Nitrogen timings to wheat crops to optimise Bioethanol Production in the North East

An ADAS study commissioned by NEPIC

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Abstract

A recent NEPIC sponsored study (Clarke *et al*., 2008) provided information on growing wheat for bioethanol production in the North East, especially with regard to variety choice and nitrogen (N) management. A lack of N fertiliser response data in the North East was noted, and experimental evaluation of the use of N timing to optimise grain quality for bioethanol was recommended. As a result further work was sponsored by NEPIC and is reported here to test whether growers can apply fertiliser N (N) earlier to reduce grain protein and increase the alcohol yield.

Four N response field experiments were set up in 2009 and three in 2010 comparing ‘normal’ with ‘medium early’ and ‘early’ N strategies. For each N response trial grain yields were measured by combine harvester and grain quality tests included grain protein content, specific weight and predicted alcohol yield. N response curves for grain yield, grain protein and alcohol yield per ha were fitted and optimum N rates for each site and timing calculated.

Results showed significant yield advantages of over 0.5t/ha for earlier N application at two of the seven sites, both second cereals with low soil N supplies. There was no deleterious effect of early N timing on grain yield at any of the sites. Applying a greater proportion of N early increased alcohol yields per tonne at 6 of the 7 seven sites, overall improving alcohol yields from 444 to 448 litres/dry tonne. Differences in alcohol yield between N rates were much greater, reducing from 466 at nil-N to 437 l/t at the highest N levels, but the large effect of N rate on grain yields meant alcohol yields per ha were more than doubled by applying fertiliser (1800 to 4000 l/ha overall) and optimal N application rates for alcohol production were only 9% lower than for grain yield. Early N timing increased alcohol yields per ha overall by around 100 l/ha. Only small effects were seen of N timing on specific weight or thousand grain weight, which would not affect value for alcohol production.

Evidence from this study and previous work suggests that applying up to 50% of the N earlier in the season would generally reduce grain protein content & increase alcohol yields per tonne, without negatively affecting grain yields, and perhaps in second cereal situations, increasing grain yields. In conclusion, recommendations can be made in low lodging-risk situations that applying a greater proportion of N fertiliser early should moderately improve grain quality for bioethanol production without reducing grain yield. Furthermore, early N applications in second wheat situations may benefit both grain yield and quality. However, all timing experiments in recent years have been conducted in dry springs, the increased risks of lodging and fertiliser N loss to leaching or denitrification from earlier N timing in a wetter year are still unquantified.

Introduction

The North East has become a major centre for bioethanol production in the UK. Ensus have now started production at the UK's first wheat to bioethanol facility in Teeside, using up to around 1.2 million tonnes of UK wheat per annum. Other large bioethanol plants are also under construction in the Humberside region. In addition, 800,000 tonnes of wheat is already used in the potable alcohol distilling industry, most of which is sourced from Northern Britain including the North East.

Combined, these markets present a large opportunity for growers in the North East. It is important both for growers and for the bioethanol industry that crops are grown in the most appropriate way. Information on processing quality and how to achieve it is needed by alcohol processors to inform buying decisions and the structuring of supply chains. Information on how best to grow wheat for bioethanol is required by growers in order to maximise returns and improve marketability. Such information was provided in a previous NEPIC sponsored study (Clarke *et al*., 2008), to inform growers and bioethanol processors of the most appropriate crop management for biofuels crops, and how this differs from conventional practice. The study used existing datasets to assess the two most important factors in growing wheat for bioethanol; variety choice and N management. It also identified areas where further research is required. Effects of *N rate* on grain yield, bioethanol yield and bioethanol production per ha were assessed, using data predominantly from past HGCA funded projects (Clarke *et al*., 2008). The study concluded however that further work is required to test appropriate N timings for biofuels wheat crops. This subsequent study therefore examines the issue of *N timing* for bioethanol production.

Nitrogen effects on bioethanol production

N fertiliser strategy may be considered the most important factor in growing a biofuel crop for a range of reasons. Whilst its use increases yields substantially, it also increases grain protein content. Grain protein reduces alcohol yields per tonne of grain, reducing processing efficiency and hence profitability for the bioethanol processor. Clarke *et al*. (2008) found that N fertiliser rates to maximise bioethanol production per ha are around 10% lower than for grain yield. In addition, N fertiliser can account for over 75% of greenhouse gas emissions from wheat production, though its use maintains yields and hence reduces pressure on land use change and consequent GHG emissions around the world (Kindred *et al*., 2008).

