Project Report No. 374

September 2005

Price: £3.50

Monitoring winter barley, wheat, oilseed rape and spring barley for sulphur in England and Wales to predict fertiliser need

by

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This is the final report of a forty-one month project that commenced in September 2001. The work was funded by a contract for £41,376 from the Home-Grown Cereals Authority (Project 2612), £30,792 from The Arable Group and £27,021 from Kemira GrowHow Ltd., making a total of £99,189.

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ABSTRACT

The dramatic reductions in sulphur deposition that have been achieved as a result of reduced sulphur emissions in the UK since the 1970's have actually resulted in increases in sulphur deficiencies in arable crops.

Methods of predicting sulphur deficiency in crops have existed for many years but it is now even more important that they are accurate. This project therefore addressed two aspects of the problem of increased sulphur deficiency in crops.

- the extent of deficiencies across soil types and geographic regions of England and Wales.
- the accuracy of techniques used to identify sulphur deficiency in crops in identifying beneficial yield responses resulting from sulphur applications.

A total of 183 trials were conducted on four crops, winter wheat, winter barley, winter oilseed rape and spring barley during 2002, 2003 and 2004 at locations stretching from Aberdeen to Trerulefoot in south Cornwall.

Replicated trials, grown at nitrogen input levels suitable for the specific locations, were treated with early season sulphur applications (22kg/ha S for cereals and 44 kg/ha S for oilseed rape) or left without a sulphur treatment.

The results confirmed that significant yield responses to sulphur applications (indicating sulphur-deficient crops) were more frequently recorded on lighter soils rather than medium or heavy soils. Significant yield responses to applications of sulphur were recorded on 16 of the 68 trials conducted on light soils whereas the 115 trials conducted on medium and heavier soils produced 11 significant yield responses to sulphur application.

It has also been previously reported that brassica crops are more likely to be sulphur deficient than cereal crops and this was again confirmed in this project.

Significant yield responses to applications of sulphur were recorded on 32% of the winter oilseed rape trials, 15% of the spring barley trials, 13% of the winter barley trials and 10% of the winter wheat trials. The highest recorded response was 81% yield increase (1.90 t/ha) in a crop of winter oilseed rape grown on light soil at Cirencester. However, in absolute yield terms the highest response was from a crop of winter wheat grown on light soil at Andover which produced a yield response to sulphur application of +2.92 t/ha (+38%).

The 183 trials reported in this project can be viewed as 183 field crop decisions on the potential value of sulphur. Was it possible to predict accurately the 27 trials out of the 183 conducted that produced significant yield responses to sulphur applications?

The malate test, which measures the malate:sulphate ratio in leaf tissue, produced a more successful indication of the likelihood of a significant yield response to a sulphur application than the soil Sppm test. However, the malate results clearly indicate that it overestimated the number of likely significant responses possibly by regularly detecting transient sulphur deficiency. The malate test suggested that 132 of the 183 trials would produce significant yield responses to sulphur applications but it only successfully identified 25 and actually did not predict two significant yield responses. In contrast, the soil test predicted 35 responses and successfully identified 11 of the 27 significant yield responses.

The lack of an accurate predictive test for sulphur deficiency will lead to the continuation of sulphur application in both situations where they are not needed and, in some cases, the lack of applications in situations where they are needed.

It is recommended that a review of the threshold levels used in the malate test is undertaken to determine if the predictive accuracy of the test can be increased.

INTRODUCTION

The dramatic decline in sulphur deposition levels in the UK since the 1970's has been well demonstrated. Action to reduce emission levels, and hence subsequent deposition levels, was necessary because high levels of emissions created health problems, damaged natural ecosystems and crops through 'acid rain'.

Successful emission controls have reduced the levels of emissions in the UK to 0.5 million t/year of sulphur, from 3.25 million t/year in 1970 which places current emission levels as similar to those of the pre-industrial era 150 years ago (McGrath et al, 2002). This remarkable achievement has produced significant environmental advantages but has also resulted in a decline in the availability of sulphur for crops growing in this country.

The national sulphur deposition predicted for the UK in 2010 is up to 4kg S/ha/year for much of the land area with some upland and industrial areas reaching levels of 4-8 kg S/ha/yr (National Expert Group on Transboundary Air Pollution, 2001).

The scale of the potential sulphur deficiency problem in Britain was well demonstrated by modelling work reported in 1995 (McGrath and Zhao, 1995a; 1995b). They predicted that by 2003, 23% of land in Britain would have a high risk of sulphur deficiency and a further 27% had a medium risk for wheat. This total of 50% of the land at medium to high risk of deficiency was exceeded by the 70% predictions for oilseed rape land at risk.

Correction of sulphur deficiency in arable crops is largely achieved by the use of fertilisers containing sulphur. The target levels of applications are around 20kg S/ha for cereals and 50kg S/ha for oilseed rape.

However, we are dealing with a rapidly changing situation. Arable crops are depleting the levels of sulphur currently available in our soils and sulphur deposition is not fully replacing the amounts of sulphur that are being used. The level of sulphur deficiency in any particular season or field situation is influenced by factors such as soil type, winter rainfall patterns, and previous cropping and so prediction of likely deficiency is a complex procedure. Nevertheless, it is vital that, as sulphur has become one of the most limiting nutrients for agricultural production in many European countries, the full extent of sulphur deficiency problems are investigated and methods of predicting sulphur deficiency in individual crops are developed.

There were therefore two key objectives in the studies outlined in this report. Firstly, a series of trials were conducted over three seasons, in a total of 19 locations in England and Scotland, to monitor the extent of sulphur deficiency in four arable crops. The crops used in the studies were winter wheat, winter barley, spring barley and winter oilseed rape. Crops were grown with or without the addition of sulphur to record the incidence of sulphur deficiency and the scale of the yield effect resulting from deficiency.

The 183 individual trials were also used to determine the suitability of certain predictive tests for sulphur deficiency. Three techniques were used to determine levels of sulphur deficiency and the results of these tests were compared to the yield responses obtained from the trials where sulphur had been applied to the crops. The three tests used were a soil test for sulphur content, the malate:sulphate tissue test and an analysis of the N:S ratio in the grain using grain harvested from each of the trials at the end of the growing season.

It is very important for growers to understand the full impact of sulphur deficiency on individual crops so that the cost: benefit assessment of sulphur application can be undertaken. However, it is also important to provide information on which crops are most likely to be at risk of sulphur deficiency so that corrective action can be taken at the optimum time. It is for this reason that the accuracy of predictive tests is so important to determine.

MATERIALS AND METHODS

There are 183 trials reported in this project, 178 conducted at locations organised by The Arable Group (TAG) and 5 provided by the Scottish Agricultural College (SAC).

The sulphur responses of four crops, winter wheat, winter barley, spring barley and winter oilseed rape were evaluated in simple trials protocols comparing two treatments, with or without a sulphur application in early spring.

All trial plots were drilled 12m long and 14 rows wide and each treatment was replicated three times in a randomised block design. The nitrogen levels used for each location were considered as best practice for the crop in that situation.

The sulphur applications were made at the time of the first nitrogen application, using Double Top.

The amount of sulphur applied to cereals was 22 kg/ha and oilseed rape 44 kg/ha.

