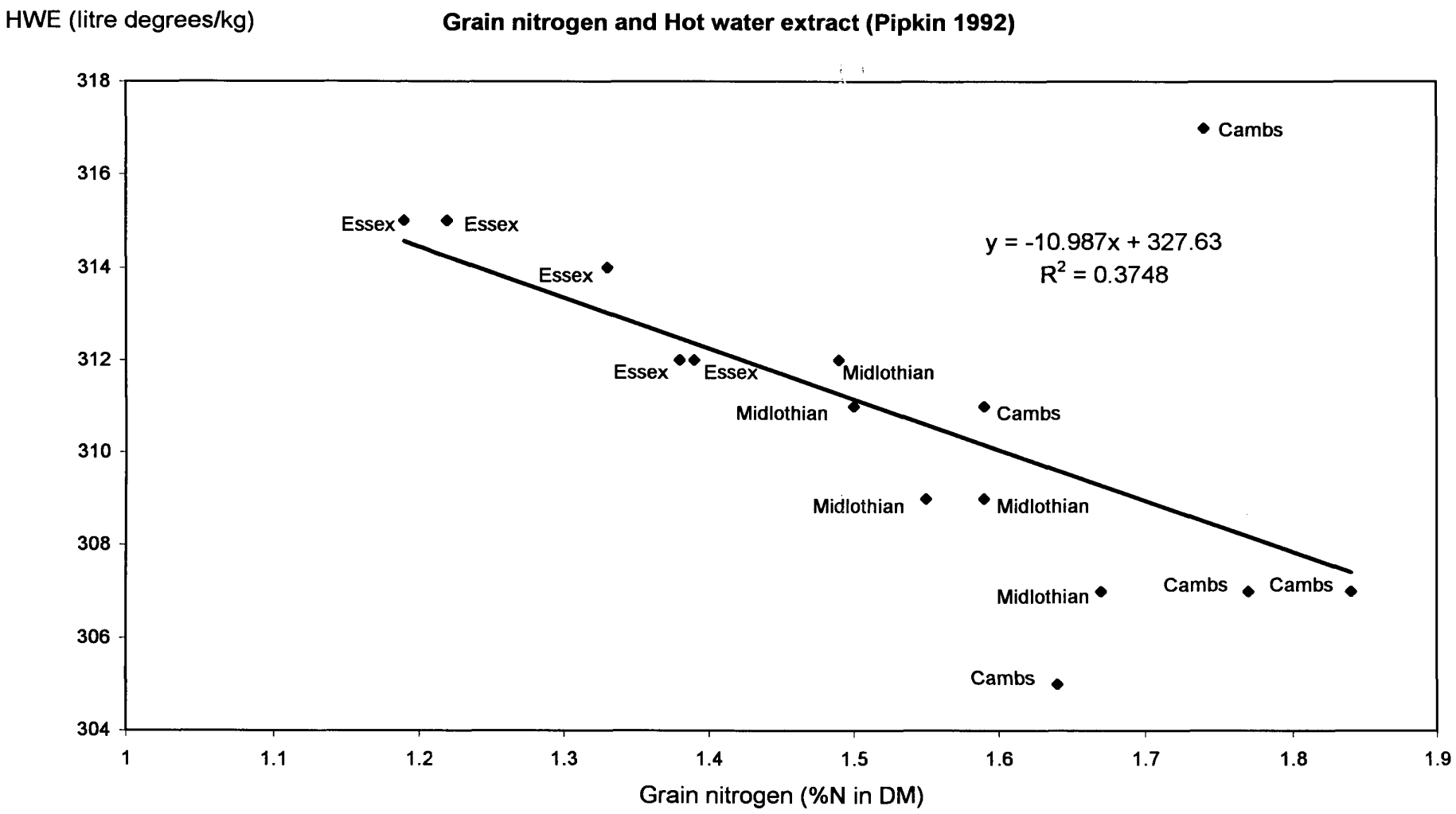

Margin over PGR costs with grain at £85 t-1 (Mean 1991-1993)-Pipkin
Margin (£ ha-1)
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
-10.00
Treatment No
2
3
4
Essex
Cambs
Humberside
Midlothian
Shrops