There are two major aspects of N management to wheat crops that are important to bioethanol production: N fertiliser application rates and N application timings. Both are important because they can both affect grain yield per ha, grain protein concentration (% dry matter), bioethanol processing yield per tonne of grain and hence bioethanol production per ha of land. Effects of N rate on grain yield and grain protein are generally larger than effects of N timings. Applying increasingly more N fertiliser increases grain yields, rapidly at first, but with diminishing returns as N rates increase further. Eventually, applying additional N gives no further increases to yield, and can in fact cause yields to decrease slightly, especially if lodging occurs. There is therefore an optimum rate of N fertiliser that gives the best financial return per ha to the grower. The economic optimum is the point where the cost of one extra kg of N fertiliser per hectare results in a yield increase which is worth the same as 1 kg of N. The optimum is therefore sensitive to the price of fertiliser N and the price of grain, the relationship between the two is known as the 'break-even ratio' calculated as the cost of 1 kg of elemental N divided by the price of 1 kg of grain.

There have been a considerable number of experiments conducted over recent years that assess the effects of N application rate on grain yield and enable the optimal N rate for growers to be determined, given different grain and fertiliser prices (eg Sylvester-Bradley *et al*., 2008). Previous studies (Kindred *et al*., 2007; Clarke *et al*., 2008) have used these data to examine how N rates are different to optimise bioethanol yield per ha, rather than grain yield. There is a difference between optimising for bioethanol yield per ha compared with grain yield because N fertiliser increases grain protein contents, and higher grain proteins gives lower bioethanol yields per tonne of grain. It would therefore be expected that economic optimal rates for bioethanol production would be lower than for grain production. Clarke *et al*. (2008) found that, on average, optimal N rates for bioethanol production are around 10-12% lower than for grain yield. However, this applies only if the grower is getting the value from the bioethanol production. If the grower is paid for grain yield only (i.e. not grain quality) then he will continue to fertilise to the optima for grain yield. Some form of economic incentive, such as a premium for low protein (or high bioethanol yield) grain will be required for growers to cut N rates below the economic optima for grain yield.

Clarke *et al*. (2008) also showed that the response of grain yield and bioethanol yield to N fertiliser was broadly similar across varieties and sites, meaning that adjustments to N rates could be made irrespective of variety. It should be noted that prior to this work, few, if any, N response experiments have been conducted recently between North Yorkshire and Southern Scotland. There is evidence that N responses in Scotland differ from those in England, with optimal N rates often being higher. It is not clear whether soils in the North East of England are best represented by Scottish or English N responses.

Nitrogen timing

As well as reducing N application rates to produce lower protein (higher bioethanol yield) grain, it may also be possible for growers to produce lower protein (higher bioethanol yield) grain by applying N earlier.

Evidence from old research on malting barley and wheat for distilling in Scotland indicates that alcohol yields may benefit from earlier N timings than have been conventional for feed wheat crops. It is known in wheat that grain protein content can be increased by delayed N applications, and there are good reasons to suppose that earlier N application can give reduced protein contents. Conventionally, some N is applied in late February or March, with the majority applied in April and early May. HGCA Report 427 (Section 5.2.7) compares conventional ‘late’ timings with two earlier strategies giving 33% or 50% of total fertiliser N before April at 5 sites in 2007. However, the unusually dry spring of that year rendered the timing comparisons inconclusive. Applying N earlier encourages the N to remain in the crop leaves and straw, rather than form protein in the grain. This may mean that grain protein can be reduced without affecting grain yields. If grain yields are maintained with earlier applications then bioethanol yields per ha could be improved with no financial penalty to the grower, and hence earlier timings could be readily adopted by the industry. Currently, N is normally applied to wheat crops in two or three split applications. Often around 40 kg/ha is applied in late February or early March, with the remainder given in two splits, generally in April to early May, with at least two weeks between applications. For bioethanol production, it may be appropriate to apply a greater proportion of the fertiliser earlier.

N timings were not explicitly examined by Clarke *et al*. (2008) because there are very few data available upon which to draw conclusions. Few N timing trials have been conducted since the 1980s. Early N timing treatments were included in some HGCA funded N response trials in 2007, but the untypically dry spring of that year meant that comparisons were effectively meaningless, as the applied N was largely taken up by the crop at the same date when the soil became moist, regardless of timing of application. It was therefore recommended by Clarke *et al* (2008) that field experiments be conducted to test the viability of early N timing to improve quality for bioethanol production. In testing N application timings it is important to consider effects of crop development, rotational position, soil N supply, spring weather and lodging risk, as follows:

- Small backward crops going into spring may benefit from earlier N appications to encourage tillering and promote rapid growth. On the other hand, larger more forward crops, whilst possibly having a greater early demand for N, may be put in risk of developing too large a canopy if N is applied early, and therefore be exposed to a greater risk of lodging later on.