At each location there were two varieties evaluated in the comparisons of with and without sulphur. One variety was funded by HGCA and the second variety designed to improve the statistical stability of the trial, was funded by TAG.

The statistical significance of the yield results was tested using the analysis of variance procedure with significance at P=0.05.

The soil, malate and grain tests were all conducted at independent laboratories. The malate tests were funded by Kemira. The malate tests were conducted on plants that had only received nitrogen, not sulphur applications. Similarly, the grain N:S ratio tests were conducted on grain sampled from the zero sulphur plots.
The soil types at the 19 different trial locations were as follows:

Table 1 - Soil Types at the 19 trial locations				
Site	**Site Code**	**Soil Series**	**Legend**	**Soil Type**
Berwick - Upon- Tweed	BR	Salop (slowly permeable reddish clay loam)	711m	M/H
Croft on Tees	DL	Dunkeswick (fine loam over clay)	711p	M/H
Bainton	BN	Panholes (well drained calcareous silty soil over chalk)	511c	M/H
Louth	LT	Carstens (wold land, silty and clayey with flints)	581d	M/H
Great Carlton	GC	Holderness (fine loamy soil with slight waterlogging)	711u	M/H
Caythorpe	CA	Elmton 1 (brashy calcareous loam over limestone)	343a	L
Andover	AN	Andover 1 (shallow calcareous soil over chalk)	343h	L
Wimborne	WM	Andover 1 (shallow calcareous soil over chalk)	343h	L
Ashford	AS	Batcombe (silty clay with flints over chalk)	582a	M/H
Trerulefoot	TR	Trusham (fine loam over deeply weathered rock)	541n	M/H
Biggleswade	BW	Cannamore (deep calcareous clay loam)	513	M/H
Chelmsford	CH	Ludford (deep well drained loam with flints)	571	M/H
Kettering	KT	Hanslope (chalky boulder clay)	411d	M/H
Bury St Edmunds	BE	Hanslope (chalky boulder clay)	411d	M/H
Morley	MR	Ashley (sandy loam over chalky boulder clay)	872a	M/H
Cirencester	CN	Elmton 1 (brashy calcareous loam over limestone)	343a	L
Taunton	TA	Whimple (Slowly permeable reddish clay loam)	572d	M/H
Warwick	WA	Salop (slowly permeable reddish clay loam)	711m	M/H
Aberdeen	SAC	Countesswell (sandy loam)		M/H

RESULTS

Yield responses

A major part of the project was devoted to monitoring the development of sulphur deficiency, by the occurrence of significant yield responses to sulphur application, across a range of locations/soil types in the country.

Whilst it is well accepted that sulphur deficiency will normally appear first, and more frequently, on lighter soils, it is important to understand the spread of the problem.

The locations chosen for the trials did reflect areas in which the crops would normally be grown so for example winter barley was not widely tested on heavy soils.

The questions posed in this part of the project were therefore:

- is sulphur deficiency already present in the location?
- did sulphur deficiency develop in the location over the number of years tested in the project?

The results presented in this section relate to the trials conducted in three seasons 2002, 2003 and 2004 where crops were grown with or without sulphur applications.

Winter Oilseed Rape

Six of the 28 trials were conducted on lighter soils and all trials were crops of winter oilseed rape following cereals, either winter wheat, winter barley or spring barley.

The application of sulphur produced nine significant (positive) yield responses from the 28 trials (Table 2), the increases ranging from +15.4% to +80.8%. The highest yield response produced a yield increase of 1.90 t/ha as a result of a single sulphur application.

The significant yield increases were recorded at the following locations:

Table 2 - Winter Oilseed Rape - significant yield responses to sulphur application			
2002	Kettering	Fortis	+26.2%
	Cirencester	Gemini	+41.8%
	Cirencester	Fortis	+79.9%
	Taunton	Gemini	+15.8%
	Taunton	Fortis	+15.4%
2003	Cirencester	Royal	+29.7%
	Cirencester	Fortis	+80.8%
2004	Cirencester	Royal	+39.7%
	Cirencester	Winner	+63.6%

All six trials conducted on light soils (Cirencester) produced significant yield responses to the application of sulphur. The three additional significant yield responses came from heavier soils at Taunton and Kettering.

The yield responses that were significant were also dramatic as they ranged from 0.60 t/ha to 1.90 t/ha.

The susceptibility of winter oilseed rape, to sulphur deficiency, when grown on lighter soil, was clearly demonstrated in this series of trials. However, on heavier soils, whilst some significant yield responses were obtained, there was no clear indication that sulphur applications were routinely beneficial to the crop.

Winter Barley

A total of 45 trials were conducted and these produced seven significant yield responses to the application of 22kg S/ha. Six of the significant yield responses were yield increases ranging from +2.5% to +18.5% (Table 3). However one was a significant yield decrease of -2.5%.

The significant (positive) yield responses were obtained at the following locations:

Table 3 - Winter Barley - significant yield responses to sulphur application					
					Previous Crop
2002	Bainton	(511c)	Pearl	+2.5%	S. Barley
2003	Croft	(711p)	Pearl	+5.5%	W. Barley
2004	Bainton	(511c)	Pearl	+7.2%	W. Wheat
	Bainton	(511c)	Siberia	+9.6%	W. Wheat
	Andover	(343h)	Pearl	+9.7%	S. Barley
	Trerulefoot	(541n)	Siberia	+18.5%	W.Barley

Using the earlier soil types definitions 18 of the 45 locations were lighter soils. However, only one lighter soil Andover (2004) - Pearl, produced a significant yield response to sulphur application. The remaining five significant (positive) yield responses were produced on medium/heavy soils and the negative response was on a medium soil (Bainton).

Caythorpe, Andover, Wimborne and Cirencester locations, being lighter soils, would be more susceptible to sulphur deficiency than the medium or heavier soils. However, only Andover, tested with six trials over the three year period, produced a significant yield increase to S application, and then only on one occasion.

In 2002 and 2003 the Cirencester location was winter barley following winter oilseed rape, a cropping sequence likely to reduce S response in the winter barley. However, in 2004 the winter barley followed winter wheat and no significant yield responses were recorded in any of the three seasons.

The Bainton location produced four significant yield responses to sulphur applications from six trials. However, three of them were positive responses but one of them, Siberia (2002) was a negative, significant yield of -2.5%. All Bainton winter barley trials, followed previous crops of cereals.

Trerulefoot in Cornwall was tested for the first time in 2004 and one of the varieties, Siberia, produced the largest yield response to a sulphur application in all of the winter barley trials, +18.5%, which was a 1.27 t/ha increase in yield.

The range in significant yield responses, from the six positive responses was 0.20 t/ha to 1.27 t/ha with an average (significant) yield response of 0.65 t/ha.

Winter Wheat

This was the most comprehensive part of the trials series with 90 trials conducted over three seasons. There were 24 trials conducted on lighter soils, the remaining 66 being conducted on medium or heavy soils.

A total of 10 significant yield responses were recorded when sulphur was applied, nine of the responses being positive and one negative, (Table 4).

