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EFFECTS OF SOIL TYPE AND NITROGEN ON THE QUALITY OF AUTUMN-SOWN MALTING BARLEY

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by

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EFFECTS OF SOIL TYPE AND NITROGEN ON THE QUALITY OF AUTUMN-SOWN MALTING BARLEY

J.R.GARSTANG, JILL VAUGHAN AND C.J.DYER

ABSTRACT

This project was carried out over three years with harvests in 1988, 1989 and 1990. Its aims were to examine the effects of soil type, nitrogen source and nitrogen rate on grain yield and quality of autumn sown malting barley. Available water capacity (AWC) was taken as the main parameter for describing soil type. Attempts were made to identify soil types which may give a good chance of achieving a malting premium, and to assess the feasibility of predicting nitrogen use so as to maximise margins over nitrogen costs. AWC was a very varied parameter with considerable overlap between the high and low classification groupings. Nevertheless, high AWC sites were more reliable producers of higher yields and lower grain nitrogen than low AWC sites. Curves fitted to the data showed, on average, 90 kg/ha N were needed to give the highest yield (5.84 t/ha) commensurate with grain nitrogen contents no higher than 1.75% N on the low AWC sites. At the high AWC sites, the values were 107 kg/ha nitrogen to give 6.44 t/ha. On both groups of AWC sites, cereals were the predominant previous crop. There were no significant differences between the effects of nitrogen sources on grain yield. Urea gave significantly lower grain nitrogen than ammonium nitrate although the effect varied between seasons, drier seasons favouring lower grain nitrogen contents from urea. Many of the natural variables of the growing season, particularly rainfall during the grain filling period, affect yield and grain nitrogen content. This makes it impossible to accurately forecast nitrogen fertiliser requirement in the spring. This effect is further confounded by the effect the overall national annual rainfall has on the premiums. High and low rainfall in different regions of production have different effects on overall supply, eg. drought in East-Anglia will more severely affect total supplies and quality than drought in the South West.

INTRODUCTION

It is a widely held belief that malting barley with low grain nitrogen content is most reliably produced on sandy or shallow soils with low organic nitrogen residues from previous crops (Archer, 1985). The demands to produce wheat crops with high protein have led to the high profitability of rotations such as wheat-beans-wheat-rape. The maintenance of high soil mineral nitrogen (SMN) by the break crop has contributed to the profitability of milling wheat, and has resulted in the heavier 'wheat and bean' type soils being maintained at relatively high fertility by either fertiliser or rotational means. However, an increased understanding of SMN reserves and their behaviour on heavier soils may enable better sites to be selected for the production of malting barley.

Heavier soils with higher available water capacity (AWC) are more able to sustain grain fill in dry conditions. Previous work, partially funded by the HGCA showed that grain nitrogen tended to be lower on high yield potential sites, and higher on very light soils where yield was limited by drought in many years (Lord & Vaughan, 1987).

Recent years have seen an increase in the use of urea as a nitrogen fertiliser, and ADAS trials have shown that grain nitrogen content is frequently lower when urea is applied compared to ammonium nitrate at the same rate per hectare (Sylvester-Bradley et al., 1987).

The aim of the work described here was to identify soil types, by way of AWC and SMN, that give a good chance of producing a malting barley crop that attracts a good premium. The AWC was estimated from the soil texture, horizon and structural parameters according to the classification developed by the Soil Survey and Land Research Centre (see Appendix 1 for details). In addition to this, the feasibility of predicting the amount and source of nitrogen (urea or ammonium nitrate) which would maximise margins over nitrogen costs was studied, and again this comparison was done on different soil types. The work summarised in this report covers three years of cropping harvested in 1988, 1989 and 1990.

MATERIALS AND METHODS

Comparison of AWC

Six pairs of sites were selected for the 1988 trials and eight pairs for 1989 and 1990. Within each pair of sites one trial was designated 'high' AWC and one 'low' AWC. The terms were relative for individual sites, so the high AWC soil at some sites were lower than the low AWC at other sites.

The mean AWC of the high sites was 120mm (range 101-172mm) and the mean AWC of the low sites was 106 (range 54-152). The mean difference between high and low sites was 21mm. The allocation to the high and low categories was done when the sites were selected, in the same way a farmer may select heavy and light soil types for feed and malting crops. Differences in AWC within paired sites were often small. The calculated AWC level was occasionally the reverse of that perceived at treatment allocation. As the perception of a site being light or heavy is the criterion by which crops would be allocated to a field, the original allocations were maintained throughout the trial and the analysis of data.

The location of all the sites is listed in Table 1.

In 1988, the crops were grown as 'farm' crops and received between 100 and 146 kg/ha of nitrogen (Table 1). The 1989 and 1990 crops received either nil, 40, 80, 120, 180, 240 or 300 kg/ha of nitrogen as ammonium nitrate on two replicates per site. In all three years, both the high and low AWC sites received the same amounts of nitrogen. Some nitrogen was applied in February with the majority in March. The SMN values are the mean of autumn and spring measurements.

Table 1. Survey site details.

Location & harvest year	**Variety**	**AWC**	**Soil texture**	**Previous Crop**	**SMN (kg/ha)**	**N applied (kg/ha)**
1988						
Barsham	Pipkin	H(152)	Sandy loam	W Wheat	46	120
(Norfolk)		L(80)	Loamy sand	W Barley	26.4	120
Brettenham	Magie	H(110)	Sand	Herbage Seed	52.8	137
(Norfolk)		L(129)	Sand	Herbage Seed	29.6	137
Sandridge	Pipkin	H(172)	Sandy silt loam	W Barley	64.8	120
(Herts)		L(152)	Sandy silt loam	W Oats	37.6	120
Bishop Burton	Pipkin	H(137)	Silty clay loam	W Barley	8.4*	100
(Humberside)		L(127)	Silty clay loam	W Barley	4.6*	100
* Shallow soil						
Preston Candover	Magie	H(160)	Silty clay loam	W Barley	70.1	120
(Hants)		L(142)	Silty clay loam	W Barley	82.0	120
Letham	Magie	H(172)	Clay loam	W Barley	90.0	146
(Northumberland)		L(152)	Sandy silt loam	S Barley	95.6	146
1989						
(N applied 0 - 300 kg/ha)						
Barsham	Pipkin	H(121)	Sandy loam	W Barley	45.8	
		L(77)	Loamy sand	S Barley	32.6	
Brettenham	Maris Otter	H(113)	Loamy sand	Carrots	42.6	
		L(96)	Loamy sand	Carrots	37.1	
Sandridge	Pipkin	H(129)	Sandy silt loam	W Wheat	77.5	
		L(120)	Silty clay loam	W Wheat	73.0	
Bishop Burton	Marinka	H(101)	Silty clay loam	S Barley	61.1	
		L(99)	Silty clay loam	S Barley	36.8	

Preston Candover	Magie	H(128) Silty clay loam	W Wheat	63.4
		L(115) Clay	W Wheat	47.0
Ellingham	Halcyon	H(123) Clay loam	W Barley	24.2
(Northumberland)		L(121) Sandy clay loam	W Barley	57.8
Market Drayton	Magie	H(125) Sandy loam	W Wheat	28.8
(Shropshire)		L(107) Sandy loam	W Barley	111.4
Harmston	Marinka	H(109) Loamy sand	W Barley	90.1
(Lincs)		L(93) Sandy loam	W Barley	117.4

1990

(N applied 0 - 300 kg/ha)

Barsham	Pipkin	H(108) Sandy loam	W Barley	23.7
		L(125) Sandy loam	W Barley	29.2
Brettenham	Halcyon	H(125) Sandy loam	Sugar Beet	69.5
		L(74) Sand	Sugar Beet	69.3
L'tle Chesterford	Maris Otter	H(115) Clay	W Wheat	74.8
		L(125) Sandy loam	W Wheat	28.1
Bishop Burton	Pipkin	H(101) Silty clay loam	W Wheat	38.8
		L(54) Silty clay loam	W Wheat	29.0
Preston Candover	Pipkin	H(115) Clay loam	W Barley	51.9
		L(107) Silty clay loam	W Barley	56.4
Letham	Halcyon	H(142) Loam	W Wheat	44.6
		L(142) Sandy clay loam	W Wheat	35.9
Market Drayton	Marinka	H(125) Sandy loam	W Barley	22.1
		L(125) Sandy loam	W Barley	35.2
Cuxwold	Halcyon	H(136) Sandy loam	W Barley	22.1
(Lincs)		L(111) Sandy loam	W Barley	35.2

Nitrogen source comparison sites

In each year, a pair of sites with high and low AWC carried three replicates of plots receiving either nil, 40, 80, 120, 180, 240, or 300 kg/ha of nitrogen both as ammonium nitrate or urea.

Details of these sites are shown in Table 2.

Table 2. Nitrogen source comparisons: sites details.

Location & harvest year	**Variety**	**AWC (mm)**	**Soil texture**	**Previous Crop**	**SMN (kg/ha)**
1988					
Blunham	Magie	H(125)	Sandy loam	Peas/Beans	17.2
Potton	Pipkin	L(98)	Loamy sand	W Barley	24.2
1989					
Blunham	Pipkin	H(121)	Sandy loam	Peas/Beans	38.7
Potton	Pipkin	L(113)	Loamy sand	W Wheat	19.6
1990					
Blunham	Pipkin	H(125)	Sandy loam	Peas/Beans	20.9
Eversholt	Pipkin	L(73)	Loamy sand	W Barley	20.5

Records

All sites were soil sampled to 90 cm (where possible) and SMN determined. Soil particle size distribution was determined for each site to give sand, clay and silt fractions.

All crops were harvested by combine, moisture content determined and yields expressed as grain at 85% dry matter (DM). Specific weight was measured. Grain nitrogen was determined by Near Infra-red reflectometry and reported as % in DM. Grain size distribution was determined by sieving through 2.8, 2.5, and 2.2mm sieves.

Data analysis

Means of all data except that from the survey sites in 1988 were compared using analysis of variance.

Grain yield response to nitrogen was fitted with the linear plus exponential function:

$$y = a + b*r**x + c*x$$

where x is applied nitrogen and constants $a>0$ and $b, c<0$, and $0<r<1$. In the large majority of cases r was between 0.98 and 1. Where trial conditions resulted in unusual growing conditions and relatively poor fit, r moved towards 0.97 the curve becoming more raised in response to the more dispersed data with yields at lower N rates increasing more steeply.

Grain nitrogen response to nitrogen was fitted with the critical exponential function:

$$y = a + (b+c**x)*r**x$$

and the response of nitrogen offtake to applied nitrogen was fitted with the ordinary exponential function:

$$y = a + b*r**x$$

with r constrained at <1.

RESULTS

The first section of results presented are the comparison of treatment means from analysis of variance. Grain yield, grain nitrogen and nitrogen offtake are presented first for the sites comparing AWC, and second for the comparisons of nitrogen sources. The second section of results presents the comparison of responses from the effects of SMN and clay content on yield and grain nitrogen content before the fitted data for all sites. The latter are used to show the effects of AWC on the response of grain yield, grain nitrogen content and nitrogen offtake to applied nitrogen.

At the few sites where the "high" AWC were calculated to be lower that the "low" AWC, all produced results similar to high AWC sites rather than low AWC sites. Details are shown in the relevant secions

SECTION I:

COMPARISON OF TREATMENT MEANS

1988

The results from the non replicated 1988 survey sites are presented first.

Table 3. Effect of site and AWC on grain yield (t/ha) in 1988

Nil nitrogen applied.

	Site AWC	
	High	Low
Barsham	3.18	1.52
Brettenham	2.73	2.07
Sandridge	2.61	4.36
Bishop Burton	2.95	2.27
Preston Candover	3.89	4.19
Letham	2.57	4.09
Mean	2.99	3.08

Nitrogen applied (mean 124 kg/ha)

	Site AWC		N applied
	High	Low	(kg/ha)
Barsham	5.39	4.10	120
Brettenham	6.26	5.14	137
Sandridge	6.76	7.21	120
Bishop Burton	6.69	5.79	100
Preston Candover	6.20	7.08	120
Letham	5.92	6.94	146
Mean	6.20	6.04	

Nitrogen application increased the difference between the mean of the high and low AWC sites. The low AWC sites with the highest sand content in their particle size distributions (Barsham and Brettenham) produced the lowest grain yields both with and without nitrogen. The highest yields from the low AWCs were from those sites with the highest AWC in that group (ie. Sandridge, Preston Candover and Letham).

Table 4. Effect of site and AWC on grain N content (%)

Nil nitrogen applied.

	Site AWC	
	High	Low
Barsham	1.38	1.30
Brettenham	1.60	1.50
Sandridge	1.16	1.34
Bishop Burton	1.33	1.30
Preston Candover	1.42	1.40
Letham	1.44	1.67
Mean	1.39	1.42

Nitrogen applied (mean 124 kg/ha)

	Site AWC		N applied
	High	Low	(kg/ha)
Barsham	1.55	1.34	120
Brettenham	1.67	1.63	137
Sandridge	1.48	1.58	120
Bishop Burton	1.43	1.37	100
Preston Candover	1.74	1.64	120
Letham	1.70	1.88	146
Mean	1.60	1.57	

Increased nitrogen use increased grain nitrogen content at all sites.
In comparisons of the high and low AWC sites the higher yield was associated with the higher grain nitrogen content at all sites except Preston Candover, where there was some evidence of dilution of grain nitrogen with increased yield. This silt clay loam site had the highest clay and silt content.

Table 5

Effect of site and AWC on grain nitrogen offtake (kg/ha) and increase in nitrogen offtake over nil N.