- Early N applications are generally recommended for second wheat crops, as such crops tend to have less N available from the soil and are likely to suffer from Take-all (a soil borne root disease) which tends to curtail late N uptake. Early N applications can help stimulate tillering and rooting, and may ameliorate the effects of Take-all.
- Where soil N supply is low, crops will run out of N for growth earlier, so early N applications are beneficial. Where soil N supplies are large, early application of N may not be necessary and can increase the lodging risk.
- The weather in spring affects both the uptake of fertiliser N and the risk of lodging encountered by the crop. If weather conditions before and after fertiliser application is very dry then uptake of the fertiliser N will be slow, and N may be lost from the soil surface as ammonia gas. Timing effects may be negated in dry springs as N uptake by the crop does not occur until sufficient rainfall is received to wash the fertiliser N into the soil. Where spring weather is wet and warm then greater spring growth occurs and lodging risks can be increased.
- In lodging prone situations (tall lodging prone varieties; high seed rates, early sowing, high soil N supply and mild winters leading to large spring crops) early N application may exacerbate lodging risks by encouraging tillering and canopy growth. In such situations growers would normally be advised to delay N fertiliser application in order to reduce the lodging risk. Lodging risk is a particularly important consideration for growers as it can seriously reduce grain yields and grain quality, as well as hampering ease of harvest. Lodged crops are likely to have poorly filled shrivelled grain with high protein content hence giving low alcohol yields.

When testing for effects of N timing on grain yield and quality it is therefore desirable to conduct experiments over sites and years with as many of the above contrasts as possible.

Objective of this study

The objective of this study is to evaluate the value of early N fertiliser applications for producing low protein grain of higher value for bioethanol production, without affecting grain yield.

It is necessary to confirm whether grain proteins can be reduced by earlier timings and, most importantly, that grain yields are not adversely affected. N timings could also affect other aspects of grain quality, particularly grain size and packing density (specific weight). Advice will be required by growers on what proportion of N to apply early, and at what time. The experiments conducted in this study aim to address these questions. Trials were placed predominantly in the North East to provide useful information on N recommendations generally for growers in the North East region, where few N response experiments have been conducted in the recent past. The experiments should help allow appropriate N *rates* for the North East to be evaluated as well as N *timings*.

To be confident about N timing effects, N *rates* must also be optimal for grain and alcohol production (litres/ha). This is because optimal N timings may differ if the N rate used is above or below the optimum N rate. It is therefore necessary to test N timings at several N rates.

Methods

N response field experiments were conducted over two seasons, harvest 2009 and harvest 2010.

Site selection

In 2009 Four winter-wheat sites were selected to give a range in soil types, rotational positions and crop development. Two sites were selected in Seaham, County Durham, one site at Towthorpe, North Yorkshire, and one site at Terrington, Norfolk (Table 1). The late harvest in 2008 meant that many crops were late-sown in autumn 2008, especially in the North. Crops were therefore generally smaller in spring than normal. The size and development of crops in spring has an important influence on the appropriate timing of N fertiliser, e.g. applying N early to 'forward' crops will increase lodging risk. It is therefore important to test early N timing on crops with a range of development in spring. For this reason a southern site (Terrington) was chosen so that a more typical 'forward' crop could be assessed. The sites chosen were uniform with no recent history of manure or grass cropping and sown with a suitable variety for bioethanol production (NABIM Group 3 or 4).

Table 1: Site Details for the 2009 experiments

	Towthorpe	Seaham WW1	Seaham WW2	Terrington
Region	North Yorks	North East	North East	East
Soil Type	Shallow (over chalk)	Medium	Medium	Deep Fertile Silt
Soil Texture	Silty clay loam	Sandy clay loam	Sandy clay loam	Silty Clay loam
SMN in Spring (kg/ha)	33	66	17	70
Potentially mineralisable N (0-30cm) kg/ha	383	135	109	93
Expected Optimum N (RB209)	280	220	260	200
Range of N applied (kg/ha)	0 to 470	0 to 370	0 to 430	0 to 330
Previous crop	Winter oilseed rape	Winter oilseed rape	Winter Wheat	Winter oilseed rape
Variety	Oakley	Oakley	Alchemy	Alchemy
Drilling date	26/9/08	19/11/08	24/10/08	26/9/08
N application dates	10/3/09 20/4/09 20/5/09	6/3/09 14/4/09 13/5/09	6/3/09 14/4/09 13/5/09	27/2/09 30/3/09 6/5/09
Harvest date	22/8/09	18/9/09	18/9/09	25/8/09

Three sites were tested in 2010, the sites chosen to give a comparison of 1st and 2nd wheats, following a yield advantage for early N timing seen in the second wheat site in 2009. All sites were in the Darlington area, the 1st and 2nd wheat sites at Eryholme being adjacent fields on the same farm (Table 2).