The significant, positive yield responses were

Table 4 - Winter Wheat - significant yield responses to sulphur applications

2002	Great Carlton	Napier	+3.1%
2003	Bainton	Napier	+5.6%
	Andover	Claire	+14.8%
	Andover	Napier	+31.7%
	Wimborne	Claire	+22.1%
2004	Andover	Claire	+37.7%
	Andover	Napier	+19.5%
	Wimborne	Claire	+20.9%
	Wimborne	Napier	+16.8%

The significant yield improvements were from 0.29 t/ha to 2.92 t/ha. Seven of the nine responses were from the lighter soils of Andover and Wimborne and the yield increases of 1.25, 1.36, 1.62, 1.74, 2.31, 2.40 and 2.92 t/ha (average 1.94 t/ha) indicate the advantage of sulphur applications at these two locations. The other trials on lighter soils, at Caythorpe and Cirencester, did not produce any significant yield response to sulphur application.

The significant negative yield response to sulphur application was produced in Somerset.

2003 Taunton - Claire -4.8% produced a yield reduction of 0.49 t/ha. This crop of winter wheat was preceded by a spring oilseed rape crop.

Spring Barley

All 20 spring barley trials were conducted on lighter soils and produced five significant yield responses to the application of sulphur. However, three of these were positive and two of them were negative yield responses.

The positive yield responses were obtained from the following trials:

2003	Andover	Cellar	+12.1%
	SAC	Optic	+15.8%
2004	Andover	Cellar	+7.5%

The improvements in yield 0.83, 0.84 and 0.43 t/ha produced an average response to sulphur application, in the significantly responding trials, of 0.70 t/ha.

The two negative, significant yield responses were from:

2003	Caythorpe	Cellar	-12.5%
	SAC	Cellar	-8.4%

Note that in 2003 the SAC location at Aberdeen produced both a positive (Optic) and a negative (Cellar), significant yield response to the application of sulphur.

The table below summarises the significant, positive, yield responses to sulphur application:

Table 5 - A summary of the significant (positive) yield responses to sulphur application

Crop	Total Significant (+) Yield Responses	Light (*)	Heavy (**)	Yield Increase	Average Response
Winter Oilseed Rape	9	6/6	3/22	0.60 t/ha to 1.90 t/ha	1.05 t/ha
Winter Barley	6	1/18	5/27	0.20 t/ha to 1.27 t/ha	0.65 t/ha
Winter Wheat	9	7/24	2/66	0.29 t/ha to 2.92 t/ha	1.59 t/ha
Spring Barley	3	3/20	N/A	0.43 t/ha to 0.84 t/ha	0.70 t/ha

(*) this indicates the number of significant (positive) yield responses recorded on trials conducted on lighter soils.

(**) this indicates the number of significant (positive) yield responses on trials conducted on medium or heavy soils.

The responsiveness of winter oilseed rape to sulphur applications, when grown on lighter soils, is well illustrated in this trial series. All six light soil trials produced significant (positive) yield responses to the application of sulphur.

The responses of winter barley and winter wheat in these trials are interesting as they do not relate to the established views on sulphur responses. There is some evidence that winter barley, being further removed from a break crop in the cropping sequence, is usually more responsive to sulphur applications (TAG trials). However, in these trials only one out of 18 light land trials produced a significant yield response to sulphur (compared to 7 out of 24 for winter wheat) and the average yield response was lower for winter barley.

The average yield response, from significant (positive) responses was 0.65 t/ha for winter barley compared to 1.59 t/ha for winter what. The winter wheat trials also produced the highest response to a sulphur application in any of the four crops tested, 2.92 t/ha at Andover in 2004.

The spring barley trials only produced three significant positive yield responses from the 20 trials. The average yield response from those three trials was 0.70 t/ha, very similar to that obtained from the winter barley trials, 0.65 t/ha.

The summary of significant yield responses, both positive and negative (Table **6)** indicates 31 responses from 183 trials, with 27 being significant increases in yield.

Table 6 is a summary of significant yield responses to sulphur application.

Table 6 - The 31 significant yield responses to sulphur applications

	2002	2003	2004
Winter Oilseed Rape			
	+ 15% Taunton (Fortis)	+ 30% Cirencester (Royal)	+ 40% Cirencester (Royal)
	+ 16% Taunton (Gemini)	+ 15% Cirencester (Fortis)	+ 64% Cirencester (Winner)
	+ 26% Kettering (Fortis)		
	+ 42% Cirencester (Gemini)		
	+ 80% Cirencester (Fortis)		
Winter Barley			
	+ 2.5% Bainton (Pearl)	+ 5.5% Croft (Pearl)	+ 7% Bainton (Pearl)
	- 2.5% Bainton (Siberia)		+ 10% Bainton (Siberia)
			+ 10% Andover (Pearl)
			+ 18% Trerulefoot (Siberia)
Winter Wheat			
	+ 3.1% Great Carlton (Napier)	+ 6% Bainton (Napier)	+ 38% Andover (Claire)
		+ 15% Andover (Claire)	+ 20% Andover (Napier)
		+ 22% Wimborne (Claire)	+ 21% Wimborne (Claire)
		+ 32% Andover (Napier)	+ 17% Wimborne (Napier)
		- 5% Taunton (Claire)	
Spring Barley			
		+ 12% Andover (Fortis)	+ 7% Andover (Claire)
		+ 16% Aberdeen (Optic)	
		- 8% Aberdeen (Cellar)	
		- 12% Caythorpe (Cellar)	

The value of predictive tests

Crops at each trial location were subjected to malate:sulphate tests of plant leaf tissue and at the end of the season N:S ratios in the harvested grain. In addition the soil S status was tested in early spring prior to any fertiliser applications.

The results of these tests were related to the yield responses obtained from the plots at each location.

Soil sulphur testing

The generally accepted level for sulphur deficiency in soil has been for sulphur levels of 10 ppm S or less. However this has not proved to be a very reliable indicator of sulphur deficiency. Many trials have not shown yield responses to sulphur applications even though they have been grown on soils with less than 10 ppm sulphur. Equally it has been regularly shown that crops can produce significant yield responses to sulphur applications when they are grown on soils with sulphur contents above 10 ppm.

There has been considerable debate around this area with some suggestions that a lower threshold level could possibly be a more accurate indicator of sulphur deficiency in soils. It was therefore decided to evaluate yield responses in comparison to two sulphur threshold levels in the soil 10ppm and 6ppm.

Sulphur is very mobile in the soil and one criticism of soil testing techniques was that analysis is often concentrated on the upper soil layers when in fact sulphur can often be further down the soil profile. However, even with this improved guidance on testing techniques the reliability of soil testing as a method of predicting likely response to sulphur applications has been seriously questioned.

Malate:sulphur ratio

This new test, developed at Rothamsted Research, using HGCA funding, was first brought to growers attention in the HGCA Topic Sheet No 66 (Winter 2002/3).

‘The malate:sulphate test can detect S deficiency as soon as plants become deficient, depending upon soil type and crop species. S deficiency usually occurs earlier on lighter soils than on medium to heavy soils’.

- A malate:sulphate ratio more than 1.5 means the plant is deficient at the time of sampling.

- A ratio less than 1.5 means the S supply is sufficient at the time of the sampling.

The original guidance indicated that plants should be sampled 'early in the spring'. However, it was acknowledged that this may be before deficiency is present in the plant so 'if only one test is possible, sample plants .... at the beginning or during stem extension'.