Nil nitrogen applied

	Site AWC	
	High	Low
Barsham	37.3	16.7
Brettenham	37.9	26.3
Sandridge	25.8	49.9
Bishop Burton	33.4	25.0
Preston Candover	46.9	49.8
Letham	31.5	58.1
Mean	35.5	37.6

Nitrogen applied (mean 124 kg/ha)

	Site AWC	
	High	Low
Barsham	70.6 (33.3)	46.7 (30.0)
Brettenham	88.6 (50.7)	71.1 (44.8)
Sandridge	85.2 (59.4)	97.1 (47.2)
Bishop Burton	81.4 (48.0)	67.2 (42.2)
Preston Candover	91.4 (44.5)	98.5 (48.7)
Letham	85.8 (54.3)	111.1 (53.0)
Mean	83.8	82.0

The increases in N offtake associated with the N applied are shown in brackets. No clear pattern emerges, although the heavy Preston Candover site, as with the grain content, responds differently with slightly higher increases in nitrogen offtake at the low AWC site as a result of nitrogen application.

Specific weight was measured on the grain from Barsham, Brettenham and Sandridge. There were no consistent differences due to soil AWC.

1989 & 1990

The results from these two years are presented together. The same rates of nitrogen were applied in both years.

Grain yield

Trials at the same location for two years, but on different fields at those same sites, are treated as separate locations in a single analysis of variance covering both years. Eight sites in each year gave 15 degrees of freedom for the site component. The two-year mean grain yields for the high and low AWC sites differed significantly ($P<0.001$) and were 6.17 and 5.56 t/ha respectively. At 11 of the 16 sites, the high AWC trial gave the highest yield. The individual site grain yields at high and low AWCs are shown in Table 6 over the page

The significant differences between sites and between AWC were reflected in a significant interaction ($P<0.001$) between site x AWC; not surprisingly, yield response to high and low AWC soils is not uniform across sites. With such a general classification as high and low AWC, differences in local weather, disease pressure and other soil attributes produce different responses at individual sites.

The cross site two-year mean grain yields at different nitrogen rates are shown in Table 7.

Table 6. The effect of site and AWC on grain yield (t/ha) (means of all nitrogen rates).

	Site AWC		
Location	High	Low	Mean
1989			
Barsham	7.82	3.96	5.89
Brettenham	4.33	3.24	3.79
Sandridge	5.97	6.71	6.34
Bishop Burton	8.51	7.65	8.08
Preston Candover	6.21	6.41	6.31
Ellingham	5.66	6.29	5.98
Market Drayton	5.03	4.02	4.53
Harmston	8.06	6.17	7.12
1989 mean	6.45	5.56	
1990			
Barsham	5.37	4.01	4.69
Brettenham	5.76	4.20	4.98
Little Chesterford	5.94	5.48	5.71
Bishop Burton	5.68	5.31	5.49
Preston Candover	5.01	5.50	5.26
Letham	7.89	7.28	7.58
Market Drayton	5.96	7.27	6.62
Cuxwold	5.49	5.40	5.44
1990 mean	5.89	5.55	
(16 site mean - 1989 and 1990)	6.17	5.56	5.86

Table 7

The effect of applied nitrogen and AWC on grain yield (t/ha): mean of 2 years (1989, 1990).

	Site AWC		
	High	Low	Mean
N applied (kg/ha)			
	(SED 0.083)		(SED 0.059)
0	4.13	3.95	4.04
40	5.40	5.14	5.27
80	6.27	5.79	6.03
120	6.66	6.07	6.36
180	6.93	6.06	6.49
240	6.87	6.01	6.44
300	6.92	5.88	6.40
Mean	6.17	5.56	5.86

Differences in grain yields between N rates were significant ($P<0.001$), and the interactions between N rates and both AWC and sites were significant ($P<0.001$) ie. the response to N, whilst higher at the high AWC sites, differs between AWCs and between sites, and between the same AWC at different sites. As with table 6 the gross classification of AWC as "high" and "low" contained much variation (see table 1 & 2) and these interactions with AWC were to have been expected. These values are shown graphically in Figure 1. SED's were not derived for the overall AWC comparison at the bottom of Table 7 (and Tables 9 & 11).

Appendix 2 shows the individual sites yields for each N rate at both high and low AWC.

Grain nitrogen content

Table 8 The effect of site and AWC on grain nitrogen content (% in DM) (means of all nitrogen rates).

	Site AWC		
Location	High	Low	Mean
1989			
Barsham	1.58	2.12	1.85
Brettenham	2.08	2.14	2.11
Sandridge	2.12	2.09	2.11
Bishop Burton	1.81	1.87	1.84
Preston Candover	1.85	1.77	1.81
Ellingham	1.55	1.56	1.56
Market Drayton	1.93	2.16	2.04
Harmston	1.96	2.10	2.03
1989 mean	1.86	1.98	
1990			
Barsham	1.88	1.85	1.87
Brettenham	2.19	2.79	2.49
Little Chesterford	1.85	1.81	1.83
Bishop Burton	1.82	1.74	1.78
Preston Candover	1.64	1.55	1.59
Letham	1.82	1.96	1.89
Market Drayton	1.97	1.95	1.96
Cuxwold	1.91	2.04	1.98
1990 mean	1.88	1.96	
(16 site mean 1989 and 1990)	1.87	1.97	1.92

As with grain yield, all three factors produced significant main effects ($P<0.001$) in grain N content. And again all interactions were significant <u>except</u> the AWC x nitrogen response (see Table 9).

Table 9

The effect of AWC and applied nitrogen on grain nitrogen content (%) mean of 2 years 1989 and 1990

	Site AWC		
N applied (kg/ha)	High	Low	Mean
	(SED 0.032)		(SED 0.022)
0	1.50	1.56	1.53
40	1.50	1.57	1.54
80	1.64	1.73	1.69
120	1.83	1.92	1.88
180	2.05	2.22	2.13
240	2.22	2.30	2.26
300	2.35	2.48	2.42
Mean	1.87	1.97	1.92

There was a significant interaction between the response of grain N content to applied N at different sites ($P<0.001$), but this was not due to differences in AWC. As with grain yield, sites responded differently to nitrogen increments, but were affected by local climate, disease pressure and soil factors other than AWC. The cross site two year mean response of grain nitrogen content to applied nitrogen produced similar responses on the high and low AWC sites, but the means of low AWC sites were consistently higher than the high AWC sites at all nitrogen rates. These values are shown in Figure 1 along with the grain yields.

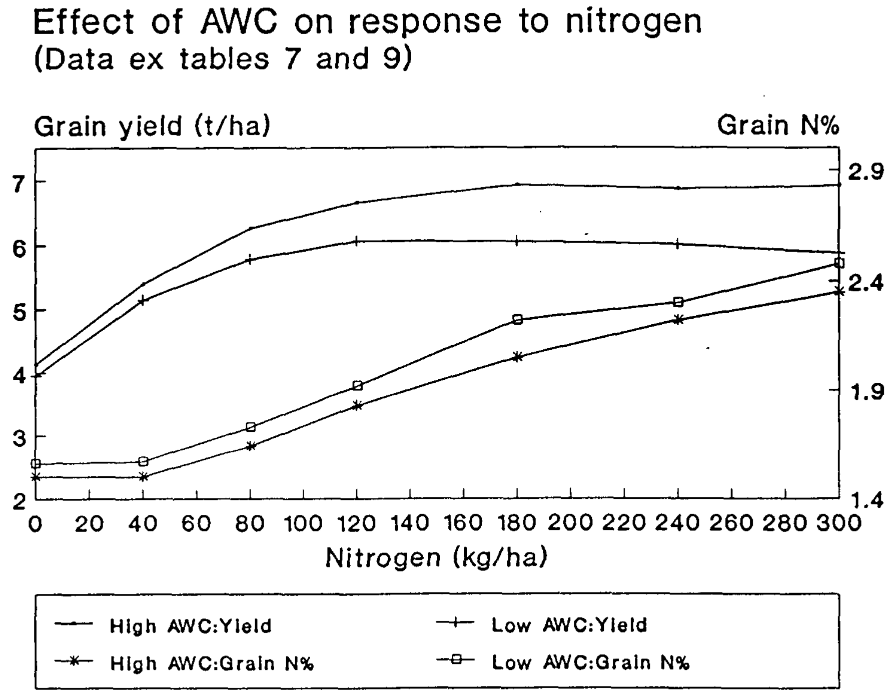

Fig.1

Grain Nitrogen Offtake

Nitrogen offtake in grain was 6.6% higher on the high AWC sites than on the low AWC sites. Grain yield was 11% higher. The resultant mean grain N contents across all sites were 5.1% lower on the high AWC sites. These changes are in line with the arithmetic calculation of lower grain N content that would be expected from higher yields per se. The differences in N offtake between high and low AWC sites relates almost entirely to the higher yield potential of the high AWC sites.

Table 10

The effect of site and AWC on grain nitrogen offtake (kg/ha): mean of 2 years 1989 and 1990

	Site AWC		
Location	High	Low	Mean
1989			
Barsham	107.5	73.0	90.2
Brettenham	78.9	60.4	69.6
Sandridge	106.9	119.2	113.1
Bishop Burton	132.7	124.5	128.6
Preston Candover	98.9	96.7	97.8
Ellingham	75.5	85.1	80.3
Market Drayton	85.0	72.7	78.9
Harmston	134.5	110.3	122.4
1990			
Barsham	119.1	91.0	105.0
Brettenham	146.3	132.8	139.6
Little Chesterford	132.9	117.2	125.0
Bishop Burton	127.1	113.4	120.2
Preston Candover	98.1	103.0	100.5
Letham	173.5	171.2	172.4
Market Drayton	141.5	166.5	154.0
Cuxwold	128.0	132.1	130.1
(16 site mean)	117.9	110.6	114.2

Table 11 The effect of AWC and applied nitrogen on grain nitrogen offtake (kg/ha): mean of two years 1989 and 1990

	Site AWC		
	High	Low	Mean
N applied (kg/ha)			
	(SED 2.46)		(SED 1.74)
0	62.9	62.7	62.8
40	81.7	82.0	81.8
80	103.8	100.8	102.3
120	123.2	117.2	120.2
180	141.8	133.2	137.5
240	152.1	136.2	144.1
300	159.8	142.0	150.9
Mean	117.9	110.6	114.2

There is a marked drop in the efficiency of nitrogen recovery in grain once applications exceed 120 kg/ha. The drop is greatest on the low AWC sites, but lower yields on these sites outweigh this effect and the grain nitrogen contents are higher (see Table 9).

Comparison of nitrogen sources

Grain yield

Table 12 Effect of AWC and ammonium nitrate (AN) or urea (U) on grain yield (t/ha) and means of each of 3 years 1988 to 1990

		Site AWC			
		High		Low	
		AN	U	AN	U
N applied(kg/ha)					
0		4.23		2.52	
40		5.98	6.15	3.92	3.38
80		6.70	6.66	3.93	4.23
120		6.81	6.63	4.45	4.14
180		6.09	6.29	5.05	4.97
240		6.06	6.44	4.41	4.16
300		5.73	6.14	4.41	4.48
		6.23	6.38	4.36	4.23
Overall AWC mean		6.15		4.16	
Year	1988	5.20	5.69	4.83	4.59
	1989	6.91	6.87	5.60	5.20
	1990	6.57	6.60	2.66	2.89

There was no significant difference between the two sources with urea performing slightly better on high AWC sites and ammonium nitrate being better on low AWC sites. This is shown clearly in Figure 2. There were no significant interactions between source and any other factors, so we can say that ammonium nitrate and urea behaved similarly in terms of grain production in the range of conditions tested.

As expected, there was a significant response to nitrogen ($P<0.001$) and other interactions indicated a differential response to nitrogen between years ($P<0.001$) and between AWC sites (AWC x Control x N). This latter term is most akin to the significant AWC x N level term in the survey site data, although the degree of divergence on the source comparison sites is limited.

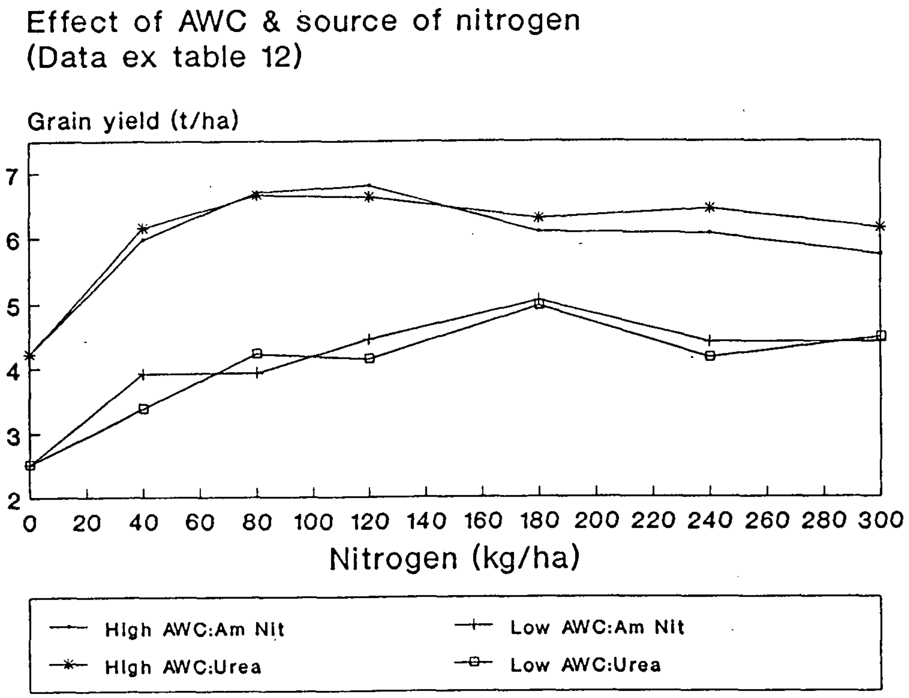

Fig 2

There were significant differences (P<0.001) between overall mean yields in the three years, 1989 being higher than 1988 and 1990. The mean of all treatments on the high AWC sites was 1.99 t/ha higher than the low AWC sites. This contrasts markedly with the 0.61 t/ha difference between the two-year mean yields for the high and low AWC survey sites (1989 and 1990). Variability between the overall means of the individual survey sites would tend to reduce the difference.