Table 2: Site Details for the 2010 experiments

	Croft WW2	Eryholme WW1	Eryholme WW2
Soil Texture	Sandy Clay	Silty clay	Sandy clay loam
SMN in Spring (kg/ha)	27	35	26
Soil organic matter %	3.33%	3.97%	4.53%
Soil organic N%	0.18%	0.22%	0.24%
Potentially mineralisable N (0-30cm) kg/ha	67	88	209
Expected Optimum N (RB209)	220	220	220
Range of N applied (kg/ha)	0 to 370	0 to 370	0 to 370
Previous crop	Winter wheat	Winter oilseed rape	Winter wheat
Variety	Duxford	Viscount	Cassius
Drilling date	~20/10/09	15/09/09	14/10/09
N application dates	11/3/2010 20/4/2010 12/5/2010	11/3/2010 20/4/2010 12/5/2010	11/3/2010 20/4/2010 12/5/2010
Harvest date	25/8/2010	25/8/2010	25/8/2010

Treatments

The soil mineral N content of the soil for each experiment area was measured to determine the likely soil N supply for the crop and hence the optimum N rate using RB209 (Anon., 2000). The N treatments for each experiment were then calculated to span the optimum, ranging from zero N, 1/3 of recommended, 2/3 of recommended, recommended N, 4/3 of recommended and 5/3 of recommended.

Three N timing strategies (normal, medium and early) were tested for each of the 5 with-N rates, with up to half of the N applied early, as in the table below. This gave 16 N treatments in total, which were replicated in 3 randomised blocks for each site. Plot size was a minimum of 12m x 3m. N applications were made in three splits (except where total N applied was less than 120kg/ha), the first in mid February to early March, the second in April and the third in late April to early May. The proportion of total N applied at the early timing was varied for the three N timing strategies (see Table 3), with the remainder of the N split equally between the two later application dates.

Table 3: N rate splits for the three N timing treatments

	Mid -February – early March	April to early May**
Normal	20%*	80%
Medium	33%	67%
Early	50%	50%

**Early amounts not being less than 30 or more than 40 kg/ha N.*

*** The April/May application was made in two equal splits, with at least 2 weeks between applications.*

Crops were grown according to good commercial practice. Programmes for herbicides, pesticides, PGRs and insecticides were applied to provide robust control against disease, weeds, pests and lodging. Kieserite was applied to crops in spring to ensure sulphur was not deficient.

N fertiliser was applied by hand as granular ammonium nitrate at the 3 N application dates. Plots were harvested using a plot combine for determination of grain yield. Sub samples of grain were collected for measurement of grain moisture and specific weight by Dickey John. Grain yield measures were adjusted to 15% moisture content. Grain protein and alcohol yield per tonne were measured by NIR using a FOSS Infratec at the Scottish Crops Research Institute, Dundee. The calibration GG0006 for alcohol yield was developed in the GREEN grain project (Weightman *et al*., 2010).

Statistical analyses

Results were analysed by anova within each site and across sites using the Genstat (v12; Anon 2008) statistical package and N response curves for yield, protein and alcohol yield (per tonne and per ha) were fitted to each of the N timing treatments using standard 'Linear plus Exponential' and 'Normal with Depletion' functions (Sylvester-Bradley *et al*., 2008). N optima for grain yield were determined using a break- even ratio of 5:1 (grain price assumed to be £128/t, Ammonium nitrate (34.5% N) price £220/t). Optima for alcohol yield per ha were determined assuming an ethanol price equal to the value of grain in a litre of ethanol at a standard alcohol yield of 435 litre per dry tonne (Kindred *et al*., 2007).

Results and Discussion

All experiments were conducted successfully. No significant lodging was experienced at any site in either year.

Weather

The weather in 2008/9 and 2009/10 played an important role in determining the conclusions drawn from the experiment results, potentially having effects on the response of the crops to N fertiliser. The autumn of 2008 (harvest year 2009) was very wet delaying drilling of many wheat crops. Combined with a cool autumn most wheat crops in spring 2009 were smaller than normal. Over-winter temperatures for the 2009/10 season were very cold, meaning that crops were again generally small in spring 2010, so lodging risks were low. Rainfall during spring in both 2009 and 2010 (as well as 2007) was very low, meaning that soil was dry when the majority of fertiliser was applied, hindering uptake of that fertiliser.