The results reported here are for the highest M:S ratio recorded from two tests, some of which were not conducted until late March (WOSR) and late May (Winter Barley).

Sampling for the malate test this far through the season significantly reduces the value of the test as a predictive test for sulphur response. As the season progresses it is clear that sulphur deficiency is less well corrected by sulphur applications so an early predictive test result is of more value to a grower.

N:S ratio (grain)

This has been viewed by many agronomists as the most accurate test for sulphur deficiency in a crop. However, it is clear that this is not a predictive test as it is conducted on the crop that has been harvested. Its value is to indicate that the harvested crop may have been sulphur deficient and that serious consideration should be given to a sulphur application on the following crop.

The threshold value for deficiency varies between crops. For winter oilseed rape N:S ratios of greater than 15:1 are considered to be sulphur deficient. In cereals the threshold value is higher at 17:1.

In the following tables the relationship between the three sulphur tests, soil ppm S, malate:sulphate ratio and N:S ratio in the grain, and the yield responses to sulphur applications are reviewed.

The format of the tables is the same for each of the four crops. The left hand column refers to the four tests (soil ppm S is included twice at both 10 ppm and 6 ppm threshold levels).

'Predicted deficient in S' refers to the number of trials that the particular test suggested were sulphur deficient. In the case of the soil test and the malate:sulphate test this inferred that the crop would respond to an application of sulphur.

‘Correct/incorrect prediction’ indicates how many of the crops that were indicated as sulphur deficient, actually produced significant yield responses (positive) to sulphur when applied.

‘Predicted sufficient in S’ is the number of trials that were not considered to be sulphur deficient by the different testing systems.

‘Correct/incorrect prediction*’ indicates how many of the trials that were indicated as sulphur sufficient actually produced significant yield responses to sulphur applications.

‘Significant responses/Number predicted’ is the comparison of the number of significant yield responses to sulphur applications that were recorded in relation to the number that the particular test had predicted were sulphur deficient.

The Appendix contains the results of these those tests related to the yield responses from each individual trial that resulted from the application of sulphur.

Winter Oilseed Rape

The higher threshold sol analysis prediction (10 ppm S) suggested that 16 of the trials would give significant yield responses to sulphur applications but actually correctly only predicted four of the nine significant responses. This was a success rate of 25% but it did fail to identify five out of the nine significant yield responses (Table 7).

Table 7						
WINTER OILSEED RAPE The accuracy of individual S testing systems in predicting significant yield responses to S applications						
	Total Trials	**Predicted Deficient in S**	**Correct/Incorrect Prediction**	**Predicted sufficient in S**	**Correct/Incorrect Prediction***	**Significant responses/ Number predicted**
Soil (10 ppm)	28	16	4/12	12	7/5	9/4
Soil (6 ppm)	28	4	2/2	24	17/7	9/2
M:S (> 1.5)	28	28	9/19	0	N/A	9/9
Grain N:S (>15)	28	1	0/1	27	18/9	9/0

The 6 ppm S threshold level predicted four significant yield responses and only accurately identified two of them, a success of 50%. However, it did fail to predict seven of the nine significant yield responses.

The malate test indicated that all 28 trials were sulphur deficient, the highest ratio being 49.8. However, only nine trials produced significant yield responses so the malate test clearly overstated the number of significant responses that were to be expected.

It did accurately predict the nine trials that illustrated significant yield responses but it also predicted 19 trials where there were no significant yield responses.

Winter Barley

Using the original soil analysis threshold level of 10 ppm sulphur, 26 of the 45 trials would be considered as sulphur deficient soils, Table 8. However, only four of them produced significant, positive yield responses to sulphur applications.

Table 8						
WINTER BARLEY **The accuracy of individual S testing systems in predicting significant yield responses to S applications**						
	Total Trials	**Predicted Deficient in S**	**Correct/Incorrect Prediction**	**Predicted sufficient in S**	**Correct/Incorrect Prediction***	**Significant responses/ Number predicted**
Soil (10 ppm)	45	26	4/22	19	16/3	7/4
Soil (6 ppm)	45	7	1/6	38	32/6	7/1
M:S (> 1.5)	45	43	6/37	2	2/0	7/6
Grain N:S (>17)	39	8	0/8	31	26/5	5/0

Using the more stringent threshold value of 6 ppm S four locations had soil S levels below the threshold (Berwick, Croft, Andover and Kettering). Using this 6 ppm S level as a predictive tool for sulphur deficiency, seven trials were at risk, but only one of them, Croft (2003) Pearl, produced a significant yield increase when sulphur was applied. Conversely five trials produced significant yield increases to sulphur applications when their soil S analyses revealed levels over 6 ppm.

The inability of this test to predict likely responses to sulphur application is demonstrated by these results. In fact the 6 ppm was actually less accurate than the 10 ppm threshold level, predicting only one of the subsequent significant yield responses in comparison to four successful predictions for the 10 ppm threshold values.

The malate ratio results were obtained from samples collected from the non-sulphur treated plots between 7th April and 13th June. In virtually every trial there was a double sampling, about one month apart, and the highest reading is presented in Table 8. The threshold level of 1.5 would suggest that only two of the 45 trials were not likely to respond to sulphur applications. These were the two trials at Berwick in 2004 where incidentally the soil S level was 30 ppm. However, of the remaining 43 trials, only six produced significant yield increases to S applications, and one produced a significant yield decrease. The second highest malate to sulphate ratio recorded in winter barley was 23.4 and this produced a +4.5% yield response which was not significant. Note also that this trial, Cirencester (2004) Pearl, also showed an N:S ratio in the grain which was S deficient. The greatest yield response to sulphur application, +18.5% was produced from a malate ratio of 4.4, even though the highest ratio recorded was 35.5, (which did not produce a significant yield response).

The malate test was clearly grossly overstating the number of trials that would demonstrate responses to sulphur application as it produced 37 wrong results from 43 predictions of deficiency. However, of the seven trials that did ultimately demonstrate significant yield responses it did successfully predict six of them. The next most successful test was the soil test (10 ppm S) which correctly predicted four of the seven significant yield responses.

The N:S ratio in the grain produced very disappointing results in the winter barley as is suggested eight crops were deficient but none of them actually demonstrated a significant yield response to sulphur application. Five trials did produce significant yield responses and all were indicated as satisfactory N:S grain ratios at harvest.

Winter Wheat

A total of 54 of the 90 trials had soil S levels below the threshold level of 10 ppm. However, only eight of the trials that illustrated a sulphur deficit, produced significant yield responses. This was a 15% success rate compared to a success of 30% using the 6 ppm S threshold level where six of the 20 predicted deficient trials actually produced significant yield responses to sulphur applications (Table 9).