The significant interaction (P<0.001) between years and AWC clearly shows the ability of the heavier (high AWC) sites to produce better yields in drier seasons (1990), with a lesser advantage in wetter seasons (1988).

There was a significant interaction between AWC and N rates. The reason for this can be seen in Figure 2. The high AWC sites have their maximum yield around 120 kg/ha N and then gradually decrease, whereas the low sites increase up to 180 kg/ha N.

Grain nitrogen content

Table 13 Effect of AWC and ammonium nitrate (AN) or urea (U) on grain nitrogen (in DM).

	Site AWC			
	High		Low	
	AN	U	AN	U
N applied(kg/ha)				
0	1.34		1.29	
40	1.29	1.29	1.38	1.38
80	1.56	1.53	1.68	1.56
120	1.72	1.68	1.94	1.74
180	2.08	2.10	2.13	2.05
240	2.44	2.30	2.42	2.31
300	2.56	2.58	2.58	2.51
	1.94	1.91	2.02	1.93
Overall AWC mean	1.88		1.92	
Year 1988	1.93	1.81	1.87	1.79
1989	1.98	2.10	1.90	1.94
1990	1.92	1.82	2.29	2.05

There was a significant difference ($P<0.001$) in grain nitrogen content between years. The dry 1990 season produced the highest grain nitrogen.

There was no difference between the high or low AWC sites in the overall 3-year mean grain nitrogen response to applied nitrogen, although there was a significant interaction between low and high AWC sites and the three different seasons. As with yield, grain nitrogen response interacts with AWC differently in seasons with differing moisture stress. In 1990, the high grain yield from the high AWC site was associated with lower overall grain nitrogen, a reversal of the situation in 1989.

Nitrogen significantly increased grain nitrogen (P<0.001), but there was no difference between high and low AWC sites in the overall, or mean annual response between nil N and the mean response of all N rates. Neither was there any significant difference in the grain nitrogen response to the 6 nitrogen rates at the high and low AWC sites in the three year mean data, although the differences between individual year data showed a significant interaction in grain nitrogen; grain nitrogen therefore responds differently to applied nitrogen on soils of different AWC in seasons where the weather differs. In wet years low AWC soils tend to produce lower grain nitrogen, whilst in dry years the greater reserves of moisture on high AWC soils give lower grain nitrogen.

In the mean of three years data, urea gave a significantly (P<0.05) lower overall increase in grain nitrogen than ammonium nitrate. Figure 3 shows the data from Table 13, the higher grain nitrogen from ammonium nitrate on the low AWC site at 80 and 120 kg/ha being the main response. The interaction between N source and year was highly significant (P<0.001); in the overall mean of the three years, urea gave lower grain nitrogen, but this was made up of two lower years (-0.10 and -0.16% N) and one higher year (+0.08).

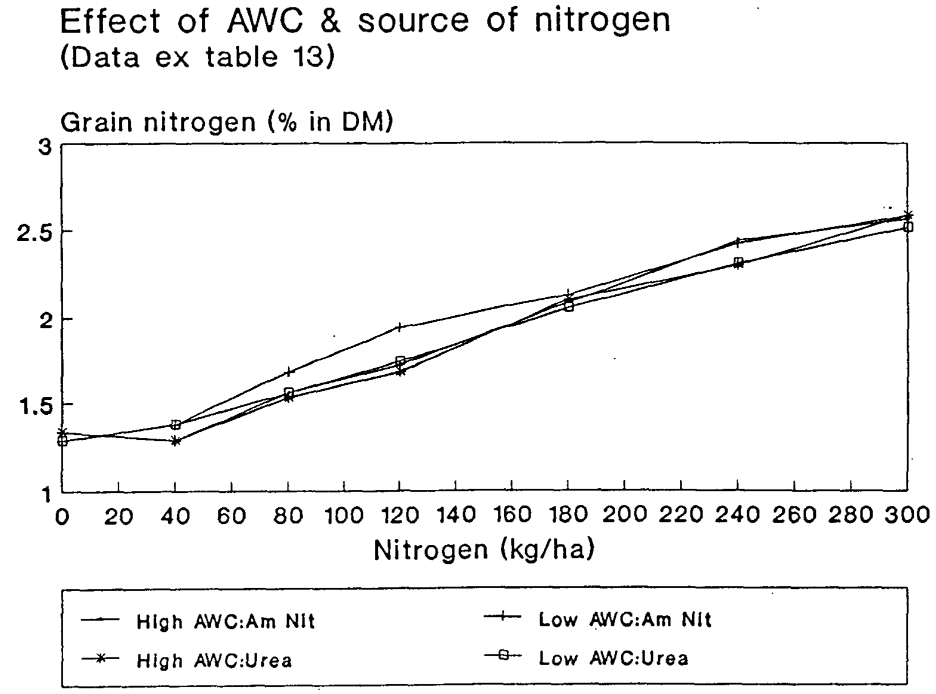

Fig 3

Of particular note in the grain nitrogen data were the much lower grain nitrogen levels from the high AWC site in the dry 1990 season over the range of nitrogen that would be contemplated by most growers.

Grain nitrogen offtake.

Table 14

Effect of AWC and ammonium nitrate (AN) or urea (U) on grain nitrogen offtake (kg/ha) and means of each of three years

		Site AWC		
	High		Low	
	AN	U	AN	U
N applied(kg/ha)				
0	48.5		27.4	
40	65.3	67.1	45.4	39.6
80	90.7	86.7	52.6	55.8
120	95.8	95.9	70.4	60.5
180	107.5	112.3	89.0	85.4
240	125.8	126.0	89.2	79.6
300	123.5	134.1	95.3	94.9
Mean	101.4	103.7	73.7	69.3
Overall AWC mean	98.4		68.1	
Year 1988	84.3	88.2	79.7	72.7
1989	114.5	120.8	90.5	85.7
1990	105.4	102.0	50.8	49.5

Many of the differences in nitrogen offtake relate directly to significant differences in grain yield. A 47.8% higher grain yield from the high AWC site over the three years was reflected in a 44.5% higher grain offtake.

Higher yields from high AWC sites were associated with higher N offtake, nevertheless, in two of the three years (1988 & 1990) the yield increments were such that they were sufficient to produce the lowest grain nitrogen contents.

Increasing nitrogen application significantly altered N offtake ($P<0.001$), but this was not affected by nitrogen source. The different response to nitrogen in the three seasons and at the high and low AWC sites produced significant interactions in the N offtake between Year x Control x N ($P=0.01$) and AWC x Control x N ($P<0.05$), and in the composite interaction Year x AWC x Control x N ($P<0.001$). As with yield and grain nitrogen, and the AWC survey site results, the different moisture stress in different years produced major differences in the nitrogen offtake in the grain in comparisons at nil nitrogen.

SECTION II

COMPARISON OF RESPONSES

Effects of Soil mineral nitrogen

Soil mineral nitrogen apparent effects across all sites were assessed at each nitrogen rate separately by linear regression. The mean yields and grain nitrogen contents at each nitrogen rate were regressed against the SMNs for each site.

The simple straight line expression $y=a + bx$ produced a better fit than the quadratic expression $y= a + bx +cx^2$ and was used for both the yield and grain nitrogen contents against SMN.

The quadratic fitted better and was used on both the yield and grain nitrogen regressions with % clay. The results are shown in Tables 15 and 16.

Table 15 Percentage variation accounted for by linear regression of grain yield (t/ha) and grain nitrogen percentage against soil mineral nitrogen at different rates of applied nitrogen. (Survey Sites)

Grain Yield & SMN

Nitrogen rate (kg/ha)	% Variation accounted for	Significance of regression
0	21.2	P=0.005
40	12.8	P=0.025
80	1.3	P=0.247 NS
120	0.0	P=0.721 NS
180	0.0	P=0.772 NS
240	0.0	P=0.531 NS
300	0.0	P=0.453 NS

Grain Nitrogen % & SMN

Nitrogen rate (kg/ha)	% Variation accounted for	Significance of regression
0	5.7	P=0.100 NS
40	31.6	P=<0.001
80	18.5	P=0.008
120	6.6	P=0.084 NS
180	1.6	P=0.232 NS
240	2.3	P=0.198 NS
300	0.0	P=0.546 NS

When nitrogen is applied the apparent effects of SMN on grain yield start to diminish, and somewhere between application rates of 40 and 80 kg/ha they cease to have any significant effect on yield, and, in effect, the applied nitrogen takes over the effect on yield.

The response of grain nitrogen content to SMN is slightly different, in that the application of relatively low rates of nitrogen (around 40 kg/ha) appear to enhance the effects SMN have on grain nitrogen.

Characteristics of both sets of data are the relatively low overall effect of SMN on yield and grain nitrogen %, even at low rates of applied nitrogen, and the lack of any significant effects of SMN once fertiliser rates exceed 40kg/ha (for grain yield) or 80 kg/ha (for grain N%). This poor relationship is probably due to the wide range of soil/site conditions.

Effects of clay content

Using the same procedure as outlined above but using the quadratic expression, the effects of % clay in the soil show similar overall effects on grain yield and nitrogen, but the trends are 'reversed', in that the percentage variation accounted for is higher at the higher rates of applied nitrogen. The values are shown in Table 16.

Table 16 Percentage variation accounted for by regression of grain yield (t/ha) and grain nitrogen percentage against soil clay content (%) at different rates of applied nitrogen. (Survey Sites)

Grain Yield & % Clay

Nitrogen rate (kg/ha)	% Variation accounted for	Significance of regression
0	0.0	P=0.450 NS
40	4.9	P=0.182 NS
80	15.5	P=0.033
120	21.1	P=0.012
180	34.5	P=0.001
240	37.4	P=<0.001
300	41.1	P=<0.001

Grain Nitrogen % & % Clay

Nitrogen rate (kg/ha)	% Variation accounted for	Significance of regression
0	12.0	P=0.059 NS
40	0.0	P=0.381 NS
80	9.1	P=0.095 NS
120	24.6	P=0.006
180	31.5	P=0.002
240	20.6	P=0.013
300	35.5	P=0.001

The significant effects of clay content on grain yield are shown at nitrogen rates of 80 kg/ha and higher. Grain nitrogen is affected at rates of 120 kg/ha and above, and exceeds what would be acceptable to attract higher malting premiums.

The percentage variation accounted for by the SMN and clay content variables are reiterated in the listings of the correlation coefficients in Table 17. These values show the positive or negative effects of the relationships shown in Tables 15 & 16 above.

Table 17 Correlation coefficients (r) between SMN and soil clay content (%) and grain yield and grain nitrogen content (%) at different rates of nitrogen

	Grain yield		Grain N content (%)	
	SMN	Clay %	SMN	Clay%
N rate (kg/ha)				
0	0.487	(0.068)	(0.296)	(-0.165)
40	0.395	(0.151)	0.582	(-0.110)
80	(0.211)	0.174	0.460	(-0.259)
120	(0.066)	0.224	(0.310)	-0.411
180	(-0.053)	0.311	(0.217)	-0.497
240	(-0.115)	0.361	(0.234)	-0.475
300	(-0.138)	0.409	(0.111)	-0.579

( ) = non significant

Using the autumn SMN values rather than the mean of the autumn and spring values, improved the correlation slightly with yield at nil nitrogen and decreased the correlation with grain N%.

Clay has an increasing, and negative effect on grain nitrogen as the applied nitrogen rates are increased. Clay is slightly less well correlated with grain yield, but positively.

Effects of applied nitrogen

The fitted linear plus exponential constants for the curves of grain yield from applied nitrogen at all sites (Survey and Reference) are listed in Appendix IVa. The derived yields at 60, 90 and 120 kg/ha nitrogen are listed in Table 18. The yield response at these rates has been calculated to show how response changes over the most commonly used nitrogen rates in malting crops. In many cases values outside these rates are unacceptable because low yields will not be compensated for by higher premiums, or high yields will be obtained at the expense of high grain nitrogen and lost premiums. The fitted values between nil and 160 kg/ha nitrogen from the source comparison sites are shown in Figures 4, 5 and 6 for the years 1988, 89 and 90.

Table 18 Calculated grain yields (t/ha) at 60, 90 and 120 kg/ha nitrogen (No data calculated where no significant fit was obtained).