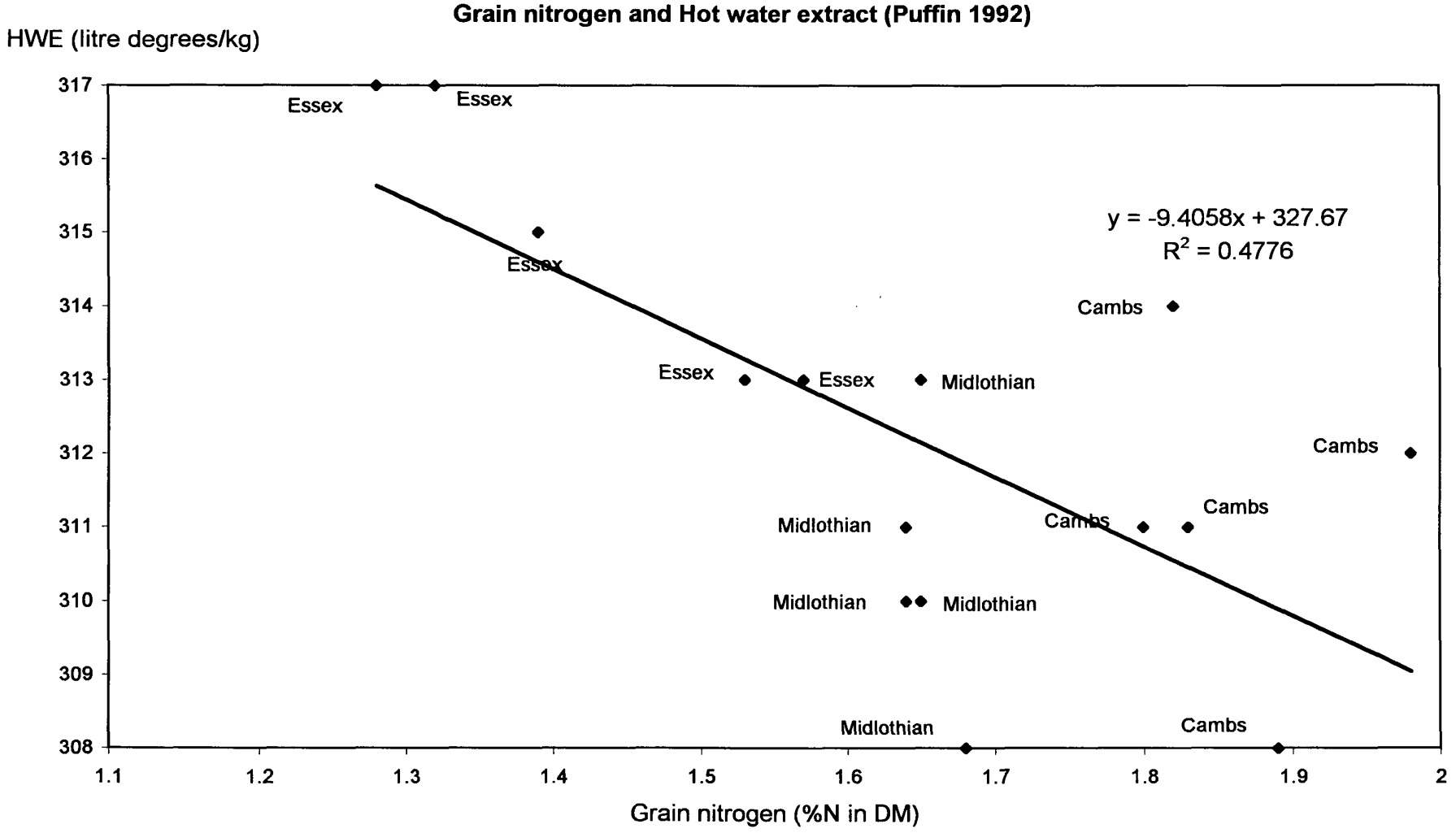

Margin over PGR costs with grain at £70 t-1 (Mean 1991-1993) -Puffin
Margin (£ ha -1)
15
10
5
0
-5
-10
-15
-20
-25
-30
Treatment No
2
3
4
Essex
Cambs
Humberside
Midlothian
Shrops

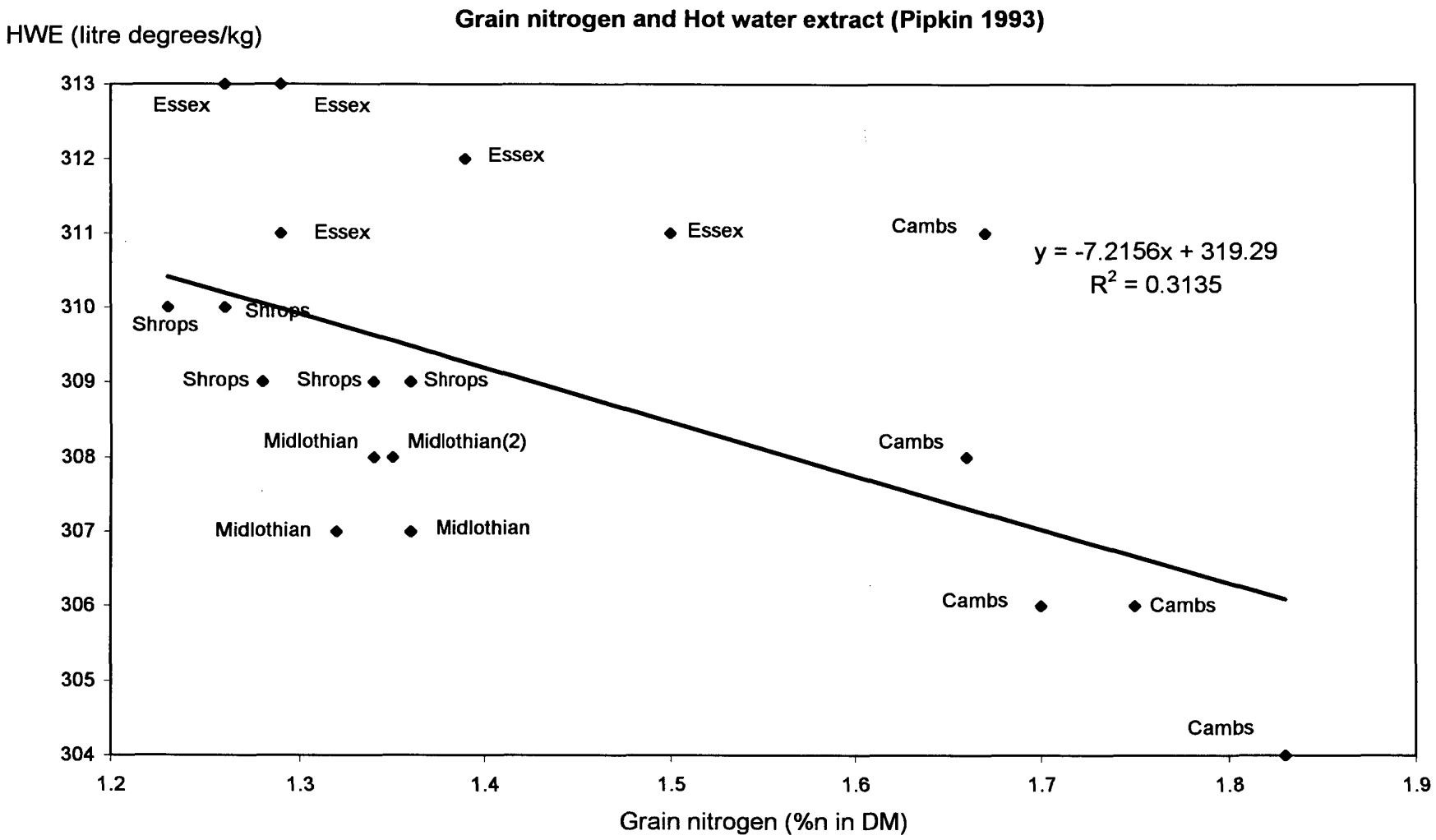

Margin over PGR costs with grain at £85 t-1 (Mean 1991-1993)-Puffin
Margin (£ ha-1)
30
25
20
15
10
5
0
-5
-10
Treatment No
2
3
4
Essex
Cambs
Humberside
Midlothian
Shrops