Table 9

WINTER WHEAT
The accuracy of individual S testing systems in predicting significant yield responses to S applications

	Total Trials	Predicted Deficient in S	Correct/Incorrect Prediction	Predicted sufficient in S	Correct/Incorrect Prediction*	Significant responses/ Number predicted
Soil (10 ppm)	90	54	8/46	36	35/1	10/9
Soil (6 ppm)	90	20	6/14	70	66/4	10/6
M:S (> 1.5)	90	45	7/38	45	42/3	10/7
Grain N:S (>17)	85	17	5/12	68	65/3	8/5

The malate test actually predicted less sulphur deficient trials than the soil 10 ppm S threshold test. In contrast, in both winter oilseed rape and winter barley the malate test produced the highest predictions of deficiency. It predicted 45 of the 90 trials to be sulphur deficient, and accurately predicted seven significant responses, a success rate of 16%. It did incorrectly predict two trials as having satisfactory malate ratios when in fact they subsequently produced significant yield responses to sulphur applications. In one case a malate ratio of 0.5 produced a yield response of +37.7%, Andover (Claire) 2004. The Andover location also produced the highest malate ratio recorded in the winter wheat trials, 32.7 (Napier, 2003) which resulted in a significant yield response of +31.7%. The third incorrect prediction was associated with a significant, negative yield response. The malate test produced a ratio of 1.3 (Taunton, Clare, 2003) but the yield response to sulphur application was -4.8%

The grain analyses on 85 trials indicated 17 to be above the N:S threshold ratio of 17:1. Five of these actually were produced from crops that had given significant yield responses to sulphur application when sulphur was added to the partner plots. This was a success rate of 42%.

Spring Barley

The 20 trials were conducted in situations where 10 of the those trials were below the 10 ppm S level and were therefore sulphur deficient Three subsequently produced significant, positive yield responses to sulphur applications but one further trial with 9 ppm S produced a -12% response to sulphur application (Table 10).

Table 10

SPRING BARLEY
The accuracy of individual S testing systems in predicting significant yield responses to S applications

	Total Trials	**Predicted Deficient in S**	**Correct/Incorrect Prediction**	**Predicted sufficient in S**	**Correct/Incorrect Prediction***	**Significant responses/ Number predicted**
Soil (10 ppm)	20	10	3/7	8	6/2	5/2
Soil (6 ppm)	20	4	2/2	14	11/3	5/2
M:S (> 1.5)	20	16	3/13	2	2/2	4/4
Grain N:S (>17)	12	1	0/1	11	11/1	1/0

Adopting the 6ppm S threshold level, four trials were predicted as S deficient and two actually produced significant yield increases when sulphur was applied.

The malate tests on the crop produced the two highest ratios recorded in all the crops over the three seasons of trials. At Andover in 2003 malate ratios of 55.2 (Cellar) and 69.8 (Optic) were recorded but only the Cellar with a yield response of +12.1% produced a significant response to sulphur application.

The malate test predicted 16 of the 20 trials to be sulphur deficient but only three trials responded significantly to the sulphur applications.

The grain N:S ratio only indicated one sulphur deficient crop, but sulphur application did not produce a significant yield response.

DISCUSSION

The 183 sulphur trials reported in this project produced 31 significant yield responses to sulphur applications. A total of 27 responses were significant yield increases as a result of sulphur applications and four were significant yield decreases.

It has been well recognised that sulphur deficiency is more prevalent on lighter soils, where organic matter levels are lower and the sulphur is more mobile in the soil. In this trial series 68 trials were conducted on lighter soils and they produced 16 significant (positive) yield responses to sulphur applications. The remaining 115 trials were conducted on medium or heavy soils and they produced 11 significant (positive) yield responses. These figures would therefore support the view that sulphur deficiency is more prevalent on lighter soils but the responses within the individual crops do indicate the more widespread nature of the sulphur deficiency problem.

Three of the four negative yield responses to the application of sulphur were produced on the medium/heavy soil types, the fourth one being found on light soil - spring barley, Caythorpe, 2003.

The largest yield response from the application of sulphur on any of the four crops tested over the three seasons was 2.92 t/ha (37.7% increase in yield) from a crop of Claire winter wheat growing on light soil at Andover in 2004. Winter wheat also recorded the second and third highest yield responses to sulphur applications.

2.40 t/ha (+31.7%) Napier, Andover, 2003
2.31 t/ha (+22.1%) Claire, Wimborne, 2003

The highest winter oilseed rape response was 1.90 t/ha (+80.8%) from Fortis at the Cirencester location in 2003.

Whilst the responses in winter wheat were not surprising as they were produced on light soils, the magnitude of the responses were surprising. The average positive (and significant) yield responses from the four crops, expressed as a % increase in yield resulting from sulphur application were:

- Winter Oilseed Rape +36%
- Winter Wheat +19%
- Spring Barley +12%
- Winter Barley +9%

Winter oilseed rape is clearly more responsive than cereals to sulphur deficiency correction.

The number of instances of sulphur deficiency on medium and heavy soils was lower than on lighter soils, only 9% of the trials giving significant yield responses to sulphur applications (light soils 23%). However, this does indicate that the problem of deficiency is not just confined to the lighter soils but is spreading to other soil types previously considered unlikely to be sulphur deficient.

Both environmental and financial pressures identify the need to produce a reliable method of predicting and identifying sulphur deficiency in crops. The techniques previously used, before the development of the malate test, were either a soil test to detect sulphur content or an end of season test for nitrogen and sulphur content of the harvested grain. This latter test was considered the more accurate of the two available, but was not a predictive test in the season in which the crop was growing.

The accuracy of these two tests, plus the malate test, at both predicting and identifying sulphur deficiency in the crops has suggested that reliable techniques are still not available.

Nine (32%) of the Winter Oilseed Rape trials produced significant yield responses to sulphur application and the soil test accurately predicted 4 whilst the grain N:S test actually indicated that none were deficient in sulphur at harvest. The more severe sulphur threshold level in the soil of 6 ppm actually produced a less accurate prediction of only 2 significant yield responses. The malate test predicted all nine significant responses so it was clearly the most accurate test. However, it predicted that all 28 trials were deficient so it did get 19 trials wrong. This could have led to 28 applications of sulphur to crops when only 9 merited sulphur application. The malate test, based on a threshold level of 1.5 malate to sulphate ratio, overstated the likelihood of sulphur deficiency.

Seven of the 45 winter barley trials produced significant yield responses to sulphur applications which was 16%, but only six were yield increases. The soil test identified four significant responses correctly but the more refined soil test only detected one significant response. The grain N:S ratio did not identify any of the significant responses. The malate test predicted 43 significant responses to sulphur application and it correctly identified all seven trials that did give significant yield responses. However, one of these significant yield responses was a yield decrease as a result of sulphur application. The test was accurate but achieved this accuracy by over prediction. Only six of the 43 trials that it predicted would give positive yield responses to sulphur application actually gave significant yield responses.

The 90 winter wheat trials produced 10 significant yield responses, one of which was a yield decrease from sulphur application. The soil tests on this occasion predicted 54 yield responses but only eight of them were significant. The more refined soil test predicted 20 responses and accurately predicted 6 of them. The malate test actually predicted less yield responses, 45, than the soil test, but only 7 were correct. This therefore produced 38 trials where the test suggested sulphur should be applied but where a significant yield response was not produced. However, it should be noted that in this crop the soil test (10 ppm) actually incorrectly predicted 46 trials as being sulphur deficient.

The 20 spring barley trials produced five significant yield responses to sulphur applications but only three of them were positive. The malate test once again predicted the highest number of deficient crops (16) but only three of them produced significant, positive yield responses to sulphur applications.

The results highlight the need for a clearer understanding of the relationship between sulphur deficiency predictions (or assessments of sulphur levels through the season) and the subsequent yield response to sulphur applications.