Survey and Reference Sites

Site (& Year)

	HIGH AWC SITES				LOW AWC SITES		
	Nitrogen rate (kg/ha)				Nitrogen rate (kg/ha)		
	60	90	120		60	90	120
Site (& Year)							
Blunham 1988				Potton 1988			
Ammonium Nitrate	5.33	5.45	5.43		3.86	4.58	5.10
Urea	5.36	5.70	5.86		3.48	4.18	4.71
Blunham 1989				Potton 1989			
Ammonium Nitrate	7.20	7.42	7.37		5.46	5.44	5.42
Urea	7.29	7.36	7.26		4.94	5.17	5.29
Blunham 1990				Eversholt 1990			
Ammonium Nitrate	6.47	6.89	7.08		No sig. fit		
Urea	6.27	6.65	6.85		No sig. fit		
Barsham (1989)	7.49	6.17	8.58		4.25	4.64	4.78
Brettenham	3.17	3.48	3.67		4.04	4.48	4.77
Sandridge	7.06	7.12	7.09		6.32	6.38	6.34
Bishop Burton	8.45	8.88	9.10		7.46	8.04	8.37
Preston Candover	5.92	6.35	6.68		5.59	6.24	6.71
Ellingham	3.43	4.05	4.59		5.46	5.84	6.21
Market Drayton	4.75	5.26	5.58		4.77	4.57	4.38

Harmston	8.23	8.37	8.40		6.34	6.48	6.51	
Barsham (1990)	5.02	5.55	5.79		3.65	4.13	4.44	
Brettenham	6.23	6.15	6.02		4.84	4.69	4.50	
Little Chesterford	5.67	6.24	6.59		5.42	5.84	6.08	
Bishop Burton	5.03	5.66	6.11		4.70	5.37	5.84	
Preston Candover	4.55	5.02	5.37		5.07	5.80	6.27	
Letham	6.96	7.58	8.04		6.73	7.28	7.68	
Market Drayton	5.81	6.29	6.57		7.52	7.68	7.72	
Cuxwold	5.12	5.72	6.12		5.40	5.92	6.21	
				Source				Source
Means (Overall)	5.95	6.34	6.56	mean	5.26	5.64	5.87	mean
Ammonium Nitrate	6.33	6.59	6.64	6.52	4.66	5.01	5.26	4.98
Urea	6.31	6.57	6.66	6.51	4.21	4.68	5.00	4.63

Mean yield difference 0.68 +0.69 +0.69
from low AWC sites.

(Some rounding variation from calculated values)

The differences between high and low AWC sites in these fitted data are between 0.681 and 0.696 t/ha. The actual difference between High and Low survey site mean grain yields at 120 kg/ha N (Table 6) was 0.59 t/ha.

The mean calculated yields from the Urea at the low AWC sites were 0.346 t/ha lower than the Ammonium Nitrate. This contrasts with the observed mean non significant difference between nitrogen sources at the low AWC site of 0.13 t/ha (Table 12) across all N rates. At the high AWC sites, the difference between nitrogen sources was calculated as 0.01 t/ha in favour of the ammonium nitrate. This contrast with the observed 0.15 t/ha non significant difference in favour of the urea.

Both the high and low AWC calculated figures show a convergence between ammonium nitrate and urea as the nitrogen rate increases. The differences at 60, 90 and 120 kg/ha N being 0.027, 0.018 and -0.025 t/ha between ammonium nitrate and urea at the high AWC sites, and 0.445, 0.336, and

0.256 t/ha for the same comparison at the low AWC sites. The observed values show no interaction between sources of nitrogen and AWC such as may be implied by differential responses.

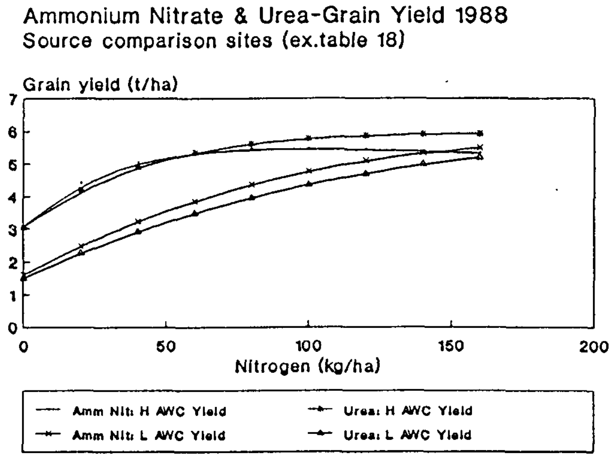
Ammonium Nitrate & Urea-Grain Yield 1988
Source comparison sites (ex.table 18)

Fig 4.

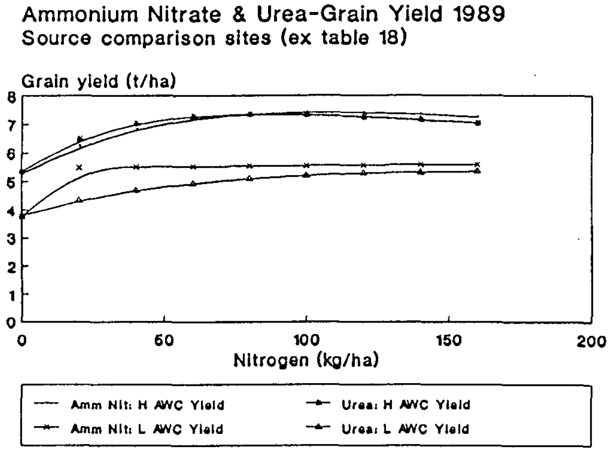
Ammonium Nitrate & Urea-Grain Yield 1989
Source comparison sites (ex table 18)

Fig 5.

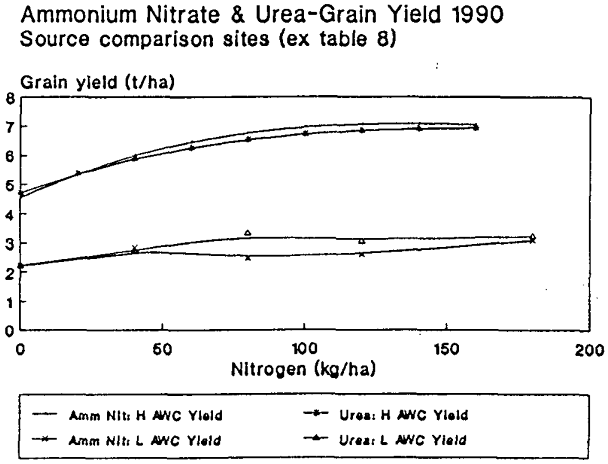
Ammonium Nitrate & Urea-Grain Yield 1990
Source comparison sites (ex table 8)

Fig 6.

Table 19 Calculated responses (Kg grain/kg N) between 60, 90 and 120 kg/ha nitrogen. (No data calculated where no significant fit was obtained) at survey and reference Sites.

	HIGH AWC Nitrogen rate (kg/ha)			LOW AWC Nitrogen rate (kg/ha)	
Site (& Year)	60 to 90	90 to 120		60 to 90	90 to 120
Blunham 1988			Potton 1988		
Ammonium Nitrate	4.04	-0.85		25.25	17.08
Urea	11.78	5.22		23.25	17.70
Blunham 1989			Potton 1989		
Ammonium Nitrate	7.49	0.24		-0.64	-0.64
Urea	2.19	-3.21		7.64	4.00
Blunham 1990			Eversholt 1990		
Ammonium Nitrate	14.09	6.21		No sig. fit	
Urea	12.66	6.87		No sig. fit	
Barsham (1989)	22.62	13.73		12.85	4.81
Brettenham	10.22	6.40		14.53	9.67
Sandridge	2.11	-1.32		2.11	-1.32
Bishop Burton	14.29	7.38		19.47	10.75
Preston Candover	14.24	10.85		21.64	15.93
Ellingham	20.50	18.23		12.91	11.95
Market Drayton	17.02	10.92		-6.49	-6.49
Harmston	4.63	1.09		4.63	1.09
Barsham (1990)	17.65	8.14		16.10	10.30
Brettenham	-2.64	-4.27		-5.01	-6.54
Little Chesterford	18.87	11.80		14.00	7.89
Bishop Burton	20.85	15.11		22.34	15.72
Preston Candover	15.96	11.39		24.20	15.66
Letham	20.78	15.12		18.55	13.33
Market Drayton	15.84	9.48		5.37	1.45
Cuxwold	20.08	13.06		17.52	9.47
Means (Overall)	12.97	7.34		12.46	7.59
Ammonium Nitrate	8.54	1.86		11.80	8.22
Urea	8.88	2.96		15.45	10.85

The overall mean responses at the high and low AWC sites are remarkably similar. The ammonium nitrate and urea responses at the high AWC site are lower than those from the low AWC site. The low AWC sites showed the greatest range in responses from +22.34 kg grain/kg N to a reduction of -6.54 kg grain/kg N. They also show the lack of correlation between site AWC and response to nitrogen.

With a grain selling price of £120-£140/tonne (12-14p/kg) and nitrogen at around 30p/kg, the responses from the second increment of 30 kg/ha N applied up to the 120 kg/ha rate would be justifiable in terms of grain yield in the absence of any detrimental effects on grain nitrogen content. Lower prices likely to result from the CAP reform would undoubtedly make these higher rates of response more questionable, but the more responsive sites, whether from better soils or more rain, would still justify the higher nitrogen.

The calculated grain nitrogen contents at the high and low AWC sites are shown in Table 20. The fitted values between nil and 160 kg/ha nitrogen from the source comparison sites are shown in Figures 7, 8 and 9 for the years 1988 to 90.

Table 20 Calculated grain nitrogen content (%) at 60, 90 and 120 kg/ha N

	HIGH AWC					LOW AWC			
	Nitrogen rate (kg/ha)					Nitrogen rate (kg/ha)			
	60	90	120			60	90	120	
Site (& Year)									
Blunham 1988					Potton 1988				
Ammonium Nitrate	1.37	1.51	1.69			1.19	1.38	1.61	
Urea	1.36	1.46	1.61			1.26	1.38	1.52	
Blunham 1989					Potton 1989				
Ammonium Nitrate	1.60	1.82	1.98			1.47	1.62	1.78	
Urea	1.55	1.70	1.89			1.50	1.67	1.83	
Blunham 1990					Eversholt 1990				
Ammonium Nitrate	1.18	1.41	1.66			1.92	2.12	2.28	
Urea	1.25	1.44	1.64			1.61	1.76	1.90	
Barsham (1989)	1.27	1.41	1.55			1.58	1.86	2.13	
Brettenham	1.68	1.84	2.03			1.64	1.75	1.91	
Sandridge	1.72	1.91	2.10			1.60	1.84	2.08	
Bishop Burton	Not Sampled								
Preston Candover	1.712	1.74	1.77			1.73	1.79	1.84	
Ellingham	1.45	1.44	1.45			1.42	1.44	1.47	
Market Drayton	1.58	1.71	1.85			1.81	1.94	2.08	
Harmston	1.74	1.84	1.95			1.97	2.07	2.15	
Barsham (1990)	1.41	1.58	1.77			1.47	1.63	1.81	
Brettenham	1.85	2.00	2.16			2.31	2.50	2.70	
Little Chesterford	1.56	1.72	1.86			1.37	1.61	1.82	
Bishop Burton	1.47	1.59	1.73			1.37	1.47	1.60	
Preston Candover	1.42	1.52	1.62			1.27	1.37	1.49	
Letham	1.57	1.68	1.80			1.77	1.87	1.96	
Market Drayton	1.54	1.73	1.92			1.60	1.78	1.95	
Cuxwold	1.56	1.82	2.01			1.62	1.85	2.05	
				Source means					Source means
Means (Overall)	1.52	1.66	1.81			1.60	1.79	1.90	
Ammonium Nitrate	1.38	1.58	1.78	1.58		1.53	1.71	1.89	1.71
Urea	1.39	1.54	1.71	1.55		1.46	1.60	1.75	1.60

(Some rounding variation from calculated values)

The calculated mean grain nitrogen content was 1.663% on the high AWC sites and 1.749% on the low AWC sites. As nitrogen rates increased the slight divergence between high and low AWC increased. Figure 5 shows this in the AWC survey sites selected as being representative of the means in Table 20.

The between site variation in the calculated grain nitrogen values reflects that shown in the observed data, with calculated grain nitrogen content ranging from 1.27% to 1.85% between the highest and lowest survey sites with high AWCs, and from 1.27% to 2.31% between sites with low AWCs. The observed differences (at 80 kg/ha N) between the highest and lowest sites values were from 1.37% to 1.88% and from 1.30% to 2.45% for High and Low AWC sites respectively. These differences contrast with the comparative grain yield differences which are around 150% between the highest and lowest calculated yields on high AWC sites and 75% on the low AWC sites. The observed ranges of difference (at 80 kg/ha N) were 108% and 132% for High and Low AWC sites respectively.

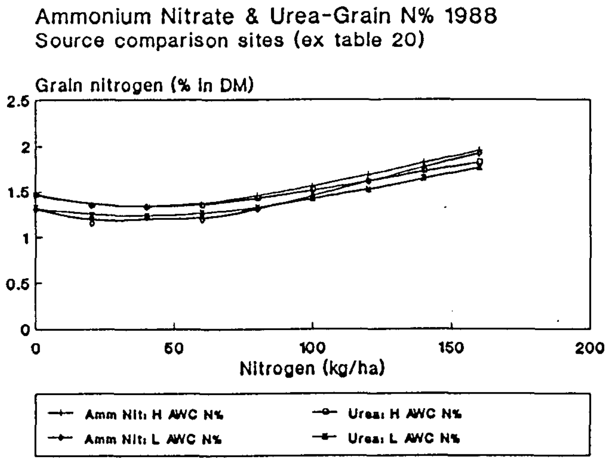
Ammonium Nitrate & Urea-Grain N% 1988
Source comparison sites (ex table 20)

Fig 7.