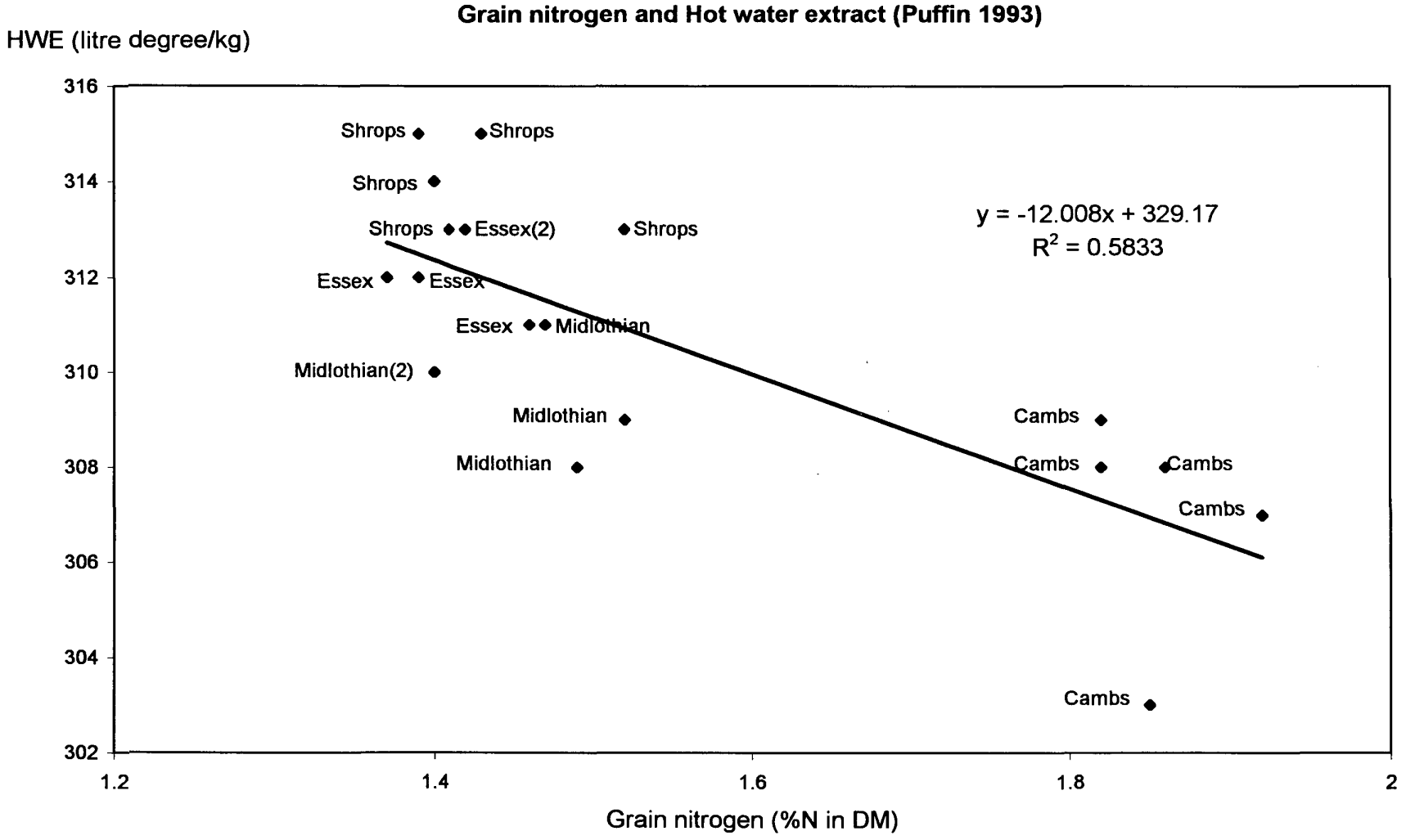

Grain nitrogen and Hot water extract (Pipkin 1991)
HWE (litre degree/kg)
y = -8.8256x + 322.65
R2 = 0.1909
Essex
Essex
Essex
Midlothian
Humberside
Humberside
Humberside
Midlothian
Cambs
Shrops
Cambs
Shrops
Midlothian
Shrops
Cambs
314
313
312
311
310
309
308
307
306
1.2
1.25
1.3
1.35
1.4
1.45
1.5
1.55
1.6
Grain Nitrogen (% in DM)

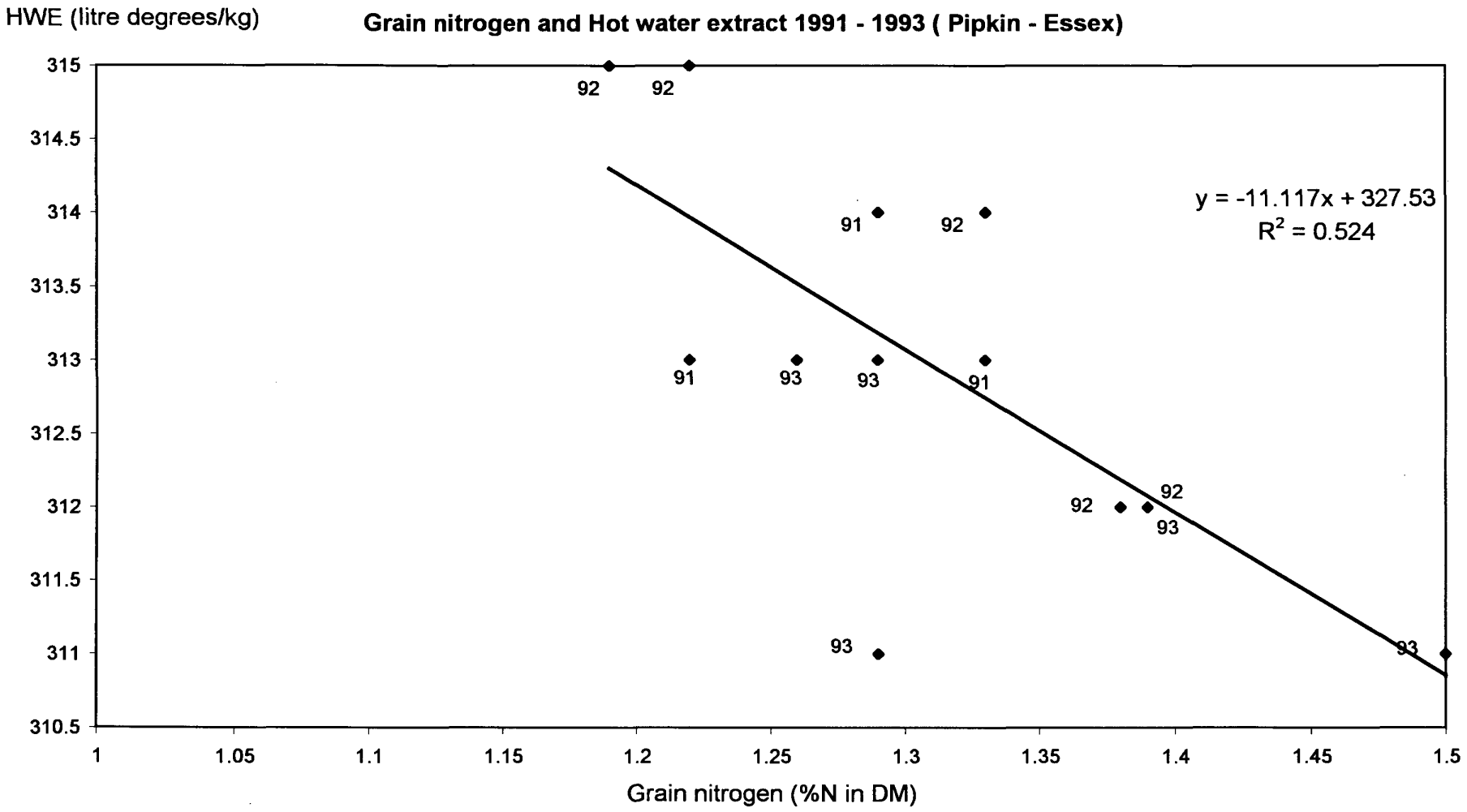

Grain nitrogen & Hot water extract (Puffin 1991)
HWE (litre degrees/kg)
315
314
313
312
311
310
309
308
307
306
1.2
1.25
1.3
1.35
1.4
1.45
1.5
1.55
1.6
1.65
1.7
Grain nitrogen (% in DM)
y = -21.44x + 342.85
R2 = 0.7868
Midlothian
Midlothian
Midlothian
Essex
Essex
Essex
Cambs
Cambs
Cambs
Humberside
Humberside
H'rside
Shrops
Shrops
Shrops