The 183 trials were the equivalent of 183 field decisions being made by a grower. With the tools at his disposal of soil tests for sulphur, malate tests and grain N:S tests how accurately could the grower have predicted whether by using the individual test he could have produced a significant yield response to the application of sulphur? There are initially two problems associated with this question. Firstly, the grain N:S ratio is conducted at the end of the season so it is effectively a predictive test for the following seasons crop. Secondly, it would appear that the malate test is only accurate later in the growing season, often at a point where sulphur application may not satisfactorily correct the deficiency and a yield reduction will still be recorded.

However, with these reservations it is interesting to note the overall prediction of sulphur deficiency and the success rate in predicting crops that actually produced a significant yield response to sulphur application.

There were 27 significant yield increases as a result of sulphur applications and the test results were as follows:

- the soil (10ppmS) test predicted 106 deficient crops and correctly identified 19
- the soil (6ppmS) test predicted 35 deficient crops and correctly identified 11
- the malate test indicated 132 crops were deficient in sulphur and correctly identified 25 significant yield responses.
- the grain N:S ratio suggested 27 crops had been sulphur deficient and correctly identified 5 crops that produced significant yield responses.

The malate test did correctly identify the highest number of sulphur deficient crops but it did so at the expense of predicting the highest number of candidate crops to be deficient. The work would suggest that a review of the threshold level for malate testing would be valuable and the project is now underway.

Details of these results and conclusions have been provided to Dr Mechteld Blake-Kalff who developed the malate test at Rothamsted (and provided the malate testing service to the project through Hill Court Farm Research). Dr Blake-Kalff has proposed that the threshold level for the malate:sulphate ratio should be increased, for winter barley, to 3:1 from the present level of 1.5:1. It is not proposed to change the 1.5 threshold level for winter wheat or oilseed rape.

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WOSR									
Location	**Variety**	**Soil (ppm)**	**Highest M:S**	**Grain N:S**	**YIELD No sulphur t/ha**	**YIELD No sulphur t/ha**	**% Yield Response**	**Yield Change (t/ha)**	**CV (%)**
2002									
Great Carlton	Gemini	7	1.7	8.6	4.61	4.74	2.8	0.13	5.69
	Fortis	7	1.9	9.2	3.96	3.76	-5.5	-0.22	5.69
Biggleswade	Gemini	7	6.8	10.1	4.06	4.18	3.1	0.12	5.35
	Fortis	7	6.0	13.7	4.06	4.13	1.7	0.07	5.35
Kettering	Gemini	13	27.7	17.5	3.27	3.66	11.9	0.39	9.54
	Fortis	13	19.6	12.9	2.56	3.23	26.2*	0.67	9.54
Cirencester	Gemini	11	49.8	11.1	3.47	4.92	41.8*	1.45	5.54
	Fortis	11	47.9	12.3	2.19	3.94	79.9*	1.75	5.54
Taunton	Gemini	12	3.9	7.7	4.42	5.12	15.8*	0.70	4.05
	Fortis	12	3.5	8.7	4.28	4.94	15.4*	0.66	4.05
2003									
Great Carlton	Royal	9	2.0	6.9	6.34	6.28	-0.9	-0.06	5.11
	Fortis	9	1.9	9.2	4.88	4.60	-5.7	-0.28	5.11
Croft	Royal	5	47.3	7.7	5.86	6.24	6.5	0.38	5.51
	Fortis	5	22.4	11.3	5.15	5.33	3.5	0.18	5.51
Biggleswade	Royal	13	2.7	6.2	4.37	4.30	-1.6	-0.07	2.22
	Fortis	13	2.4	8.7	4.21	4.07	-3.3	-0.14	2.22
Suffolk	Royal	7	4.1	7.3	3.78	4.02	6.3	0.24	2.33
	Foris	7	9.7	9.6	3.86	3.62	-6.2	-0.24	2.33
Cirencester	Royal	9	18.9	13.7	3.67	4.76	29.7*	1.09	10.40
	Fortis	9	12.1	9.8	2.35	4.25	80.8*	1.90	10.40
Taunton	Royal	9	3.8	9.6	3.76	3.98	5.9	0.22	4.10
	Fortis	9	3.9	11.4	3.33	3.36	0.9	0.03	4.10
2004									
Great Carlton	Royal	11	13.4	6.4	4.17	4.39	5.3	0.22	0.34
	Winner	11	11.4	8.6	4.16	4.54	9.1	0.38	0.34
Chelmsford	Royal	12	2.2	6.8	3.88	3.62	-6.7	-0.26	5.63
	Winner	12	2.4	8.7	3.54	3.29	-7.1	-0.25	5.63
Cirencester	Royal	5	26.0	8.8	1.51	2.11	39.7*	0.60	17.90
	Winner	5	42.1	7.6	0.99	1.62	63.6*	0.63	17.90

*significant yield response

WINTER WHEAT									
Location	**Variety**	**Soil (ppm)**	**Highest M:S**	**Grain N:S**	**YIELD No sulphur t/ha**	**YIELD with sulphur t/ha**	**% Yield Response**	**Yield Change (t/ha)**	**CV (%)**
2002									
Berwick	Claire	11	1.0	14.4	10.43	10.27	-1.8	-0.16	1.17
	Napier	11	2.5	15.9	10.88	10.74	-1.3	-0.14	1.17
Bainton	Claire	11	0.8	15.0	11.33	11.27	-0.5	-0.06	1.80
	Napier	11	0.5	14.8	11.83	11.80	-0.3	-0.03	1.80
Louth	Claire	23	0.3	12.2	10.98	11.34	3.3	0.36	2.43
	Napier	23	0.4	13.4	10.85	11.18	3.0	0.33	2.43
Great Carlton	Claire	9	0.4	14.5	9.01	8.97	-0.4	-0.04	1.02
	Napier	9	0.5	13.2	9.30	9.59	3.1*	0.29	1.02
Caythorpe	Claire	12	0.5	12.9	10.05	10.00	-0.5	-0.05	1.22
	Napier	12	0.8	12.4	10.71	10.65	-0.6	-0.06	1.22
Wimborne	Claire	8	1.2	17.2	8.33	8.26	-0.8	-0.07	1.40
	Napier	8	1.9	12.6	8.89	8.76	-1.5	-0.13	1.40
Wye	Claire	6	1.0	16.3	8.94	9.12	2.0	0.18	1.27
	Napier	6	1.2	17.0	8.99	8.93	-0.7	-0.06	1.27
Andover	Claire	10	0.9	18.3	9.16	9.51	3.8	0.25	2.88
	Napier	10	2.4	18.9	7.87	8.11	3.0	0.24	2.88
Kettering	Claire	17	1.0	16.5	11.90	11.96	0.4	0.06	0.50
	Napier	17	1.6	13.3	12.50	12.45	4.6	-0.05	0.50
Dunmow	Claire	10	0.8	15.5	10.63	10.50	-1.2	-0.13	4.16
	Napier	10	1.2	15.8	10.89	11.34	6.7	0.45	4.16
Bury	Claire	8	3.6	14.1	10.50	10.48	-0.3	-0.02	3.46
	Napier	8	3.2	14.4	10.50	10.49	-0.2	-0.01	3.46
Cirencester	Claire	15	1.7	15.8	11.28	11.40	1.1	0.12	1.48
	Napier	15	3.1	15.3	11.53	11.39	-1.2	-0.14	1.48
Warwick	Claire	19	1.8	16.4	4.67	4.91	5.1	0.25	4.19
	Napier	19	2.7	18.3	5.10	5.44	6.7	0.34	4.19