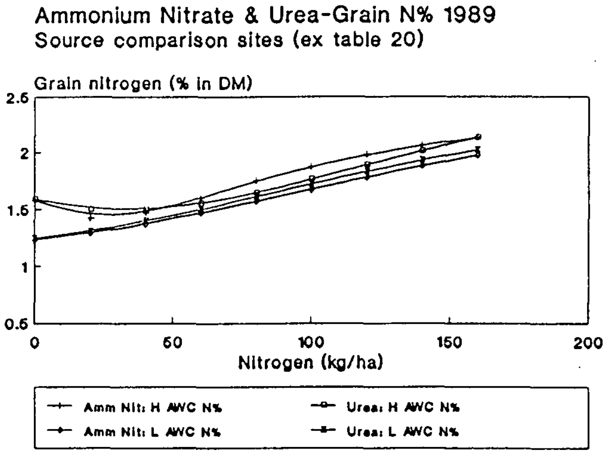
Ammonium Nitrate & Urea-Grain N% 1989
Source comparison sites (ex table 20)

Fig 8.

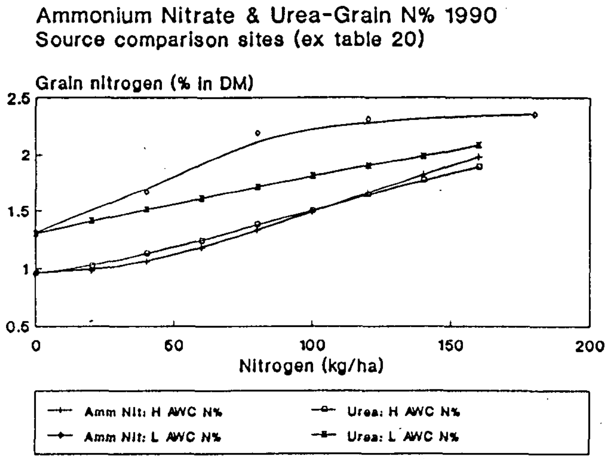
Ammonium Nitrate & Urea-Grain N% 1990
Source comparison sites (ex table 20)

Fig 9.

The calculated mean difference between urea and ammonium nitrate were 3x greater at the low AWC sites (0.104%) than at the high AWC sites (0.035%). There is however, a significant difference in this comparison when the data are split into the individual years 1990 showing higher grain nitrogen particularly over the 0 - 120 kg/ha N range.

Table 21 Calculated nitrogen offtake in grain (kg/ha) at 60,90 and 20 kg/ha N. For missing data see footnote.

Survey and Reference Sites

	HIGH AWC			LOW AWC		
	Nitrogen rate (kg/ha)			Nitrogen rate (kg/ha)		
	60	90	120	60	90	120
Site (& Year)						
Blunham 1988				Potton 1988		
Ammonium Nitrate	61.6	70.7	78.7	45.0	58.7	70.9
Urea	61.9	72.1	81.2	39.7	51.3	62.2
Blunham 1989						
Ammonium Nitrate	91.3	104.4	114.7	67.8	70.0	86.4
Urea	96.2	108.9	118.6	64.4	74.0	82.0
Blunham 1990						
Ammonium Nitrate	98.1	118.1	135.3	61.0	67.5	71.6
Urea	94.5	112.6	128.6	58.8	65.3	69.5
Barsham (1989)		- - - - (1) - - -			- - - (1) - - -	
Brettenham	45.6	53.4	60.4	59.0	69.5	78.9
Sandridge	104.5	115.2	123.8	92.3	103.0	111.6
Bishop Burton		- - - - (2) - - - -			- - - (2) - - -	
Preston Candover	87.4	94.6	100.2	84.4	95.6	104.4
Ellingham		- - - - (1) - - - -			- - - (1) - - -	
Market Drayton	66.5	78.3	88.2		- - - (3) - - -	
Harmston	127.4	135.0	140.3	103.0	110.6	116.0
Barsham (1990)	91.4	109.2	123.9	68.7	83.6	96.0

Brettenham	142.0	146.3	149.3		113.6	135.9	136.9	
Little Chesterford	109.5	128.0	142.2		98.4	110.4	120.4	
Bishop Burton	89.6	108.3	125.4		77.7	95.0	111.1	
Preston Candover	78.8	90.4	100.3		79.6	95.6	108.7	
Letham	134.6	155.8	174.6		142.2	160.8	176.4	
Market Drayton	112.4	130.6	145.9		147.0	162.2	174.0	
Cuxwold	102.8	122.8	138.3		114.0	130.2	142.7	
Means (Overall)	94.5	108.1	119.5	Source means	85.4	97.1	106.6	Source means
Ammonium Nitrate	83.6	97.7	109.6	97.0	58.0	68.1	76.3	67.43
Urea	84.2	97.9	109.5	97.2	54.2	63.5	71.2	63.01

(Some rounding variation from calculated values)

(1): No significant fit with N offtake = a + br**N

(2): No sample taken

(3): Variable data

The low AWC sites have lower calculated offtake figures, and this is particularly noticeable in the data calculated for the N source comparison sites. At the high AWC source comparison sites there was little difference between the N offtakes from either ammonium nitrate or urea [urea mean offtake 0.21 kg/ha higher than ammonium nitrate]. At the Low AWC sites crops receiving ammonium nitrate removed 4.42 kg/ha more N than the urea treated crops, as a result of higher fitted yield values (Table 18), and higher fitted grain nitrogen content (Table 20)

Effects on grain size and specific weight

Appendix III shows the sieving results from the N source comparison sites in each of the three years. Much of the data is not normally distributed. It has not been subject to analysis of variance.

In 1988 varietal effects overrode AWC effects. Magie is relatively large grained and, when grown at the Blunham high AWC site, produced a much higher percentage of large grains than the small grained variety Pipkin grown at the Potton low AWC site. In view of this, the not dissimilar <2.2mm fractions at nil nitrogen of both the Magie and Pipkin support the lack of pronounced effect of AWC in a relatively wet season.

Pipkin was grown at both sites in 1989. The percentage grains <2.2mm at nil nitrogen at the low AWC site were twice that from the high AWC site. In the dry 1990 season, the percentage of grain <2.2mm was much higher at both sites than in the previous two seasons. At the low AWC site, the percentage was more than 50% greater than at the high AWC site.

In all years, the 40 kg/ha nitrogen rate (both ammonium nitrate and urea) reduced the percentage of grains <2.2mm at the high AWC site relative to the nil nitrogen rate, before it was increased by additional nitrogen applications.

Specific weight was little affected by treatments in this trial series. Nitrogen had an effect on specific weight at some sites, but the consistently non significant AWC x nitrogen interaction indicated the differences in yield already described were not associated with large differences in specific weight.

DISCUSSION

Available water capacity

Variation in yield and grain quality was considerable from site to site, and year to year. 1988 was less affected by moisture stress than the two following seasons. The non-replicated survey site data show that there was no difference in the high and low AWC overall sites mean with no nitrogen applied. However, the two sites in Norfolk with the most sandy soils, and the shallow soil site at Bishop Burton produced lower yields from their low AWC trials.

On the Brettenham site in Norfolk the site allocated to low AWC on selection, turned out to have a higher AWC than that allocated the high AWC. The low AWC site nevertheless produced lower yields. AWC calculation is clearly not a reliable quantitative indicator of performance when moisture is not limiting. Or conversely, the experienced eye can gauge other factors not taken into account by the AWC classification.

In the wetter 1988 season, the three locations with the highest overall AWCs produced their highest yield from their low AWC plots, both at nil nitrogen and with fertiliser applied. The use of nitrogen improved the overall mean yield of the high AWC sites so instead of being 0.09 t/ha lower in yield, they exceeded the low AWC mean by 0.16 t/ha. This increase was entirely from the relative improvement of the high AWC sites from the three locations with the lowest overall AWC. In a wet season low AWC sites appear to respond better to nitrogen than heavier high AWC sites.

Although variety (genotype) was not a treatment in these studies the mix of premium malting varieties (PM) and feed/malt dual purpose varieties (DP) during the first two years further showed how AWC affects crop performance. The effects were not evident in grain yield variation, but the grain nitrogen content showed consistent effects.

Table 22. The effect of AWC and additional nitrogen on grain nitrogen content of PM and DP winter barley (1988 non replicated sites)

Percentage N in DM

	High AWC		Low AWC	
	PM	DP	PM	DP
Nil N	1.29	1.49	1.31	1.52
+ N	1.49	1.70	1.43	1.72

The choice of variety type is important in offsetting the effects of additional fertiliser nitrogen use on grain nitrogen content. This sort of analysis can be repeated with the 1989 sites again comparing PM varieties (Pipkin, Halcyon and Maris Otter) and DP varieties (Magie and Marinka). The 0 and 120 kg/ha nitrogen rates have been selected from the replicated trial data.

Table 23. The effect of AWC and additional nitrogen on grain nitrogen content of PM and DP winter barley.(1989 Replicated sites)

Percentage N in DM

	High AWC		Low AWC	
	PM	DP	PM	DP
Nil N	1.47	1.56	1.44	1.65
120 kg/ha	1.74	1.88	1.92	1.94

Unlike 1988, the drier season prevented the variety effect offsetting the effects of nitrogen fertiliser on grain nitrogen content. In addition it seems likely that grain nitrogen may have been increased by the seasonal rainfall pattern. Carreck & Christian (1991) suggest that in 1989 whilst dry weather caused a greater proportion of assimilates to be derived from pre-anthesis assimilation than in 1988, nitrogen concentrations increased later in the grain fill period when rainfall occurred.

Comparisons of each years performance in the reference site analysis of variance showed significant differences between years. The widespread survey site data for 1989 and 1990 were analysed as a single group, but examination of the "years" data within the trial supports the hypothesis that while AWC affects grain yield and nitrogen content, it does so in conjunction with the effects of rainfall and other factors.

Table 24. Survey sites : Grain yield (t/ha) and nitrogen content(% in DM) at 120 kg/ha applied nitrogen. (Mean of eight sites in each year)

	Grain Yield		Nitrogen Content	
	AWC			
	H	L	H	L
1989	6.94	6.03	1.81	1.94
1990	6.38	6.11	1.86	1.91

Grain yields were higher and grain nitrogen contents lower in both years from the high AWC sites. But the low AWC sites were not adversely affected by the dry 1990 season. Indeed whilst the high AWC performance worsened from a good position, the low AWC sites improved albeit marginally from a poor position. The late transfer of nitrogen into the grain which may have occurred in 1989, was unlikely to have occurred in the dry conditions of 1990.

The more controlled comparison of the three years possible at the source comparison sites is seen in Tables 12 and 13.

The dry 1990 season and the low (73mm) AWC combined to produce very low (uneconomic) yields and very high grain nitrogen contents. As the cell number in the endosperm is controlled by the supply of assimilates during the two weeks after anthesis (Brocklehurst, 1977) early drought will reduce this supply and the consequent grain size. This effect was more severe on low AWC soils, although it was not worsened by rain during late ear filling.

In 1989 the high AWC source comparison site produced the highest yields of the three years but also the highest grain nitrogen. With pulses as the previous crop, late rainfall and nitrogen uptake was sufficient to produce high grain nitrogen.

Correlations of AWC values with the survey site yields and grain nitrogen contents for each of the nitrogen rates used are shown in the correlation matrix in Appendix VI. The values are only significantly correlated at 240 and 300 kg/ha, and only account for a small percentage of the variation. The correlation of AWC with grain yield is positive, and negative with grain nitrogen content.

The matrix also shows the correlation with individual monthly rainfall from March to July and the total rainfall. The correlations are low, the only significant values being those between the June rainfall and the grain yields at and above nitrogen rates of 120 kg per hectare.

Tables 16 and 17 show that percent clay in the soil has a similar small but significant effect on yield and quality at the higher rates of nitrogen. Yet the data show no correlation between AWC and percent clay (r = 0.153 NS). It appears that soil moisture supply (as gauged by AWC or % Clay) was only correlated with yield when the highest nitrogen rates in the trial encouraged the more rapid expansion of larger leaves. Such a canopy would have a greater capacity for transpiration, but the yield figures would indicate it not to be associated with higher grain yields. High nitrogen rates on heavier soils have long been known to encourage vigorous canopy development.

In summary, the high AWC sites produced higher grain yields and lower grain nitrogen contents than the low AWC sites. AWC is poorly correlated with most yield parameters and other factors play a large part in determining yield and quality, although some of these may well be associated with AWC if efforts are made to select sites on this basis. The low but significant correlation of AWC with yield and grain nitrogen only occur at the two highest levels of nitrogen application (240 and 300 kg/ha). Vigorous foliage development may make greater demands on soil moisture supply.

The genotype of the premium malting varieties can offset the effects of applied nitrogen on grain N content in comparison with dual purpose varieties in moist seasons. In dry seasons, although premium malting varieties still have lower grain N contents than the dual purpose types, they cannot offset the effects of fertiliser nitrogen particularly on low AWC sites.

Late rainfall during the grain filling period appeared to increase grain nitrogen and the lower yields on the low AWC sites were worse affected.

Soil mineral nitrogen

Yield and grain nitrogen are only correlated to a small extent with SMN at low rates of applied nitrogen. (See Table 15 and Appendix VI). Garstang & Giltrap (1990) showed little variation in the grain nitrogen of winter barley from sites with widely differing SMN (35 cf 146 kg/ha SMN), and wide yield differences between sites with the same SMN.

In a widely distributed trial series as described here, climate will inevitably interact with the effects of previous cropping. However, the distribution of previous crop types was heavily skewed in favour of cereals. Table 25 shows the mean SMN values related to the previous crops and AWC.