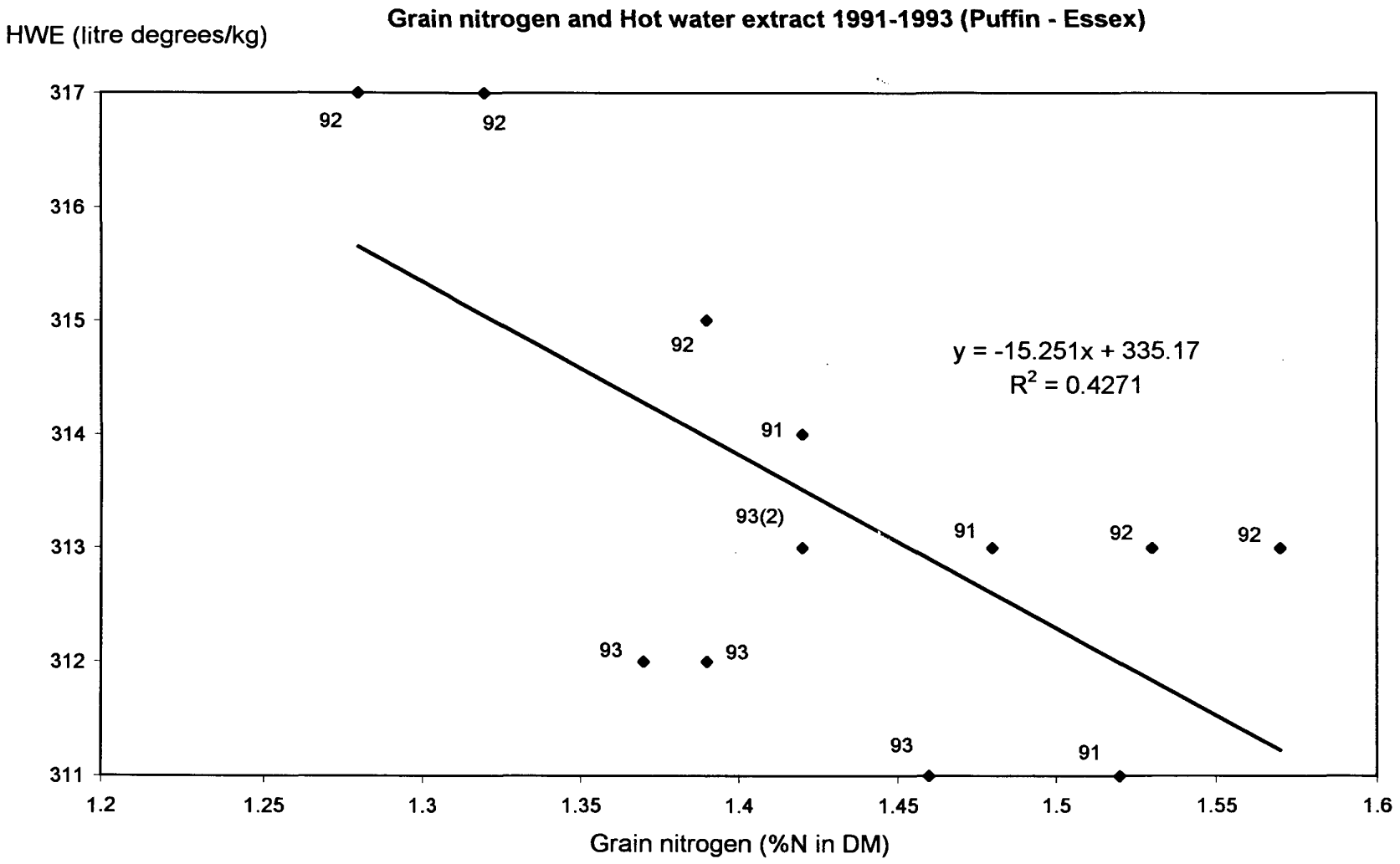

HWE (litre degrees/kg)
Grain nitrogen and Hot water extract (Pipkin 1992)
318
316
314
312
310
308
306
304
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
Grain nitrogen (%N in DM)
y = -10.987x + 327.63
R2 = 0.3748
Cambs
Essex
Essex
Essex
Essex
Essex
Midlothian
Midlothian
Cambs
Midlothian
Midlothian
Midlothian
Cambs
Cambs
Cambs

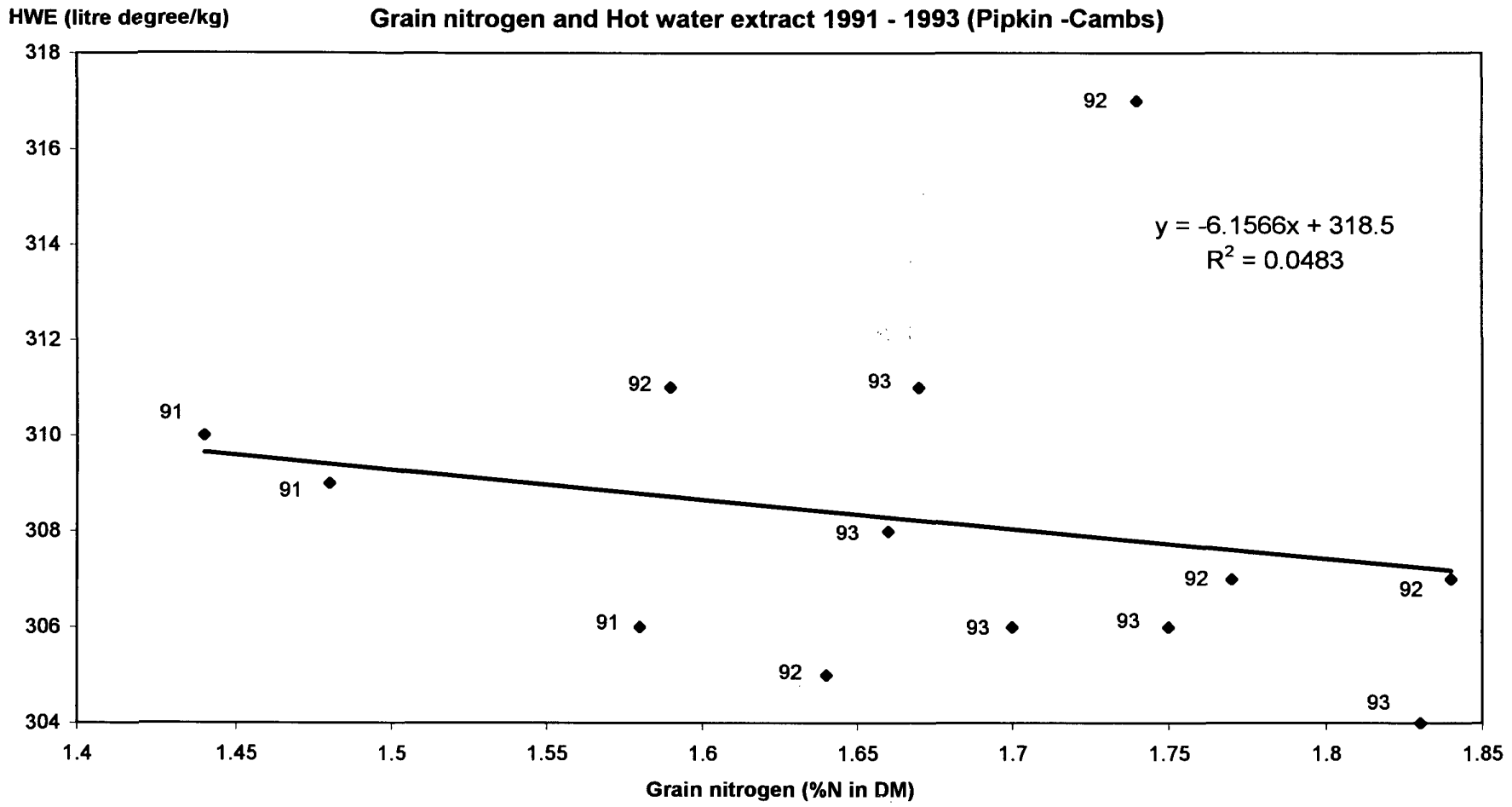

Grain nitrogen and Hot water extract (Puffin 1992)
HWE (litre degrees/kg)
317
316
315
314
313
312
311
310
309
308
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2
Grain nitrogen (%N in DM)
y = -9.4058x + 327.67
R2 = 0.4776
Essex
Essex
Essex
Essex
Essex
Midlothian
Cambs
Cambs
Cambs
Cambs
Midlothian
Midlothian
Midlothian
Midlothian
Cambs