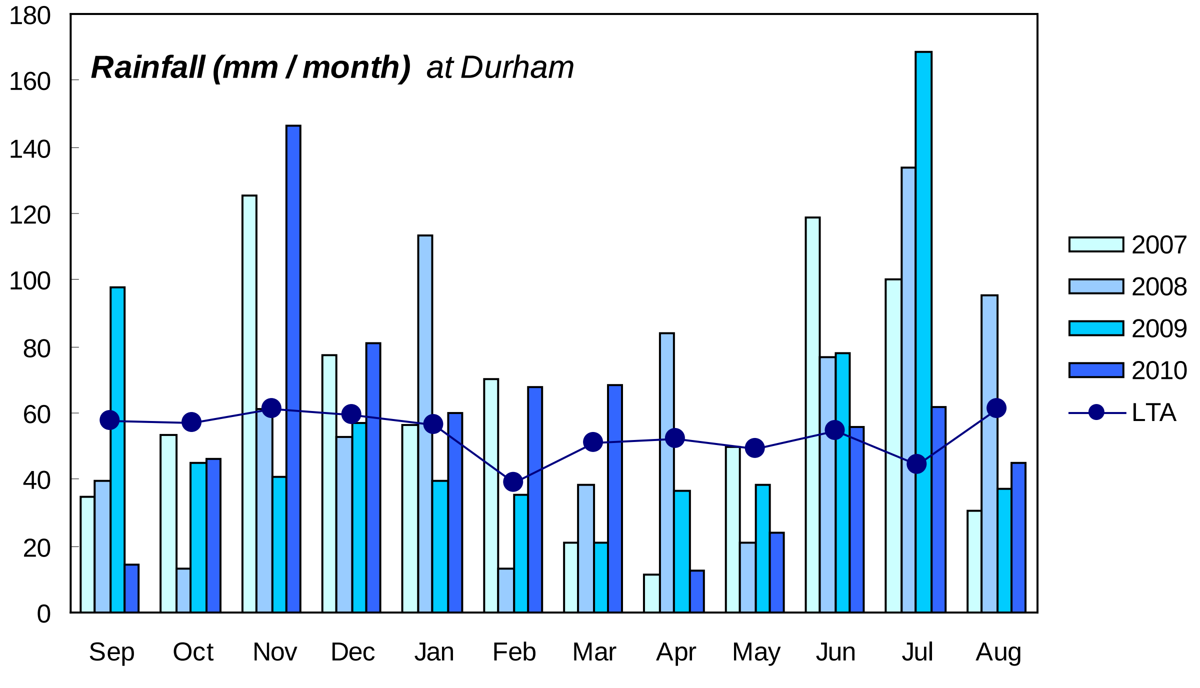

Figure 1. Monthly rainfall for Durham in each of four harvest years, with long term average (LTA) as solid line.