Table 25. Soil mineral nitrogen: (kg/ha - mean of autumn and spring, grouped by previous crop and AWC).

	Nos. of	AWC	
	sites	High	Low
<u>Previous Crop</u>			
Winter wheat	13	53.4 (7)	38.7 (6)
Winter barley	23	46.6 (11)	51.6 (12)
Spring barley	4	61.1 (1)	55.0 (3)
Herbage seed	2	52.8	29.6
Winter oats	1	-	37.6
Sugar beet	2	69.5	69.3
Peas	3	34.7	-
Carrots	2	42.6	37.1
	Weighted means	48.6	47.6

The weighted means for both high and low sites were similar. When viewed over a range of crops and a range of seasonal weather patterns AWC does not appear to have affected SMN. In Figure 1 the responses to nitrogen at high and low AWC sites diverge. The divergence must therefore be due to the direct effect of better moisture supply related to soil AWC, rather than any coincidental associated effects of high AWC on SMN.

Three high AWC sites followed peas. At these sites, their contribution to SMN appear to be slightly lower than that from most other crops. Sylvester-Bradley & Cross (1991) suggest that there is a need to adjust nitrogen applications to wheat by about 25 kg/ha. On the limited evidence of these three site/years this would not appear necessary over the range of nitrogen rates used on malting crops. Grain yields were higher and grain nitrogen contents lower from the high AWC sites in each of the three years, although Table 19 shows lower responses between 60 and 120 kg/ha nitrogen from these high AWC sites.

However, although there was no marked divergence of yields on the source comparison sites, there was a fall in yield at 180 kg/ha nitrogen rate on the high AWC sites (Figure 3). This contrasted with the increase in yield from the low AWC site. It appears that any benefits of lower disease levels following a break crop, along with the higher AWC were sufficient to offset the effects of nitrogen remaining from the pea crop until optimum levels of nitrogen had been exceeded. (See comments in <u>Economic Implications</u> about optimum levels of nitrogen).

Economic implications

Interim data analysis for this trial series has fitted return over nitrogen cost curves to show where the optimum returns were for the nitrogen applied (Vaughan (1988) unpublished). Lord & Vaughan (1987) also used this approach of retrospective financial analysis.

As with the physical crop data, this information is characterised by large variation in profiles of the curves produced, both from year to year and between sites. The changes often resulting from only small changes in yield, quality and price. The main problem with this approach however, is that because of these variable factors it is not possible to forecast the level of premiums likely to be offered in such a way that crop management decisions can be altered. A wet growing season followed by dry ripening and harvest will lower premiums (a good supply of low N grain) whereas a dry season with rain during grain filling will give high premiums (a reduced supply of low N grain).

The forecasting approach adopted in this report attempts to give guide figures for nitrogen use at high and low AWC sites, the target being the highest yield that can be produced without exceeding 1.75% N in the grain. Increases in the demand for lager beers has allowed premiums to be generated at higher grain nitrogen (Patterson, 1991). This also gives the grower more scope for higher yield. The fitted curves selected have been those of premium malting varieties where the yield and grain nitrogen figures at 60, 90 and 120 kg/ha N were most similar to the overall means. Using average curves selected on this basis ignores abnormalities in fitted data outside the typical levels of nitrogen used on malting crops. Similarly, it allows the combination of average yield and average grain nitrogen data from different sites.

The sites chosen are shown in Figures 10 and 11, and were 1990 Little Chesterford yield data for both the high and low AWC sites (Maris Otter), and grain nitrogen from Letham 1990 high AWC (Halcyon) and 1989 Brettenham low AWC (Maris Otter).

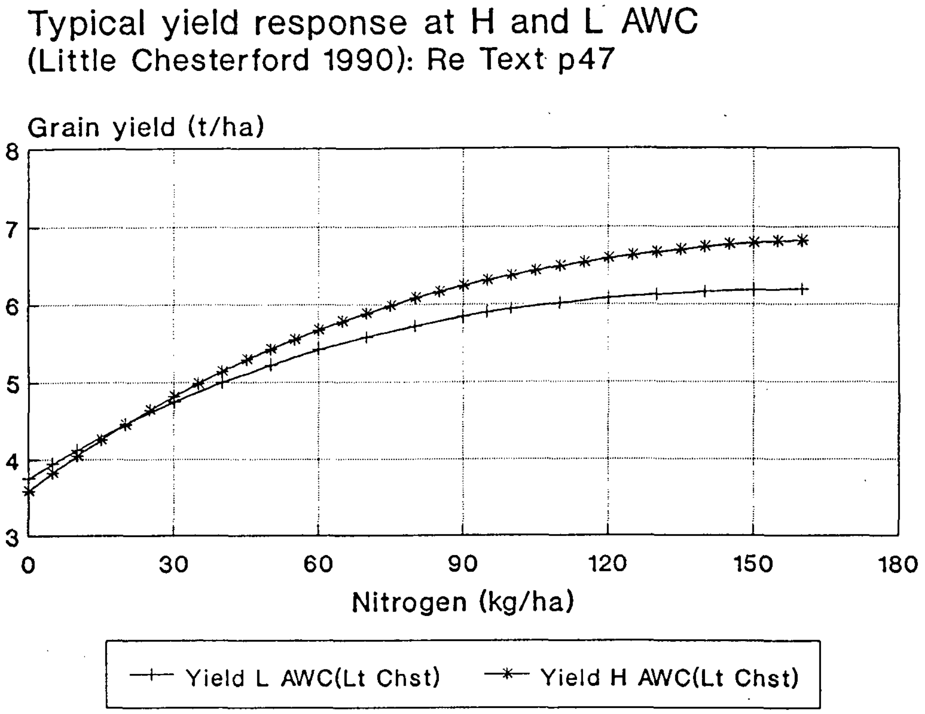
Typical yield response at H and L AWC
(Little Chesterford 1990): Re Text p47

Fig. 10

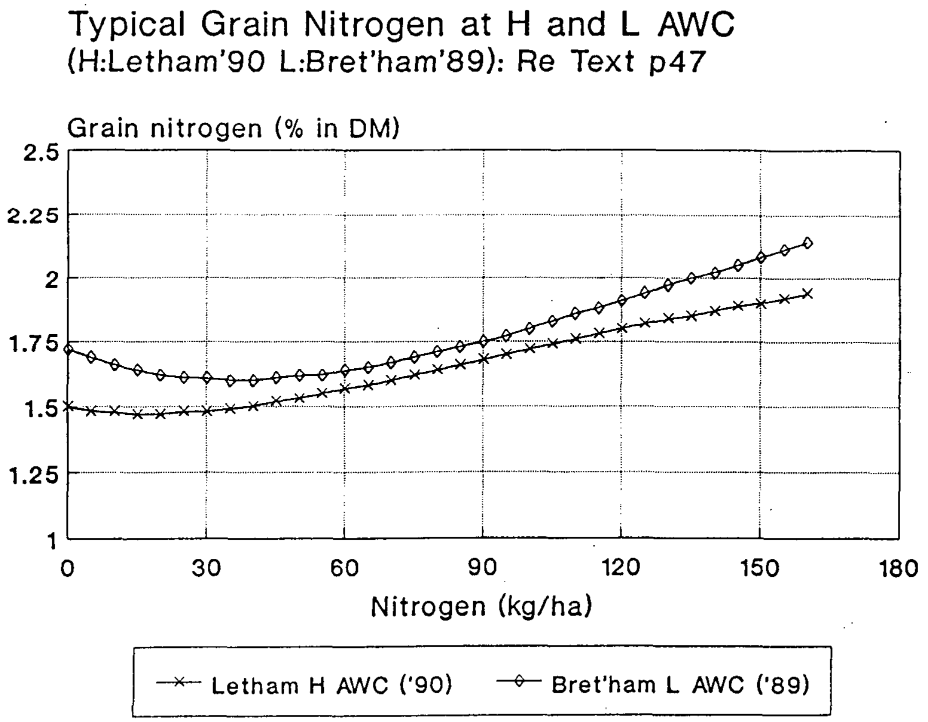
Typical Grain Nitrogen at H and L AWC
(H:Letham'90 L:Bret'ham'89): Re Text p47

Fig 11.

Sites were rejected because yields were too high, too low, or plateaued. The latter was particularly noticeable in the dual purpose varieties in 1989. Grain nitrogen data caused rejection for the same reasons.

Sage (1990) pointed out varieties like Magie and Marinka have a lower proportion of crops with lower grain nitrogen than premium varieties. At both high and low AWC, the dual purpose varieties had higher grain nitrogen than the overall mean.

One possible criticism of selecting curves on this basis is that the premium malting varieties chosen will perhaps be at the upper end of the range of yield and nitrogen content values for those types, as the overall mean is raised by the effects of the dual purpose varieties above the mean in the sample. However, it can be argued that such curves near the upper limit of premium malting performance will be a good approximation to an optimum within such a variable data set.

From Figures 4 and 5, the optimum yield commensurate with a grain nitrogen of 1.75% is achieved at about 90 kg/ha on average low AWC sites, and at 107 kg/ha on average high AWC sites. Within the high AWC group, sites with higher AWC can be selected with both higher yields ie Letham, 1990 and lower yields Cuxwold, 1990. Similarly, within the low AWC group sites can selected with lower AWC that yield both higher and lower than the selected site. As already mentioned factors external to those being studied have a considerable bearing on how individual sites perform.

From the fitted yield curves in this series of trials, it was possible to calculate the optimum nitrogen application (Nopt), assuming the grain was priced as feed barley and did not vary in price with grain nitrogen content. The mean Nopt values for 1988 and 1989 on the reference sites were 120 kg/ha for the high AWC and 163 kg/ha for the low AWC. The dry season in 1990 reduced the accuracy (and value) of such a calculation. It is clear that such calculations show optima well in excess of the range likely to be used for the production of grain with suitable nitrogen contents for malting. The average responses in grain yield between nil N and Nopt were 17.4 kg grain/kg N.

The Figures in Table 19 show the differences in the grain nitrogen response to applied nitrogen at the different AWCs. In the 60-120 kg/ha range, (below the optimum), 22.0 kg/ha N are required to produce an increase of 0.1% in grain nitrogen at low AWC sites, whereas at high AWC sites 25.7 kg/ha N are required

One of the main aims of this series of trials was to see if the nitrogen requirement of malting barley could be forecast using knowledge of the site such as its AWC and SMN status. In addition, if the requirement could be forecast, would the source of nitrogen alter the forecast amount because of differences in the efficiency of use?

The conclusion must be that whilst it is possible to calculate reasonably sound 'average' forecast figures for nitrogen use - 90 kg/ha on low AWC sites and 107 kg/ha on high AWC sites - it is not possible to refine these values into an accurate individual site forecasting technique that will allow spring applications to be tailored to the final crop yield and quality. The effects of weather and other factors between nitrogen application and harvest have a large effect on how crops respond to nitrogen. This cannot be forecast. However some further refinement may be possible if an AWC of 110mm is taken as the dividing line for low and high AWC sites. Beyond this in the wetter west 100mm could serve as the AWC above which the higher nitrogen rates could be used, whilst on sandy soils in the lower rainfall areas of the east 120mm AWC may be a better point at which to consider the higher nitrogen rates.

These recommendations represent a refinement, and perhaps more cautious approach than the previous recommendations. Fertiliser Recommendations (Anon, 1988) recommends not more than 120 kg per hectare regardless of soil type. These recommendations should allow malting premiums to be obtained more reliably, and to be adjusted depending on soil type.

The dual purpose varieties grown in this trial series produced similar grain yields but higher grain nitrogen. Reduction of nitrogen use to lower grain nitrogen would be counterproductive, leading to a lower yield of a less than premium product. They are best managed to obtain maximum yield, with any malting premium taken as bonus.

On the data generated in this trial series between 1988 and 1990, it appears that high AWC sites produce about 10% more grain within the nitrogen range used for malting, using 17kg more nitrogen to produce an additional 0.6 t/ha of grain at 1.75% N, and within the 60 -120 kg/ha range of nitrogen fertiliser use, each 0.1% increase in grain nitrogen requires 17% more nitrogen than on low AWC sites. The comparisons of ammonium nitrate and urea showed little difference in grain yield, and a variabile effect on grain nitrogen contents between season. In many situations, the unit cost of nitrogen will remain the main determinant of choice.

For every 0.1% increase in grain nitrogen the yield of fermentable extract is reduced by 0.1% (Hulton 1922). These figures show that crops from high AWC sites will be less prone to this, as more nitrogen is needed to increase grain nitrogen contents.

Recommendations for further study

a) A study of the effect of soil mineral nitrogen, its effects on crop development before the application of fertiliser nitrogen and the interaction of these effects with subsequent yield and quality.

b) The ability of AWC/soil moisture supply to offset the effects of deficits on grain yield and nitrogen content. (Malting barley grown under controlled rainfall/irrigation).

c) Review of the effects of weather on market price fluctuations caused by supply, quality and geographic factors.

d) Clearer definition of the role of malting genotype (variety) interactions with AWC and SMN under the controlled experimental conditions in items a) and b).

The results of this trial series have refined the fertiliser recommendations for the production of autumn sown malting barley, and give more confidence to growers wishing to produce malting samples on soils with higher AWCs. Whilst several other interesting aspects of malting barley management have come to light, the above proposals are intended to outline areas of work where it is felt progress could be made. In any further work it would be necessary to limit studies to crops on more similar soils grown within a narrower climatic range.