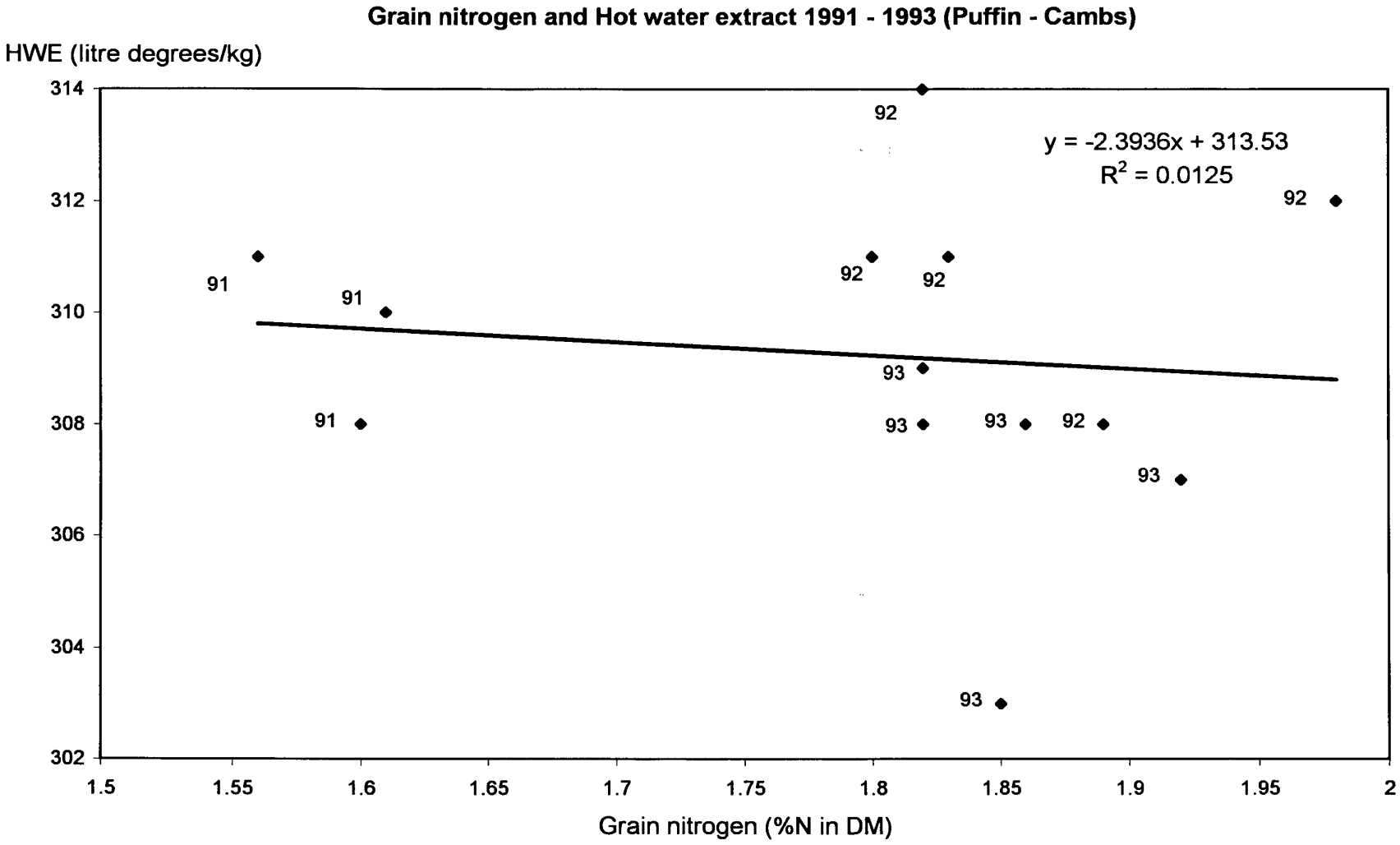

Grain nitrogen and Hot water extract (Pipkin 1993)
HWE (litre degrees/kg)
313
312
311
310
309
308
307
306
305
304
Essex
Essex
Essex
Essex
Essex
Cambs
y = -7.2156x + 319.29
R2 = 0.3135
Shrops
Shrops
Shrops
Shrops
Shrops
Midlothian
Midlothian(2)
Midlothian
Midlothian
Cambs
Cambs
Cambs
Cambs
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
Grain nitrogen (%n in DM)