*significant yield response

WINTER WHEAT									
Location	**Variety**	**Soil (ppm)**	**Highest M:S**	**Grain N:S**	**YIELD No sulphur t/ha**	**YIELD with sulphur t/ha**	**% Yield Response**	**Yield Change (t/ha)**	**CV (%)**
2003									
Croft	Claire	5	0.9	15.5	11.78	11.99	1.8	0.21	2.14
	Napier	5	0.9	16.7	12.52	12.37	-1.2	-0.15	2.14
Bainton	Claire	8	1.3	18.3	8.45	8.60	1.8	0.15	2.13
	Napier	8	2.7	18.2	8.08	8.53	5.6*	0.45	2.23
Louth	Claire	25	0.4	13.0	11.18	11.00	-1.6	-0.18	1.50
	Napier	25	0.6	13.1	11.07	10.96	-1.0	-0.11	1.50
Great Carlton	Claire	6	0.8	10.7	11.11	10.91	-1.8	-0.20	3.92
	Napier	6	1.1	11.9	10.18	10.24	0.6	0.06	3.92
Caythorpe	Claire	9	1.2	13.3	9.27	9.32	0.5	0.05	2.13
	Napier	9	4.0	15.4	8.77	8.91	1.6	0.14	2.13
Andover	Claire	4	17.1	17.7	8.42	9.67	14.8*	1.25	4.99
	Napier	4	32.7	18.2	7.57	9.97	31.7*	2.40	4.99
Wye	Claire	4	1.5	17.0	11.19	11.36	1.5	0.17	2.04
	Napier	4	1.7	17.3	11.33	11.42	0.8	0.09	2.04
Wimborne	Claire	18	7.5	16.1	10.46	12.77	22.1*	2.31	5.04
	Napier	18	12.9	17.5	8.67	9.77	12.7	1.10	5.04
Biggleswade	Claire	7	1.3	13.3	10.08	10.15	0.7	0.07	2.84
	Napier	7	1.6	13.5	10.26	10.38	1.2	0.12	2.84
Kettering	Claire	7	0.9	12.6	9.58	9.66	0.8	0.08	2.09
	Napier	7	1.0	15.8	8.59	8.67	0.9	0.08	2.09
Dunmow	Claire	3	1.6	14.9	9.51	9.32	-2.0	-0.19	2.37
	Napier	3	1.9	13.9	9.55	9.78	2.4	0.23	2.37
Bury	Claire	5	1.4	13.4	8.86	9.02	1.8	0.16	4.66
	Napier	5	1.9	13.9	7.89	8.19	3.8	0.30	4.66
Cirencester	Claire	12	2.6	15.6	8.84	8.94	1.1	0.10	4.50
	Napier	12	2.4	16.7	8.75	8.93	2.1	0.18	4.50
Warwick	Claire	11	4.1	17.1	6.27	6.23	-0.6	-0.04	4.80
	Napier	11	2.5	15.8	6.81	6.93	1.8	0.12	4.80
Taunton	Claire	9	1.3	15.0	10.21	9.72	-4.8*	-0.49	1.90
	Napier	9	1.7	14.6	10.26	10.10	-1.6	-0.16	1.90

*significant yield response

WINTER WHEAT									
Location	**Variety**	**Soil (ppm)**	**Highest M:S**	**Grain N:S**	**YIELD No sulphur t/ha**	**YIELD with sulphur t/ha**	**% Yield Response**	**Yield Change (t/ha)**	**CV (%)**
2004									
Croft	Claire	10	1.1	15.7	12.91	12.82	-0.7	-0.09	2.96
	Napier	10	1.8	15.6	14.19	13.90	-2.0	-0.29	2.96
Bainton	Claire	8	1.7	15.0	9.16	9.58	4.6	0.42	2.95
	Napier	8	1.7	15.3	9.09	9.22	1.4	0.13	2.95
Louth	Claire	26	0.4	16.9	9.96	9.86	-1.0	-0.10	1.55
	Napier	26	0.5	18.1	10.06	10.08	0.2	0.02	1.55
Great Carlton	Claire	31	1.1	15.8	10.88	10.93	0.4	0.05	1.06
	Napier	31	1.1	15.2	11.00	10.83	-1.5	-0.07	1.06
Caythorpe	Claire	10	1.1	17.6	9.55	9.48	-0.7	-0.07	1.25
	Napier	10	1.9	14.8	9.42	9.44	0.2	0.02	1.25
Berwick	Claire	14	1.1	15.5	10.35	10.21	-1.4	-0.14	5.43
	Napier	14	1.1	15.5	10.54	10.87	3.1	0.33	5.43
Andover	Claire	4	0.5	18.0	7.74	10.66	37.7*	2.92	2.28
	Napier	4	1.6	19.7	8.91	10.65	19.5*	1.74	2.28
Ashford	Claire	8	1.2	15.3	10.64	10.92	2.6	0.28	3.30
	Napier	8	2.1	15.5	10.36	9.93	-4.2	-0.43	3.30
Wimborne	Claire	4	4.5		7.74	9.36	20.9*	1.62	3.49
	Napier	4	17.0		8.08	9.44	16.8*	1.36	3.49
Biggleswade	Claire	37	1.2	15.1	11.18	11.42	2.1	0.24	1.27
	Napier	37	1.4	15.0	11.90	11.77	-1.1	-0.13	1.27
Kettering	Claire	29	1.5	15.4	10.40	10.11	-2.8	-0.29	1.85
	Napier	29	1.6	15.3	11.02	10.92	-0.9	-0.10	1.85
Chelmsford	Claire	10	4.5		11.81	11.87	0.5	0.06	1.38
	Napier	10	5.6	15.1	12.35	12.27	-0.6	-0.08	1.38
Bury	Claire	11	2.6	15.6	10.53	10.53	0.0	0.00	3.61
	Napier	11	2.3	15.6	10.44	10.01	-4.1	-0.43	3.61

*significant yield response

WINTER WHEAT									
Location	**Variety**	**Soil (ppm)**	**Highest M:S**	**Grain N:S**	**YIELD No sulphur t/ha**	**YIELD with sulphur t/ha**	**% Yield Response**	**Yield Change (t/ha)**	**CV (%)**
2004									
Cirencester	Claire	1	4.3	14.7	7.03	7.19	2.3	0.16	7.55
	Napier	1	7.1	18.0	6.95	7.78	11.9	0.83	7.55
Warwick	Claire	21	0.6	15.0	11.31	10.86	-4.0	-0.45	5.13
	Napier	21	0.5	15.3	12.22	12.29	0.6	0.07	5.13
Trerulefoot	Claire	10	1.5	14.4	8.50	8.62	1.4	0.12	2.20
	Napier	10	2.6	14.1	8.57	8.45	-1.4	-0.12	2.20
Taunton	Claire	7	0.8	15.3	7.89	7.90	0.1	0.01	6.23
	Napier	7	0.9	14.3	8.89	9.31	4.7	0.42	6.23