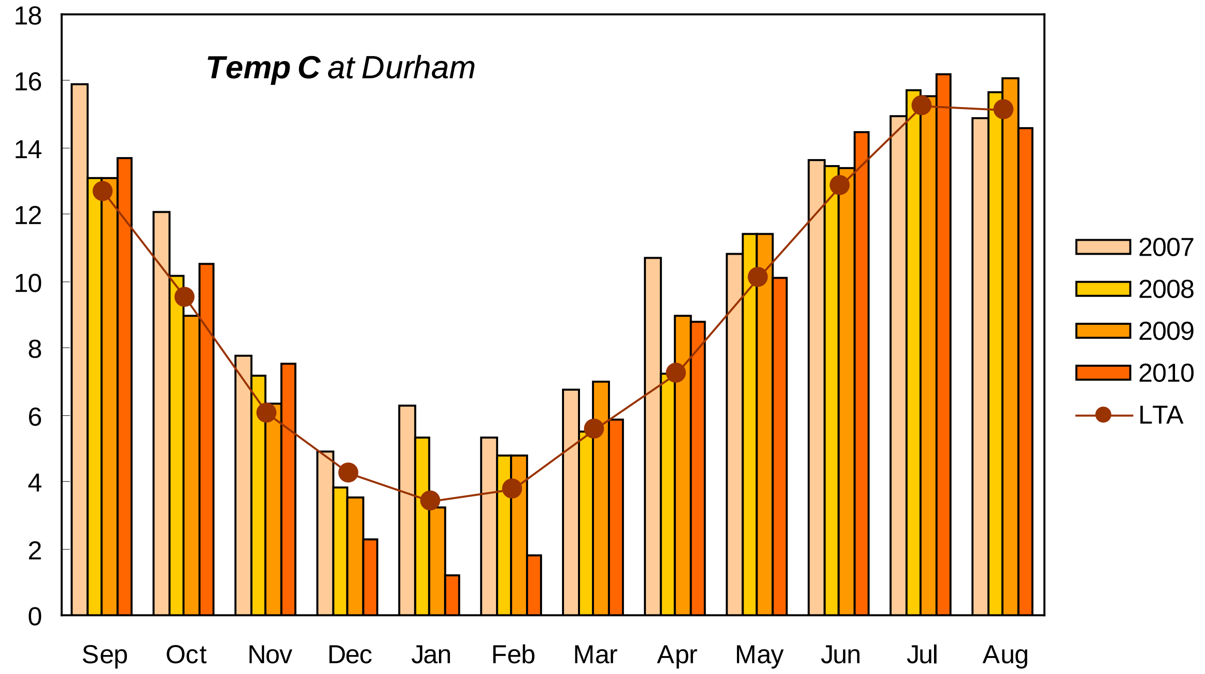

Figure 2. Monthly average temperatures for Durham in each of four harvest years, with long term average (LTA) as solid line.

Whilst crop measurements were not taken before harvest from these experiments visual differences between N rates and N timings were evident. In particular in 2010 it was clear that plots which had received the bulk of their N early were much thicker with more ears per m^2 than plots where N had been applied at conventional timings.

Grain yield & optimum N rate

High or reasonable yields were achieved at all sites, fertilised yields ranging from 8 to 14t/ha in 2009 (Figure 1) and 8 to 10t/ha in 2010 (Figure 3). Unfertilised grain yields ranged from 2t/ha up to 8t/ha, generally reflecting differences in measured soil N supply (see Tables 1 & 2). In 2010 measured soil N supply were all low (<50kg/ha) and subsequent unfertilised yields were also low (2-4 t/ha). The optimum N rate for grain yield varied from 112kg N/ha to 393kg N/ ha in 2009 and from 209 to 388kg N/ha in 2010. Generally the measured N optima were slightly higher than the expected optima (see Tables 1 & 2), except for Seaham WW1 in 2009 where the optima was lower than expected (112 kg N/ha compared to 220kg N/ha); this was associated with high unfertilised grain yield (8 t/ha) but could not be explained by soil analyses taken in spring. Two of the second wheat sites (Seaham in 2009 and Eryholme 2010) had very high N optima (>300kg N/ha) corresponding to very low measured SMN (<30kg/ha) and very low unfertilised grain yields (~2 t/ha). The reason for N optima in these trials generally being higher than expected may be due to the very dry springs encountered in both 2009 and 2010 hence poor recovery of later applied N and/or the very low SNS measured at most of the sites.