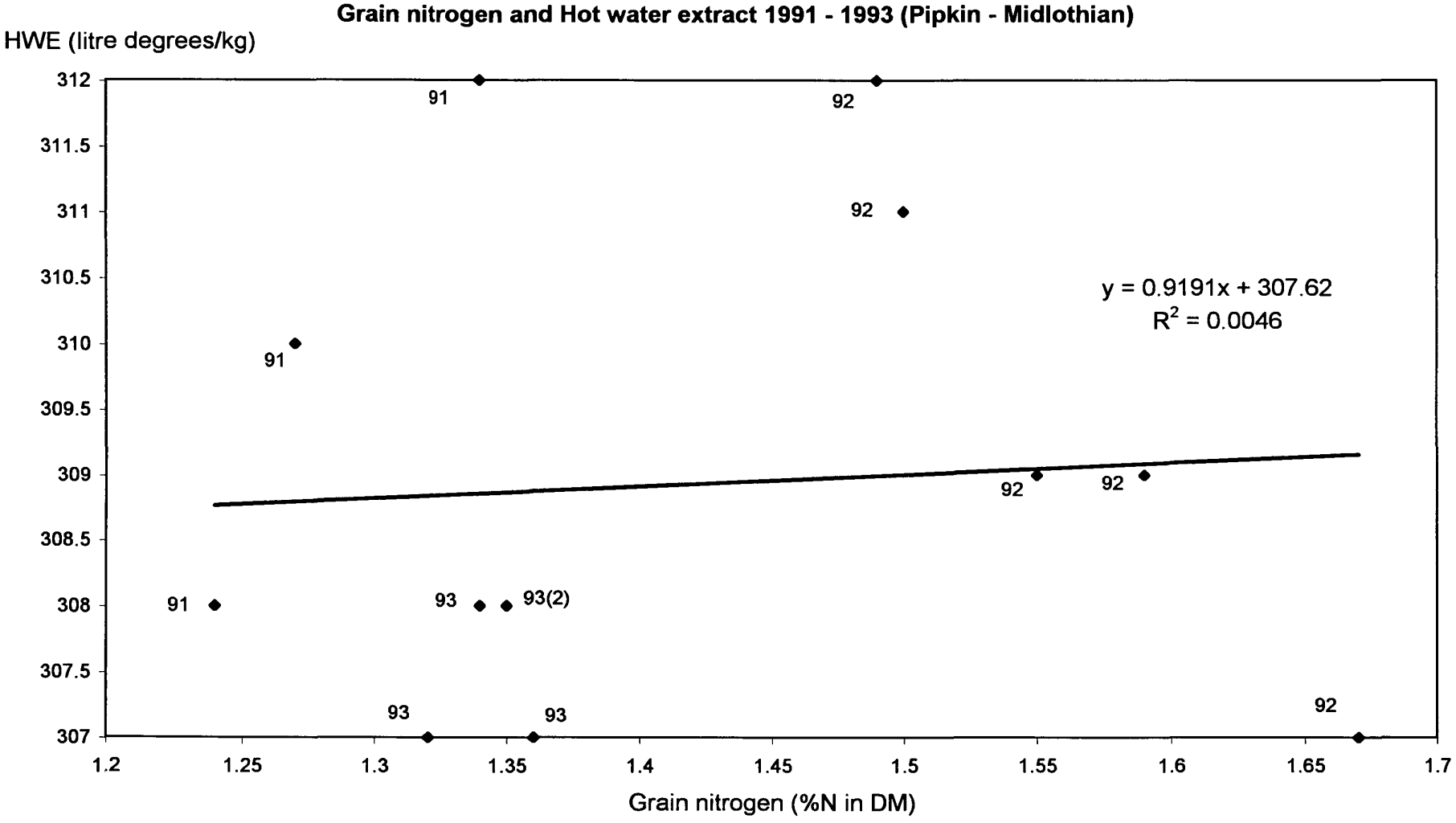

Grain nitrogen and Hot water extract (Puffin 1993)
HWE (litre degree/kg)
316
314
312
310
308
306
304
302
1.2
1.4
1.6
1.8
2
Grain nitrogen (%N in DM)
y = -12.008x + 329.17
R2 = 0.5833
Shrops
Shrops
Shrops
Shrops
Essex(2)
Shrops
Essex
Essex
Essex
Midlothian
Midlothian(2)
Midlothian
Midlothian
Cambs
Cambs
Cambs
Cambs
Cambs

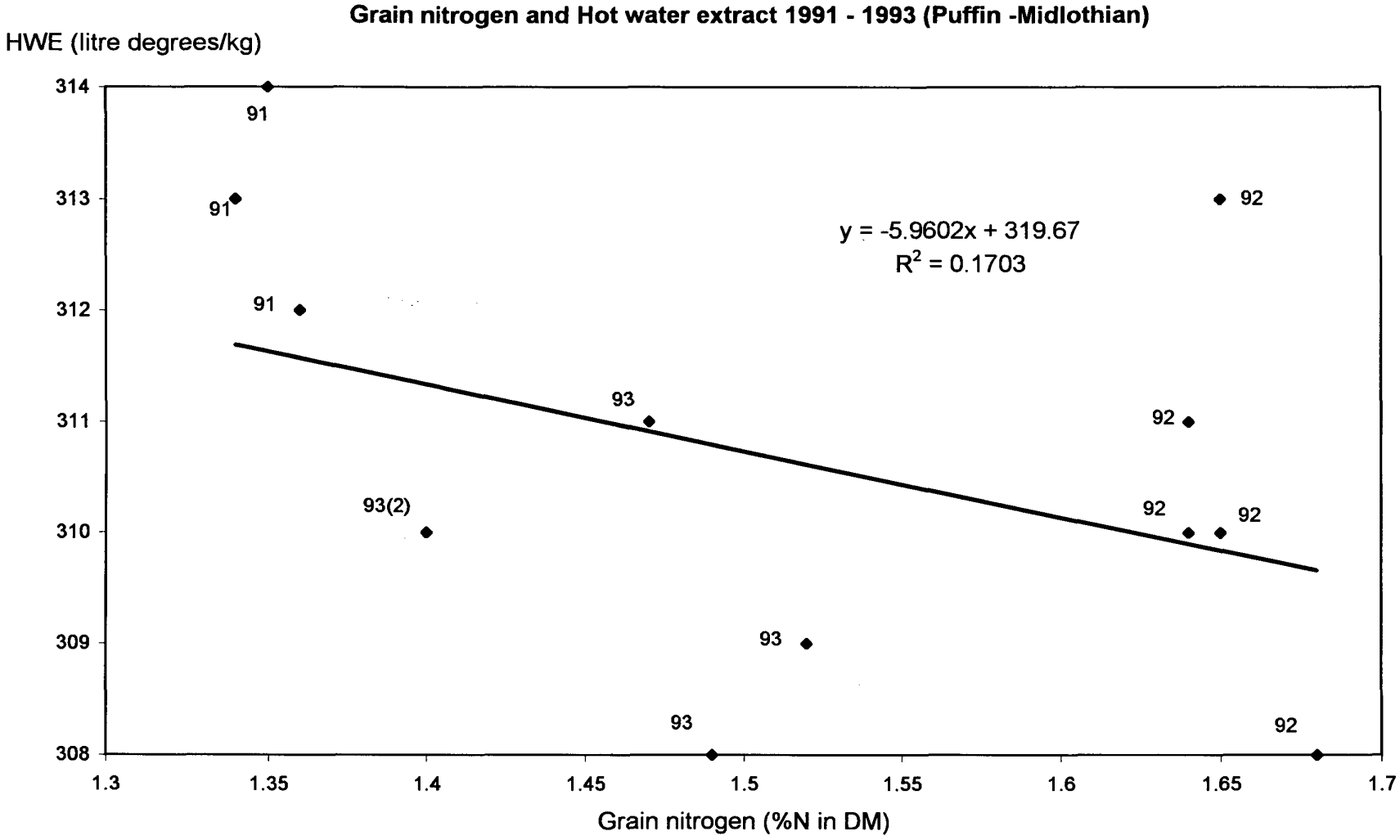

HWE (litre degrees/kg)
Grain nitrogen and Hot water extract 1991 - 1993 (Pipkin - Essex)
y = -11.117x + 327.53
R2 = 0.524
315
314.5
314
313.5
313
312.5
312
311.5
311
310.5
1
1.05
1.1
1.15
1.2
1.25
1.3
1.35
1.4
1.45
1.5
Grain nitrogen (%N in DM)
92
92
91
92
91
93
93
91
92
92
93
93
93