*significant yield response

WINTER BARLEY									
Location	Variety	Soil (ppm)	Highest M:S	Grain N:S	YIELD No sulphur t/ha	YIELD plus sulphur t/ha	% Yield Response	Yield Change (t/ha)	CV (%)
2002									
Berwick	Pearl	10	4.5	14.8	8.18	7.93	-3.1	-0.25	3.59
	Siberia	10	4.9	14.8	8.69	9.11	4.8	0.42	3.59
Bainton	Pearl	11	10.8	13.0	8.09	8.29	2.5*	0.20	0.96
	Siberia	11	6.4	15.2	8.70	8.48	-2.5*	0.22	0.96
Caythorpe	Pearl	12	7.1	17.2	8.91	8.66	-2.8	-0.25	3.58
	Siberia	12	2.4	13.7	9.16	8.71	-4.9	-0.45	3.58
Andover	Pearl	11	3.7	17.1	5.10	5.62	10.2	0.52	4.85
	Siberia	11	8.9	17.6	6.73	7.20	7.0	0.47	4.85
Biggleswade	Pearl	9	7.0	17.5	8.94	9.22	3.1	0.28	3.29
	Siberia	9	3.2	11.6	10.35	10.21	-1.4	-0.14	3.29
Cirencester	Pearl	12	12.2	12.1	1`0.40	10.27	-1.3	-0.13	3.96
	Siberia	12	7.7	11.2	9.27	9.16	-1.2	-0.11	3.96
2003									
Berwick	Pearl	5	3.4	13.7	10.63	10.53	-0.9	-0.10	1.93
	Siberia	5	3.7	13.9	11.04	10.86	-1.6	-0.18	1.93
Bainton	Pearl	7	15.8	15.5	8.07	8.48	5.1	0.41	2.85
	Siberia	7	11.2	16.2	8.70	8.56	-1.6	-0.14	2.85
Caythorpe	Pearl	9	10.5	13.1	8.20	8.25	0.6	0.05	3.94
	Siberia	9	10.8	14.6	8.14	7.94	-2.5	-0.20	3.94
Croft	Pearl	2	3.8	16.1	7.29	7.69	5.5*	0.40	2.53
Andover	Pearl	4	35.5		4.98	5.42	8.8	0.44	4.48
	Siberia	4	18.9		6.38	6.30	-1.3	-0.08	4.48
Biggleswade	Pearl	7	7.8	12.2	9.03	8.98	0.6	-0.05	2.14
	Siberia	7	5.9	13.4	9.56	9.54	0.2	-0.02	2.14
Cirencester	Pearl	12	13.8	14.8	6.68	7.29	9.1	0.61	5.70
	Siberia	12	4.5	13.2	6.97	6.94	-0.4	-0.03	5.70
Kettering	Pearl	5	1.6	15.5	5.30	5.67	7.0	0.37	4.98
	Siberia	5	1.6	16.0	6.25	6.15	-1.6	-0.10	4.98

*significant yield response

WINTER BARLEY									
Location	**Variety**	**Soil (ppm)**	**Highest M:S**	**Grain N:S**	**YIELD No sulphur t/ha**	**YIELD plus sulphur t/ha**	**% Yield Response**	**Yield Change (t/ha)**	**CV (%)**
2004									
Berwick	Pearl	30	0.7	12.7	10.20	10.23	0.3	0.03	1.61
	Siberia	30	0.6	14.0	11.14	11.29	1.3	0.15	1.61
Bainton	Pearl	9	19.6	15.0	7.96	8.53	7.2*	0.57	2.40
	Siberia	9	14.3	14.5	8.50	9.32	9.6*	0.82	2.40
Caythorpe	Pearl	10	5.5	12.3	8.70	8.52	-2.1	-0.18	2.44
	Siberia	10	2.9	13.8	9.52	9.30	-2.3	-0.22	2.44
Croft	Siberia	7	16.5	18.0	9.06	9.56	5.5	0.50	4.09
Andover	Pearl	11	1.6		6.81	7.47	9.7*	0.66	4.57
	Siberia	11	2.6		6.78	7.02	3.5	0.24	4.57
Kettering	Pearl	15	16.7	12.9	4.82	4.68	-2.9	-0.14	2.28
	Siberia	15	6.3	14.4	6.71	6.71	0.0	0.00	2.28
Biggleswade	Pearl	11	5.2	12.9	7.86	7.74	-1.5	-0.12	4.37
	Siberia	11	6.8	14.5	9.71	9.42	-3.0	-0.29	4.37
Cirencester	Pearl	9	23.4	24.2	6.95	7.25	4.5	0.31	4.83
	Siberia	9	4.9	26.1	8.71	8.25	-5.3	-0.46	4.83
Trerulefoot	Pearl	9	9.6		6.43	6.95	8.1	0.52	6.14
	Siberia	9	4.4		6.86	8.13	18.5*	1.27	6.14
SAC	Pastoral	11	4.8	18.5	9.24	9.35	1.2	0.11	3.10

*significant yield response

SPRING BARLEY									
Location	**Variety**	**Soil (ppm)**	**Highest M:S**	**Grain N:S**	**YIELD No sulphur t/ha**	**YIELD No sulphur t/ha**	**% Yield Response**	**Yield Change (t/ha)**	**CV (%)**
2002									
Caythorpe	Optic	12	1.3	14.2	5.62	6.06	7.8	0.44	3.15
	Tavern	12	1.2	14.3	6.07	6.15	1.3	0.08	3.15
Andover	Optic	10	9.5	15.0	6.17	6.38	3.4	0.21	5.60
	Tavern	10	10.3	14.8	6.21	6.34	2.1	0.13	5.60
2003									
Caythorpe	Cellar	9	4.0	11.5	5.29	4.63	-12.5*	-1.34	5.86
	Optic	9	2.9	11.3	4.94	5.34	8.1	0.40	5.86
Andover	Cellar	2	55.2		6.85	7.68	12.1*	0.83	5.32
	Optic	2	69.8		6.80	6.96	2.3	0.16	5.32
Cirencester	Cellar	11	23.5	14.9	6.16	5.98	-2.9	-0.18	2.80
	Optic	11	30.4	14.4	6.95	7.14	2.7	0.19	2.80
SAC	Cellar	12	3.2		5.95	5.45	-8.4*	-0.50	3.10
	Optic	12	2.1		5.31	6.15	15.8*	0.84	3.10
2004									
Caythorpe	Cellar	10	2.0	16.7	6.73	6.57	-2.4	-0.16	2.47
	Optic	10	2.8	12.8	6.59	6.55	-0.6	-0.04	2.47
Andover	Cellar	5			5.70	6.13	7.5*	0.43	2.73
	Optic	5			7.11	7.27	2.2	0.16	2.73
Cirencester	Cellar	12	39.9	17.2	5.82	5.82	0.0	0.00	10.13
	Optic	12	3.1	16.0	5.47	5.24	-4.2	-0.23	10.13
SAC	Cellar		3.1		4.36	4.35	-0.2	-0.01	6.30
	Optic		3.0		4.02	4.30	9.0	0.28	6.30

*significant yield response