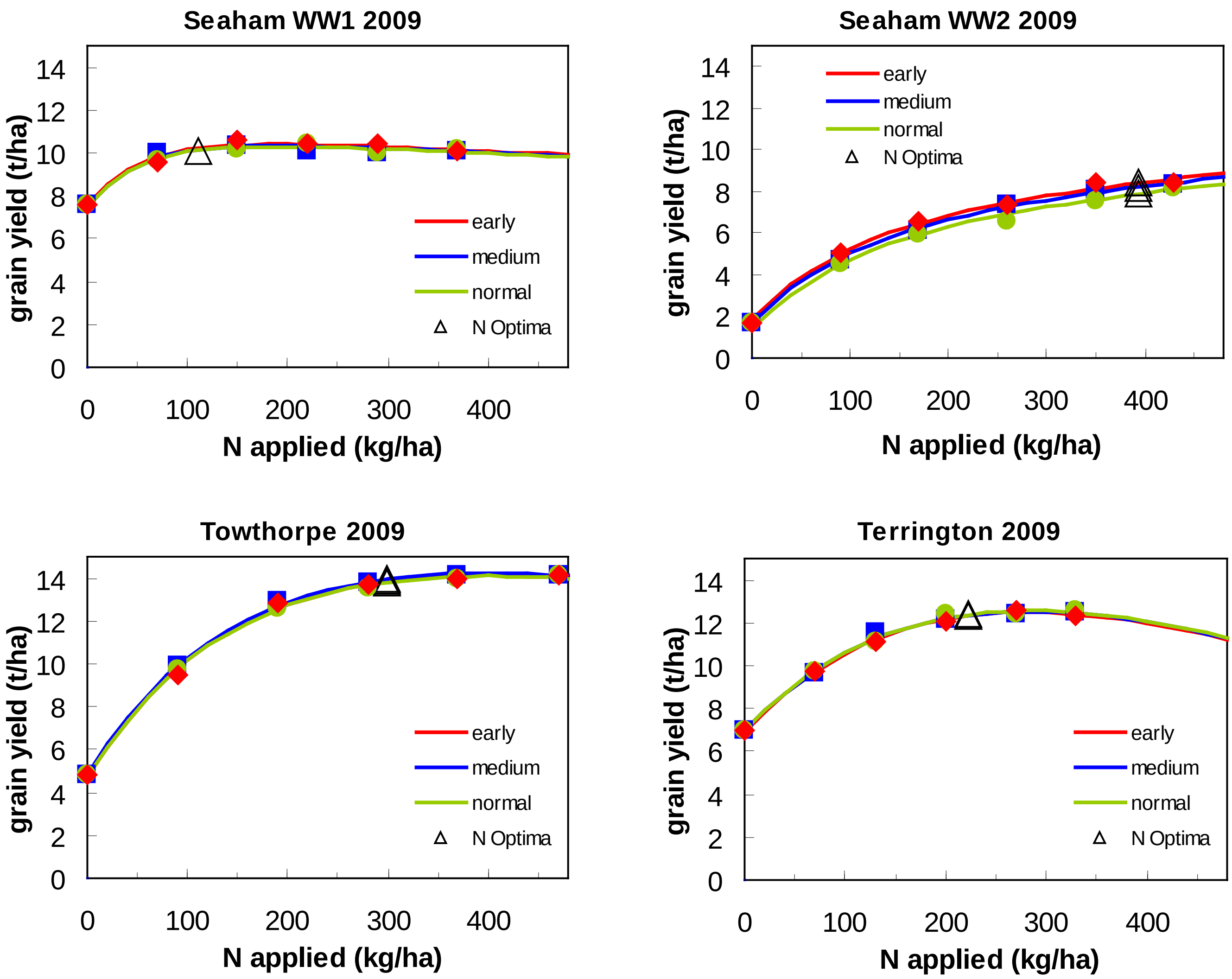

Figure 3: Grain yield response to applied N at three N timing strategies (early; medium early & normal) for each of the four trials in 2009; triangles show N optima for grain yield