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Appendix 1 Estimation of available water from texture class, horizon and structural conditions

Texture class	Topsoil available water % (easily available %)	Subsoil available water % (Easily available %)		
		Good structural conditions	Average structural conditions	Poor structural conditions
Clay	17 (10)	21 (15)	16 (8)	13 (7)
Silty clay	17 (10)	21 (15)	15 (8)	12 (7)
Sandy clay	17 (11)	19 (14)	15 (10)	13 (8)
Sandy clay loam	17 (11)	19 (14)	15 (10)	13 (8)
Clay loam	18 (11)	21 (14)	16 (10)	12 (7)
Silty clay loam	19 (10)	21 (12)	17 (10)	12 (6)
Silt loam	23 (15)	23 (17)	22 (14)	15 (9)
Fine sandy silt loam	22 (14)	22 (14)	21 (15)	15 (9)
Medium sandy silt loam	19 (11)	19 (13)	17 (11)	15 (9)
Coarse sandy silt loam	19 (11)	23 (17)	19 (11)	15 (7)
Fine sandy loam	18 (13)	22 (17)	18 (13)	17 (11)
Medium sandy loam	17 (11)	17 (13)	15 (11)	11 (B)
Coarse sandy loam	17 (11)	22 (15)	16 (11)	11 (8)
Loamy fine sand	18 (14)	15 (13)	15 (13)	-
Loamy medium sand	13 (9)	12 (9)	9 (6)	-
Loam coarse sand	11 (7)	11 (7)	8 (6)	-
Fine sand	-	14 (12)	14 (12)	-
Medium sand	12 (8)	7 (5)	7 (5)	-
Coarse sand	-	5 (4)	7 (5)	-
Marine light silts*	-	33 (30)	28 (22)	-

* Use these figures <u>only for subsoils</u> in marine alluvium where textures are fine sandy silt loam, fine sandy loam or loamy fine sand <u>and</u> most of the sand is finer than 0.1 mm.

\- Rare occurrences for which there are no data.

Source:- Soil Survey and Land Research Centre

Appendix 2 - Grain yield (t/ha): At each nitrogen rate for all survey sites 1989 and 1990

		N LEVEL				
SITES	AWC	0	40	80	120	180
BISHOP BURTON 1989	HIGH	6.22	8.01	9.06	8.97	9.06
	LOW	4.77	6.50	8.05	8.40	8.76
PRESTON CANDOVER	HIGH	3.69	4.91	6.10	6.69	7.23
	LOW	4.58	5.71	6.19	6.86	6.89
MARKET DRAYTON	HIGH	2.94	4.12	5.17	5.78	5.65
	LOW	3.43	4.91	4.44	4.55	4.14
BARSHAM	HIGH	4.82	6.78	7.89	8.64	9.01
	LOW	2.17	3.96	4.63	4.60	4.59
BRETTENHAM	HIGH	2.65	3.47	4.36	4.72	5.27
	LOW	1.97	2.95	3.44	3.63	3.75
SANDRIDGE	HIGH	5.54	6.11	6.59	6.55	6.13
	LOW	6.28	6.79	7.05	7.08	6.83
ELLINGHAM	HIGH	2.88	3.85	5.02	5.68	6.84
	LOW	4.86	4.59	5.74	6.61	6.78
HARMSTON	HIGH	7.20	7.97	8.24	8.52	8.33
	LOW	5.45	5.99	6.78	6.50	6.36
BARSHAM 1990	HIGH	2.79	4.52	5.93	5.72	6.58
	LOW	1.86	3.16	4.14	4.54	4.84
BRETTENHAM	HIGH	6.10	6.27	6.40	6.03	5.46
	LOW	4.88	5.07	4.70	4.43	3.86
LITTLE CHESTERFORD	HIGH	3.52	5.19	6.30	6.39	6.80
	LOW	3.65	5.07	6.28	5.79	5.93
PRESTON CANDOVER	HIGH	2.81	4.43	4.86	5.34	5.71
	LOW	2.07	4.98	6.03	5.77	6.35
MARKET DRAYTON	HIGH	4.08	5.12	6.25	6.78	6.59
	LOW	6.33	7.77	7.79	8.06	6.72
BISHOP BURTON	HIGH	3.07	4.60	4.86	6.46	6.93
	LOW	2.51	4.06	5.11	5.86	6.57
LETHAM	HIGH	4.94	6.52	7.65	8.06	9.02
	LOW	4.98	6.12	7.09	7.72	8.22
CUXWOLD	HIGH	2.94	4.53	5.64	6.25	6.22
	LOW	3.44	4.65	5.57	6.27	5.55
MEAN		4.04	5.27	6.03	6.36	6.49

Appendix III SIEVE ANALYSIS - Graom ex nitrogen source comparison sites

	POTTON								BLUNHAM							
Applied N	>2.8mm		2.5-2.8mm		2.2.2.5mm		<2.2mm		>2.8		2.5-2.8mm		2.2-2.5mm		<2.2mm	
Kg/ha N	AMMONIUM NITRATE	UREA	AMMONIUM NITRATE	UREA	AMMONIUM NITRATE	UREA	AMMONIUM NITRATE	UREA	AMMONIUM NITRATE	UREA	AMMONIUM NITRATE	UREA	AMMONIUM NITRATE	UREA	AMMONIUM NITRATE	UREA
0	8.7		60.5		17.6		13.5		6.9		76.3		10.8		6.2	
40	11.7	3.1	65.6	60.8	10.9	20.2	11.9	16.4	9.5	10.3	74.9	76.6	10.3	8.6	5.6	4.6
80	12.4	14.9	54.4	53.0	14.9	13.2	18.5	18.9	11.9	10.3	68.7	66.4	18.8	12.9	8.8	10.4
120	15.0	8.7	52.9	48.8	12.7	17.7	19.5	24.9	14.7	9.1	55.9	52.1	14.2	19.2	15.3	19.9
180	15.0	12.8	50.4	46.7	13.4	14.7	21.5	25.8	9.3	11.8	43.1	56.6	17.8	15.5	30.0	16.2
240	6.0	12.8	33.8	40.7	17.5	14.9	43.0	31.8	11.3	5.4	38.2	40.1	15.6	20.7	35.1	33.9
300	12.4	12.7	38.7	42.6	14.2	14.5	30.8	30.8	5.4	8.9	39.2	43.9	18.0	17.9	37.5	29.6
Mean	12.1	10.9	49.3	49.8	13.9	15.8	24.2	24.7	10.4	10.4	53.3	56.1	14.5	15.8	22.1	17.4

Appendix III

SIEVE ANALYSIS (%) 1988

	POTTON								BLUNHAM							
Applied N	>2.8mm		2.5-2.8mm		2.2.2.5mm		<2.2mm		>2.8		25.5-2.8mm		2.2-2.5mm		<2.2mm	
Kg/ha N	AMMONIUM NITRATE	UREA	AMMONIUM NITRATE	UREA	AMMONIUM NITRATE	UREA	AMMONIUM NITRATE	UREA	AMMONIUM NITRATE	UREA	AMMONIUM NITRATE	UREA	AMMONIUM NITRATE	UREA	AMMONIUM NITRATE	UREA
0	26.8		36.3		28.2		8.5		73.1		13.2		8.4		5.3	
40	18.8	15.6	39.8	35.8	33.7	38.0	7.6	10.4	76.4	75.8	13.7	12.6	6.3	7.0	3.5	4.7
80	19.1	18.8	39.8	37.8	32.2	33.0	8.8	10.0	64.4	72.9	18.2	14.4	11.7	8.0	5.7	4.7
120	19.2	12.0	35.4	31.5	33.9	41.3	11.4	15.2	59.3	67.3	21.0	17.7	13.3	10.2	6.3	4.8
180	21.2	19.6	32.2	32.2	35.0	35.8	11.6	12.2	51.0	53.2	20.3	19.3	18.5	17.2	10.2	10.3
240	17.4	13.8	26.0	25.0	38.8	42.0	17.6	19.2	35.7	46.0	22.4	21.7	26.4	22.0	15.5	10.3
300	13.0	13.0	21.7	22.0	40.6	40.6	24.8	24.5	26.4	34.8	22.8	22.9	32.5	26.7	18.2	15.6
Mean	18.1	15.5	32.5	30.7	35.7	38.4	13.6	15.2	52.2	58.3	19.7	18.1	18.1	15.2	9.9	8.4

Appendix III

SIEVE ANALYSIS (%) 1988

	EVERSHOLT								BLUNHAM							
Applied N	>2.8mm		2.5-2.8mm		2.2.2.5mm		<2.2mm		>2.8		25.5-2.8mm		2.2-2.5mm		<2.2mm	
Kg/ha N	AMMONIUM NITRATE	UREA	AMMONIUM NITRATE	UREA	AMMONIUM NITRATE	UREA	AMMONIUM NITRATE	UREA	AMMONIUM NITRATE	UREA	AMMONIUM NITRATE	UREA	AMMONIUM NITRATE	UREA	AMMONIUM NITRATE	UREA
0	1.6		20.1		41.8		36.5		3.4		42.7		30.9		22.8	
40	1.6	1.6	19.4	17.0	41.0	37.9	38.0	43.5	6.9	6.9	59.1	63.0	27.8	24.6	5.7	5.5
80	2.1	2.1	16.6	20.7	33.0	37.8	48.3	39.8	5.8	6.6	38.2	31.9	40.0	34.8	16.1	26.6
120	2.8	2.0	14.4	14.5	32.9	34.5	49.9	49.0	5.9	8.5	20.9	36.5	46.9	37.3	26.4	17.7
180	3.6	2.8	15.1	17.2	31.2	32.7	50.2	47.2	5.6	5.6	19.0	22.4	37.8	40.2	37.5	31.7
240	4.0	2.4	14.6	12.8	30.5	32.8	50.8	52.0	6.6	6.6	9.4	18.2	31.1	37.4	52.9	37.9
300	5.9	5.2	16.7	18.4	31.1	36.1	46.3	40.3	4.6	3.9	12.4	20.5	31.9	40.8	51.1	34.8
Mean	3.3	2.7	16.1	16.8	33.3	35.3	47.2	45.3	5.9	6.4	26.5	32.1	35.9	35.8	31.6	25.7

Appendix IVa

Grain Yield - Constants for y = a + b * r ** x + c * x

High AWC

	Site	a	b	r	c
	Blunham 1988				
1.	Ammonium nitrate	5.89	2.82	0.96580	0.003510
2.	Urea	6.19	3.15	0.97670	0.001160
	Blunham 1989				
3.	Ammonium nitrate	8.85	3.58	0.98079	0.008950
4.	Urea	8.16	2.80	0.97020	0.006860
	Blunham 1990				
5.	Ammonium nitrate	10.93	6.38	0.99000	0.016200
6.	Urea	9.41	4.69	0.99000	0.009600
	1988				
7.	Barsham	10.37	5.60	0.98715	0.005010
8.	Brettenham	5.49	3.44	0.99087	0.005689
9.	Sandridge	7.96	1.70	0.98122	0.005791
10.	Bishop Burton	9.81	3.53	0.98244	0.002468
11.	Preston Candover	9.45	4.78	0.99352	0.004862
12.	Ellingham	1090.00	1088.00	1.00026	0.308900
13.	Market Drayton	7.77	4.88	0.98988	0.006210
14.	Harmston	9.00	1.76	0.98106	0.003483
	1989				
15.	Barsham	10.37	7.70	0.99000	0.018900
16.	Brettenham	7.49	1.32	0.99000	0.008900
17.	Little Chesterford	9.30	5.72	0.99000	0.008300
18.	Bishop Burton	7.65	4.64	0.99000	0.001200
19.	Preston Candover	6.67	3.70	0.99000	0.001600
20.	Letham	9.53	4.59	0.99000	0.001000
21.	Market Drayton	9.15	5.15	0.99000	0.008600
22.	Cuxwold	8.65	5.68	0.99000	0.006900

Low AWC

	Site	a	b	r	c
	Potton 1988				
1.	Ammonium nitrate	15.400	13.800	0.99474	0.024800
2.	Urea	18.500	17.000	0.99607	0.026600
	Potton 1989				
3.	Ammonium nitrate	5.499	1.745	0.80280	0.000645
4.	Urea	5.640	1.850	0.98220	0.001100
	Eversholt				
5.	Ammonium nitrate	*	*	*	*
6.	Urea	*	*	*	*
	1988				
7.	Barsham	7.319	5.073	0.98715	0.012170
8.	Brettenham	6.909	4.373	0.99087	0.005689
9.	Sandridge	7.215	1.704	0.98122	0.005791
10.	Bishop Burton	9.100	4.456	0.98244	0.001684
11.	Preston Candover	11.680	8.061	0.99352	0.010590
12.	Ellingham	469.700	465.100	1.00026	0.136200
13.	Market Drayton	5.158	1.728	0.80000	0.006490
14.	Harmston	7.107	1.756	0.98106	0.003483
	1989				
15.	Barsham	6.591	4.698	0.99000	0.006200
16.	Brettenham	6.176	1.240	0.99000	0.010900
17.	Little Chesterford	8.697	4.951	0.99000	0.009500
18.	Bishop Burton	7.821	5.359	0.99000	0.003100
19.	Preston Candover	9.368	6.909	0.99000	0.008600
20.	Letham	9.127	4.223	0.99000	0.001500
21.	Market Drayton	9.834	3.174	0.99000	0.009700
22.	Cuxwold	9.767	6.513	0.99000	0.013400