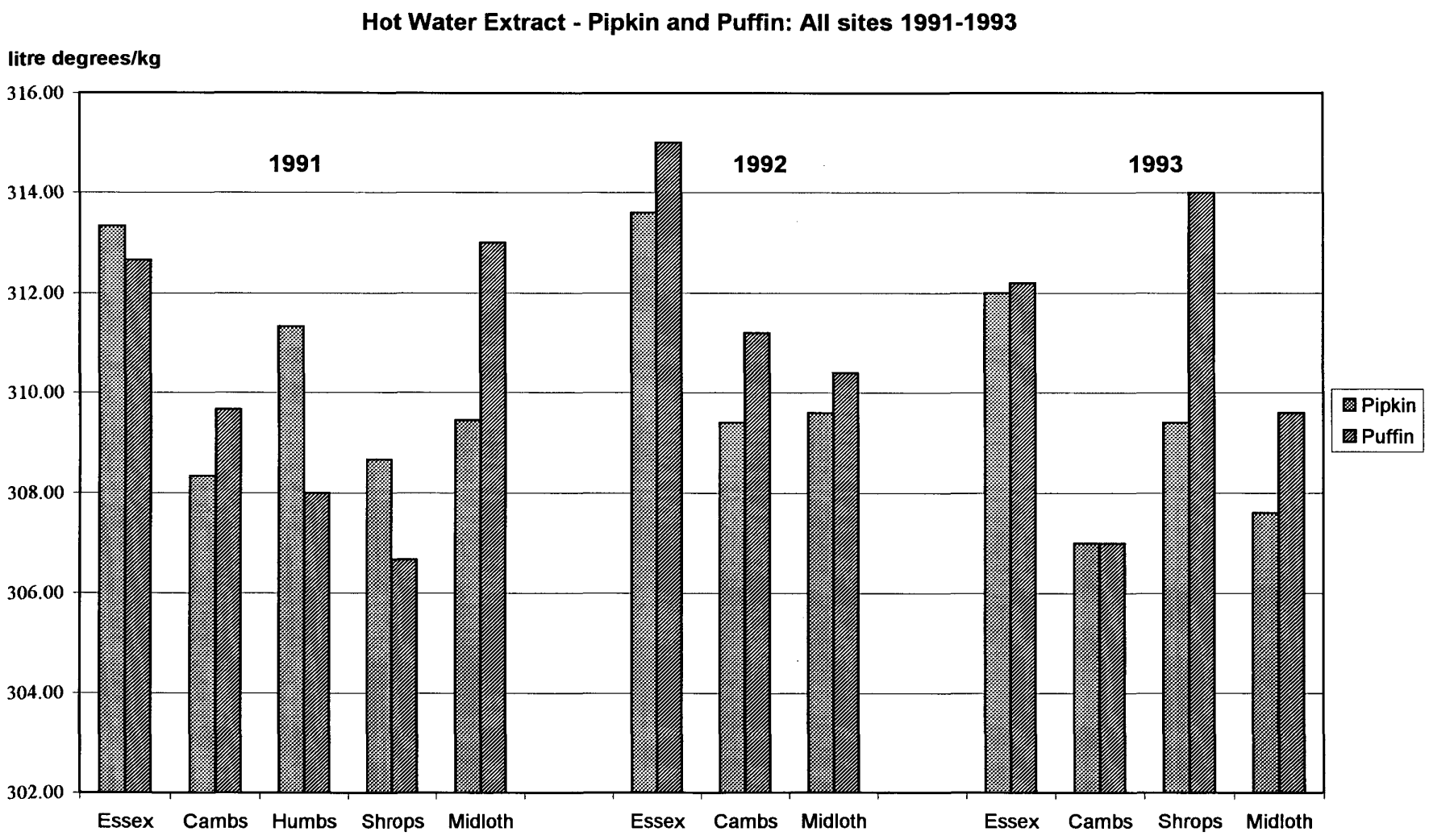

Grain nitrogen and Hot water extract 1991-1993 (Puffin - Essex)
HWE (litre degrees/kg)
317
316
315
314
313
312
311
1.2
1.25
1.3
1.35
1.4
1.45
1.5
1.55
1.6
Grain nitrogen (%N in DM)
y = -15.251x + 335.17
R2 = 0.4271
92
92
92
91
93(2)
91
92
92
93
93
93
91