Appendix IVb

Grain N% - Constants for y = a + (b + c ** x) * r ** x

High AWC

	Site	a	b	c	r
	Blunham 1988				
1.	Ammonium nitrate	3.2480	1.7820	0.025580	0.99058
2.	Urea	2.8100	1.3510	0.021080	0.99027
	Blunham 1989				
3.	Ammonium nitrate	2.2810	0.6960	0.033500	0.97720
4.	Urea	3.1540	1.5660	0.023600	0.98968
	Blunham 1990				
5.	Ammonium nitrate	3.3140	2.3420	0.024230	0.99043
6.	Urea	2.9470	1.9850	0.015930	0.99092
	1988				
7.	Barsham	2.0420	0.7802	0.018960	0.98488
8.	Brettenham	3.4470	1.9120	0.018800	0.99104
9.	Sandridge	2.8310	1.3940	0.016790	0.98731
10.	Bishop Burton	*	*	*	*
11.	Preston Candover	1.8580	0.1670	0.003152	0.98493
12.	Ellingham	5.0440	3.4870	0.011480	0.99749
13.	Market Drayton	2.8250	1.3240	0.014820	0.99040
14.	Harmston	2.3560	0.7037	0.011470	0.98657
	1989				
15.	Barsham	2.8580	1.4490	0.024420	0.98844
16.	Brettenham	2.7380	0.9160	0.020120	0.98554
17.	Little Chesterford	2.3516	0.9634	0.015120	0.98568
18.	Bishop Burton	2.7970	1.3990	0.015240	0.99083
19.	Preston Candover	1.9048	0.4095	0.016900	0.98237
20.	Letham	2.2706	0.7719	0.013740	0.98642
21.	Market Drayton	2.6910	1.1890	0.024780	0.98600
22.	Cuxwold	2.3200	0.9030	0.038900	0.97613

Low.AWC

	Site	a	b	c	r
	Potton 1988				
1.	Ammonium nitrate	3.0230	1.7110	0.032430	0.98858
2.	Urea	3.3480	2.0330	0.021500	0.99229
	Potton 1989				
3.	Ammonium nitrate	2.6580	1.4140	0.012560	0.99003
4.	Urea	2.6210	1.3730	0.012900	0.98917
	Eversholt				
5.	Ammonium nitrate	2.6830	1.3960	0.000000	1.00000
6.	Urea	4.2000	2.9000	0.003300	0.99700
	1988				
7.	Barsham	3.0090	1.6620	0.031920	0.98488
8.	Brettenham	3.3640	1.6430	0.021980	0.99104
9.	Sandridge	3.1260	1.7410	0.025660	0.98731
10.	Bishop Burton	*	*	*	*
11.	Preston Candover	2.0370	0.3165	0.007377	0.98493
12.	Ellingham	4.8230	3.3860	0.009526	0.99749
13.	Market Drayton	3.0550	1.3240	0.014820	0.99040
14.	Harmston	2.3740	0.6685	0.003913	0.98657
	1989				
15.	Barsham	2.4890	1.0250	0.022820	0.98587
16.	Brettenham	4.6200	2.6300	0.013820	0.99330
17.	Little Chesterford	2.1900	0.4890	0.049000	0.97650
18.	Bishop Burton	2.9090	1.5180	0.016830	0.99175
19.	Preston Candover	2.0010	0.6457	0.017810	0.98597
20.	Letham	2.3530	0.7080	0.008860	0.98754
21.	Market Drayton	2.6620	1.3070	0.015470	0.98770
22.	Cuxwold	2.4758	0.6791	0.03550	0.97926

Appendix IVc Nitrogen offtake - Constants for $y = a + b * r ** x$

High AWC

	Site	a	b	r
	Blunham 1988			
1.	Ammonium nitrate	136.50	97.10	0.995690
2.	Urea	157.10	119.50	0.996220
	Blunham 1989			
3.	Ammonium nitrate	151.40	98.60	0.991790
4.	Urea	149.90	92.00	0.991061
	Blunham 1990			
5.	Ammonium nitrate	245.00	196.70	0.995145
6.	Urea	252.00	201.00	0.995940
	1988			
7.	Barsham	*	*	*
8.	Brettenham	122.30	95.00	0.996431
9.	Sandridge	157.40	83.30	0.992471
10.	Bishop Burton	*	*	*
11.	Preston Candover	120.10	53.70	0.991766
12.	Ellingham	*	*	*
13.	Market Drayton	139.70	104.10	0.994150
14.	Harmston	152.60	51.60	0.988150
	1989			
15.	Barsham	192.00	148.70	0.993510
16.	Brettenham	156.93	29.04	0.988930
17.	Little Chesterford	191.53	136.47	0.991550
18.	Bishop Burton	310.50	263.80	0.997050
19.	Preston Candover	159.40	109.80	0.994850
20.	Letham	323.40	239.50	0.996040
21.	Market Drayton	228.80	163.40	0.994360
22.	Cuxwold	191.20	147.80	0.991470

Low AWC

	Site	a	b	r
	Potton 1988			
1.	Ammonium nitrate	179.00	166.20	0.996420
2.	Urea	244.90	230.50	0.998065
	Potton 1989			
3.	Ammonium nitrate	127.30	86.40	0.993790
4.	Urea	124.40	84.80	0.994240
	Eversholt 1990			
5.	Ammonium nitrate	78.14	44.50	0.984200
6.	Urea	77.15	44.23	0.985490
	1988			
7.	Barsham	*	*	*
8.	Brettenham	162.00	127.60	0.996431
9.	Sandridge	145.20	83.27	0.992471
10.	Bishop Burton	*	*	*
11.	Preston Candover	135.55	84.01	0.991766
12.	Ellingham	*	*	*
13.	Market Drayton	76.66	27.59	0.800000
14.	Harmston	128.30	51.64	0.988150
	1989			
15.	Barsham	153.10	124.80	0.993510
16.	Brettenham	137.60	23.21	0.971200
17.	Little Chesterford	172.10	105.10	0.994100
18.	Bishop Burton	314.70	275.80	0.997476
19.	Preston Candover	167.10	131.10	0.993290
20.	Letham	256.00	162.70	0.994060
21.	Market Drayton	215.60	112.80	0.991730
22.	Cuxwold	176.60	113.90	0.990080

Appendix Va - Rainfall mm (for medium/low AWC soils)
Location & Harvest Year

	March	April	May	June	July
1988					
Barsham	85	23	38	31	114
Brettenham	78	30	51	141	75
Sandridge	76	37	51	48	99
Bishop Burton	76	24	47	38	118
Preston Candover	80	53	37	26	98
Letham	57	32	31	23	97
1989					
Barsham	46	59	12	73	65
Brettenham	54	69	5	73	33
Sandridge	58	88	9	44	53
Bishop Burton	47	77	17	74	38
Preston Candover	93	80	29	72	29
Ellingham	49	36	24	59	16
Market Drayton	63	80	25	53	29
Harmston	53	77	12	78	39
1990					
Barsham	23	15	48		28
Brettenham	16	42	21	40	12
L'tle Chesterford	16	38	12	44	26
Bishop Burton	17	18	19	67	22
Preston Candover	6	42	11	55	9
Letham	11	11	22	66	25
Market Drayton	18	30	24	68	20
Cuxwold	17	18	19	67	22
Reference Sites					
1988					
Blunham (med AWC)	74	41	49	52	101
Potton (low)					
1989					
Blunham (med)	47	91	11	45	46
Potton (med)					
1990					
Blunham (med)	26	35	6	42	19
Eversholt(low)					

Appendix
Vb - Soil Moisture Deficits (mm) (for medium/low AWC soils)
Location & Harvest Year

	March	April	May	June	July
1988					
Barsham	0	30/29	77/69	97/83	49/36
Brettenham	0	26	67	87	67
Sandridge	0	29	62	81	36
Bishop Burton	3	29	72	100	49
Preston Candover	0	17	71	98	59
Letham	4	16	55	97	79
1989					
Barsham	9	2	91/80	109/87	87/66
Brettenham	10	1	100/87	114/94	141/117
Sandridge	10	1	96	121	124
Bishop Burton	6	0	76	81	91
Preston Candover	9	12	93	111	120
Ellingham	3	11	70	88	116
Market Drayton	2	13	84	112	120
Harmston	6	1	90/79	102/79	108/84
1990					
Barsham	18	41	97	118	121
Brettenham	23/21	55/50	104/88	121/97	126/101
L'tle Chesterford	24	59	111	124	128
Bishop Burton	30	71	109	122	126
Preston Candover	28	62	114	125	130
Letham	56	87	107	115	126
Market Drayton	22	59	103	118	123
Cuxwold	30	71	109	122	126
Reference Sites					
1988					
Blunham (med AWC)	5	31	58	70	23
Potton (low)	5	30	54	63	17
1989					
Blunham (med)	11	1	92	116	119
Potton (med)	11	1	92	116	119
1990					
Blunham (med)	26	60	113	125	129
Evershołt(low)	24	54	93	100	103

Medium AWC for SMD calculation 105 - 175 mm, Low AWC < 105mm

Appendix VI

Correlation Matrix: AWC, Yield (YLD) at NO - N300, Mean Yield, Grain nitrogen (GRN%) at NO - N300, % Clay, SMN, and Rainfall March - July and Total.

	AWC:MM	**YLD-N0**	**YLD-N40**	**YLD-N80**	**YLD-N120**	**YLD-N180**	**YLD-N240**	**YLD-N300**
YLD-N0	0.216							
YLD-N40	0.205	0.908						
YLD-N80	0.274	0.795	0.932					
YLD-N120	0.331	0.721	0.857	0.951				
YLD-N180	0.307	0.501	0.670	0.847	0.931			
YLD-N240	0.369	0.456	0.608	0.793	0.901	0.971		
YLD-N300	0.364	0.406	0.557	0.749	0.859	0.953	0.975	
MEANYLD	0.333	0.747	0.866	0.957	0.987	0.940	0.916	0.885
GRN%N0	-0.073	0.132	-0.085	-0.228	-0.286	-0.346	-0.337	-0.406
GRN%N40	-0.066	0.431	0.180	-0.027	-0.125	-0.248	-0.251	-0.318
GRN%N80	-0.228	0.404	0.215	0.018	-0.127	-0.306	-0.348	-0.434
GRN%N120	-0.028	0.229	0.086	-0.097	-0.242	-0.416	-0.486	-0.585
GRN%N180	-0.197	0.142	-0.016	-0.231	-0.379	-0.581	-0.645	-0.733
GRN%N240	-0.365	0.115	-0.024	-0.215	-0.363	-0.498	-0.605	-0.651
GRN%N300	-0.353	0.030	-0.113	-0.297	-0.427	-0.579	-0.658	-0.720
MEANGRN%	-0.278	0.210	0.018	-0.201	-0.350	-0.525	-0.594	-0.677
%CLAY	0.156	0.068	0.151	0.174	0.224	0.311	0.361	0.409
AVE SMN	-0.123	0.487	0.395	0.211	0.066	-0.052	-0.115	-0.138
MARCH	-0.007	0.155	0.046	0.030	0.037	0.014	-0.001	0.017
APRIL	-0.127	0.312	0.257	0.170	0.072	-0.043	-0.101	-0.103
MAY	0.183	-0.161	-0.170	-0.101	-0.067	-0.007	0.015	0.050
JUNE	-0.157	0.075	0.171	0.262	0.368	0.416	0.406	0.396
JULY	-0.099	0.207	0.256	0.275	0.235	0.190	0.068	0.038
TOTAL	-0.085	0.239	0.201	0.191	0.168	0.117	0.058	0.061

	MEANYLD	GRN%N0	GRN%N40	GRN%N80	GRN%N120	GRN%N180	GRN%N240	GRN%N300
GRN%N0	-0.254							
GRN%N40	-0.068	0.767						
GRN%N80	-0.109	0.680	0.833					
GRN%N120	-0.259	0.552	0.644	0.890				
GRN%N180	-0.408	0.492	0.556	0.804	0.904			
GRN%N240	-0.374	0.274	0.503	0.707	0.796	0.865		
GRN%N300	-0.456	0.359	0.425	0.707	0.822	0.923	0.909	
MEANGRN%	-0.355	0.603	0.718	0.906	0.939	0.956	0.897	0.914
%CLAY	0.279	-0.165	-0.110	-0.259	-0.411	-0.497	-0.475	-0.579
AVE SMN	0.122	0.296	0.582	0.460	0.310	0.217	0.234	0.111

MARCH	0.046	0.123	0.330	0.113	0.008	-0.065	-0.012	-0.100
APRIL	0.079	0.117	0.342	0.282	0.184	0.123	0.188	0.098
MAY	-0.064	0.020	0.047	-0.135	-0.148	-0.085	-0.083	-0.145
JUNE	0.338	-0.095	-0.076	-0.062	-0.116	-0.316	-0.221	-0.289
JULY	0.193	-0.329	-0.110	0.052	0.169	0.118	0.223	0.172
TOTAL	0.160	0.007	0.251	0.148	0.076	-0.024	0.071	-0.041

	MEANGRN%	%CLAY	AVE SMN	MARCH	APRIL	MAY	JUNE	JULY
%CLAY	-0.461							
AVE SMN	0.324	0.100						
MARCH	0.028	0.190	0.322					
APRIL	0.204	0.186	0.551	0.841				
MAY	-0.100	-0.103	-0.287	-0.024	-0.400			
JUNE	-0.223	-0.022	-0.077	0.312	0.174	-0.241		
JULY	0.097	-0.127	0.168	0.490	0.544	-0.291	0.278	
TOTAL	0.061	0.107	0.350	0.943	0.872	-0.139	0.438	0.687