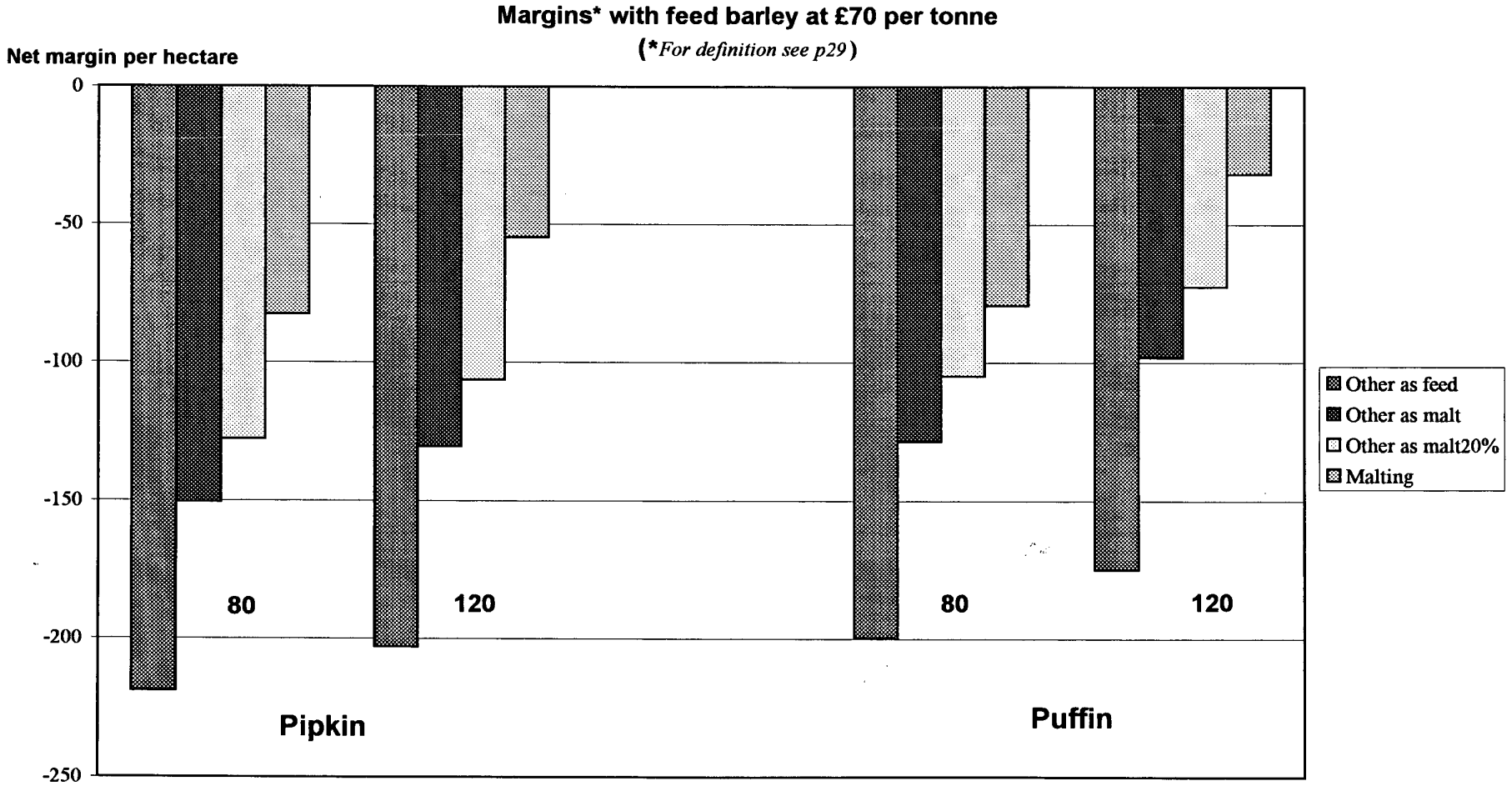

HWE (litre degree/kg)
Grain nitrogen and Hot water extract 1991 - 1993 (Pipkin -Cambs)
318
316
314
312
310
308
306
304
y = -6.1566x + 318.5
R2 = 0.0483
92
92
93
91
91
93
92
92
91
93
93
92
93
1.4
1.45
1.5
1.55
1.6
1.65
1.7
1.75
1.8
1.85
Grain nitrogen (%N in DM)

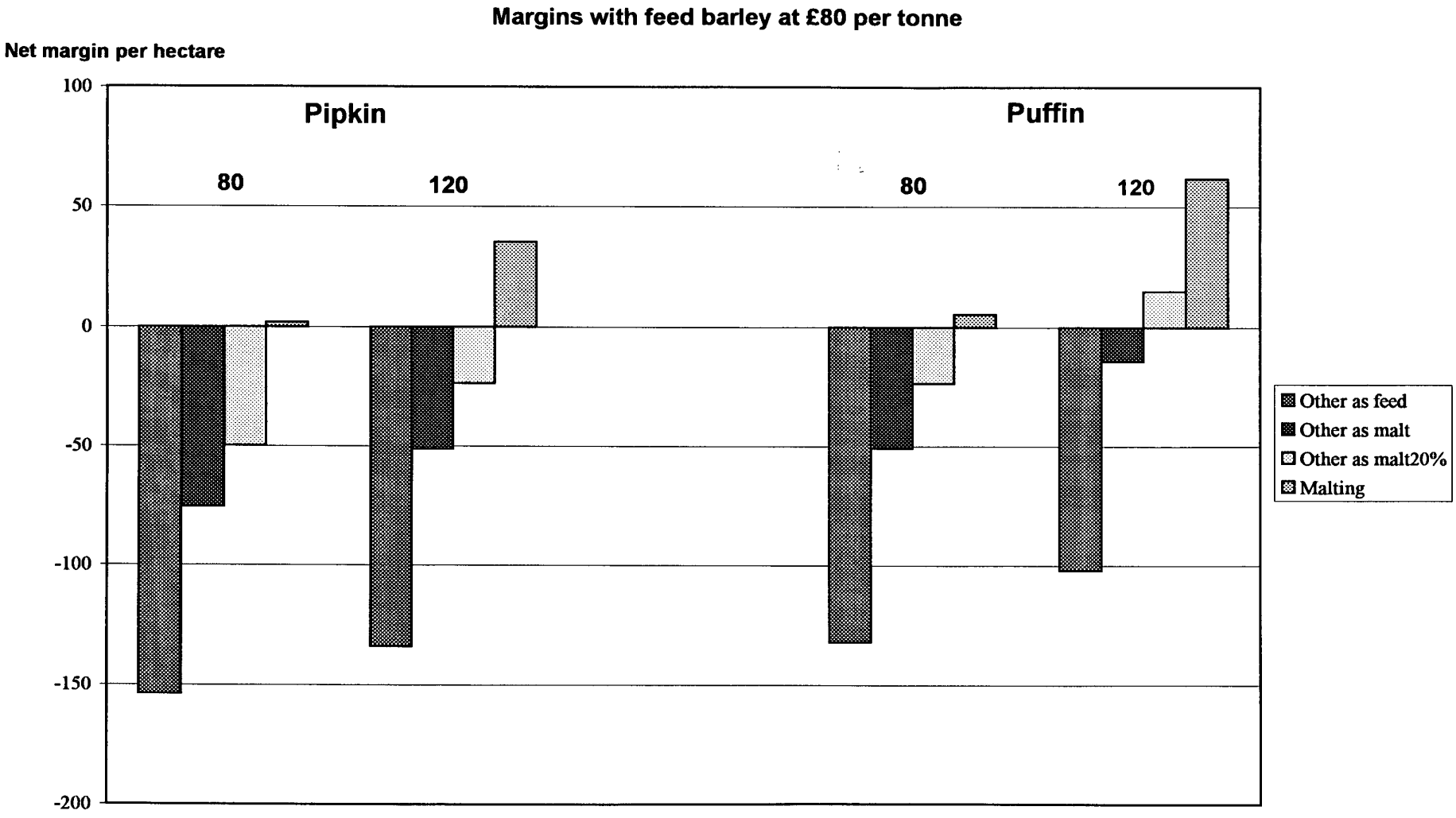

Grain nitrogen and Hot water extract 1991 - 1993 (Puffin - Cambs)
HWE (litre degrees/kg)
y = -2.3936x + 313.53
R2 = 0.0125
92
92
91
91
92
92
93
91
93
93
92
93
93
314
312
310
308
306
304
302
1.5
1.55
1.6
1.65
1.7
1.75
1.8
1.85
1.9
1.95
2
Grain nitrogen (%N in DM)


Grain nitrogen and Hot water extract 1991 - 1993 (Pipkin - Midlothian)
HWE (litre degrees/kg)
312
311.5
311
310.5
310
309.5
309
308.5
308
307.5
307
1.2
1.25
1.3
1.35
1.4
1.45
1.5
1.55
1.6
1.65
1.7
Grain nitrogen (%N in DM)
y = 0.9191x + 307.62
R2 = 0.0046
91
92
92
91
92
92
91
93
93(2)
93
93
92


Grain nitrogen and Hot water extract 1991 - 1993 (Puffin -Midlothian)
HWE (litre degrees/kg)
314
313
312
311
310
309
308
1.3
1.35
1.4
1.45
1.5
1.55
1.6
1.65
1.7
Grain nitrogen (%N in DM)
y = -5.9602x + 319.67
R2 = 0.1703
91
91
91
92
92
93
93(2)
92
92
93
93
92


Hot Water Extract - Pipkin and Puffin: All sites 1991-1993
litre degrees/kg
316.00
314.00
312.00
310.00
308.00
306.00
304.00
302.00
1991
1992
1993
Pipkin
Puffin
Essex
Cambs
Humbs
Shrops
Midloth
Essex
Cambs
Midloth
Essex
Cambs
Shrops
Midloth


Margins* with feed barley at £70 per tonne
(*For definition see p29)
Net margin per hectare
0
-50
-100
-150
-200
-250
80
120
80
120
Pipkin
Puffin
Other as feed
Other as malt
Other as malt20%
Malting


Margins with feed barley at £80 per tonne
Net margin per hectare
100
50
0
-50
-100
-150
-200
Pipkin
Puffin
80
120
80
120
Other as feed
Other as malt
Other as malt20%
Malting