ADAS

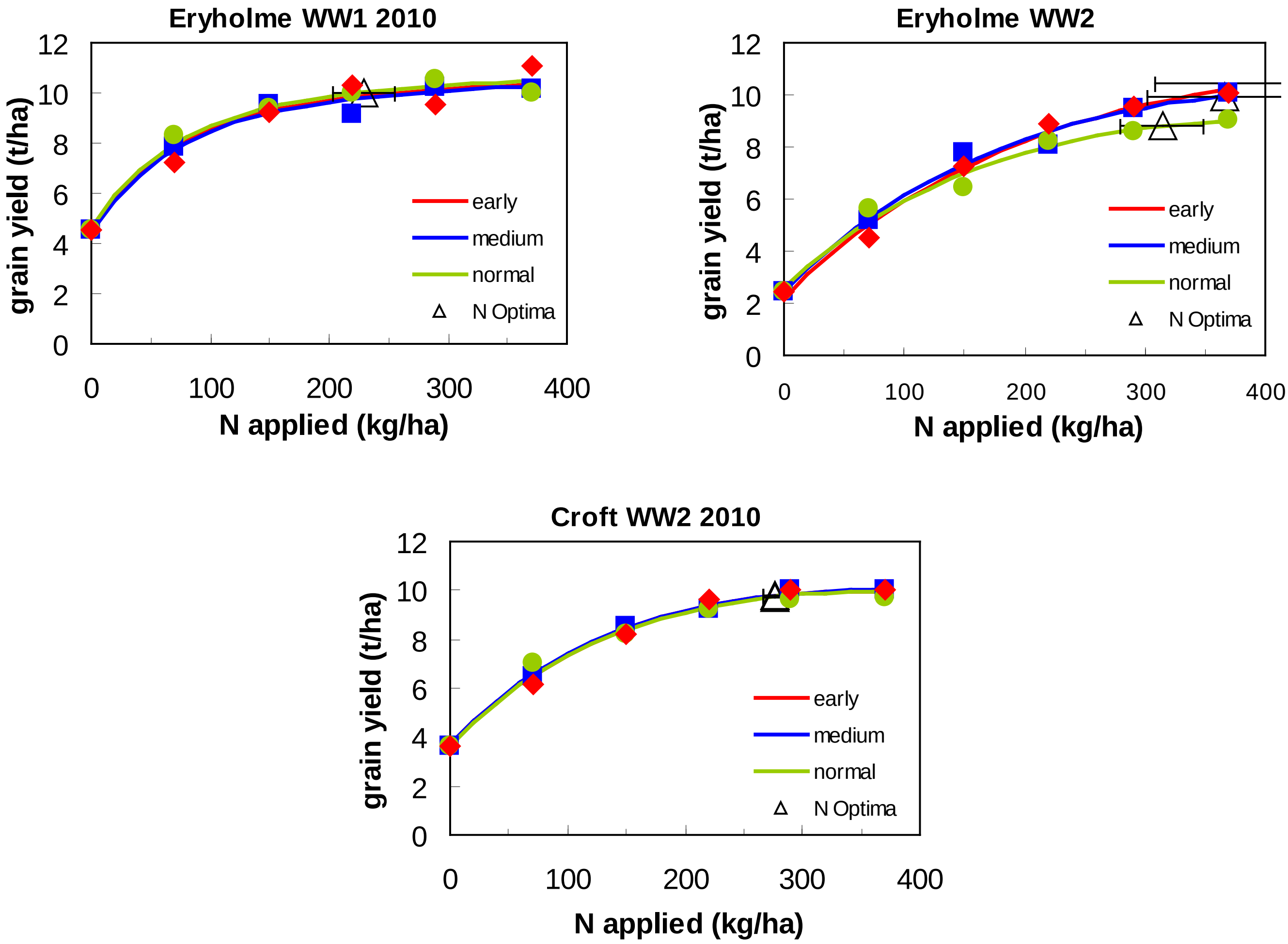

Figure 4: Grain yield response to applied N at three N timing strategies (early; medium early & normal) for each of the four trials in 2010; triangles show N optima for grain yield

N timing effects on grain yield

Timing of N application had a significant effect on grain yield in 2 of the 7 experiments (Seaham WW2 (p=0.051) and Eryholme WW2 (p=0.003)), there was a significant interaction between N rate and N timing at one experiment (Eryholme WW1 (p=0.007) and no effect of timing on grain yield at the 4 remaining sites. At 2 of the 3 second wheat sites the early N application strategy gave a substantial increase in grain yield, by 0.5t/ha at Seaham WW2 in 2009 and by up to 1t/ha at Eryholme in 2010. This large yield effect in the second cereal position suggests large positive effects of early N on tillering and rooting ameliorating the effects of take-all disease.

Early N at the first wheat site at Eryholme in 2010 gave lower yields when N rates were low, but higher yields when N rate were high. A similar pattern was also apparent at the other sites in 2010 (and N timing interaction was significant in the cross-site anova (p=0.021)) , suggesting that where N applied is substantially sub-optimal higher yields may be achieved when the application dates best meet crop demand, ie at the later conventional timing. At commercially relevant N rates however there is no evidence from any of the 7 sites that applying N earlier is detrimental to yield, although it should be noted that there was no lodging at any site and lodging risks at all sites were considered low.

N timing effects on N optima

The shape of the response of yield to N fertiliser, and hence the N optima, was not affected by N timing except at one of the 7 sites; at the 2nd wheat site at Eryholme in 2010 the early N timing gave a higher yield and also a higher N optima (388 vs 297 kg N/ha). It should be noted that the error on these estimates of N optima are very large, exceeding 100 kg N/ha for the early N treatment. Nevertheless, it is not unusual for factors that increase grain yield to also increase N optima; it is usually economically justifiable to apply more N to achieve higher yield potential.

Grain protein and alcohol yield.

Applying N increased grain protein levels at all sites from ~7% of dry matter (DM) or less to a maximum of around 12% DM at most sites, and 11% DM at Towthorpe 2009 and Eryholme WW1 2010 (Figure 2). Across sites and N rates early N timing significantly ($p<0.001$) reduced grain protein content (10.21% early; 10.47% medium; 10.91% normal; SED 0.09% DM). The effect of N timing on grain protein was greater in 2010 than in 2009 (1.07% vs 0.41% average difference between normal and early respectively). Within sites, significant N timing effects were found at Towthorpe and Seaham WW2 in 2009 ($p<0.001$) with a significant interaction between N rate and timing at Seaham WW2 ($p=0.002$) where early timing at very low N applications produced much lower protein. There were significant N timing effects ($P<0.001$) on grain protein and Timing x N rate interactions in all 3 experiments in 2010 ($P<0.001$) with differences between timings greatest at the lower N rates.

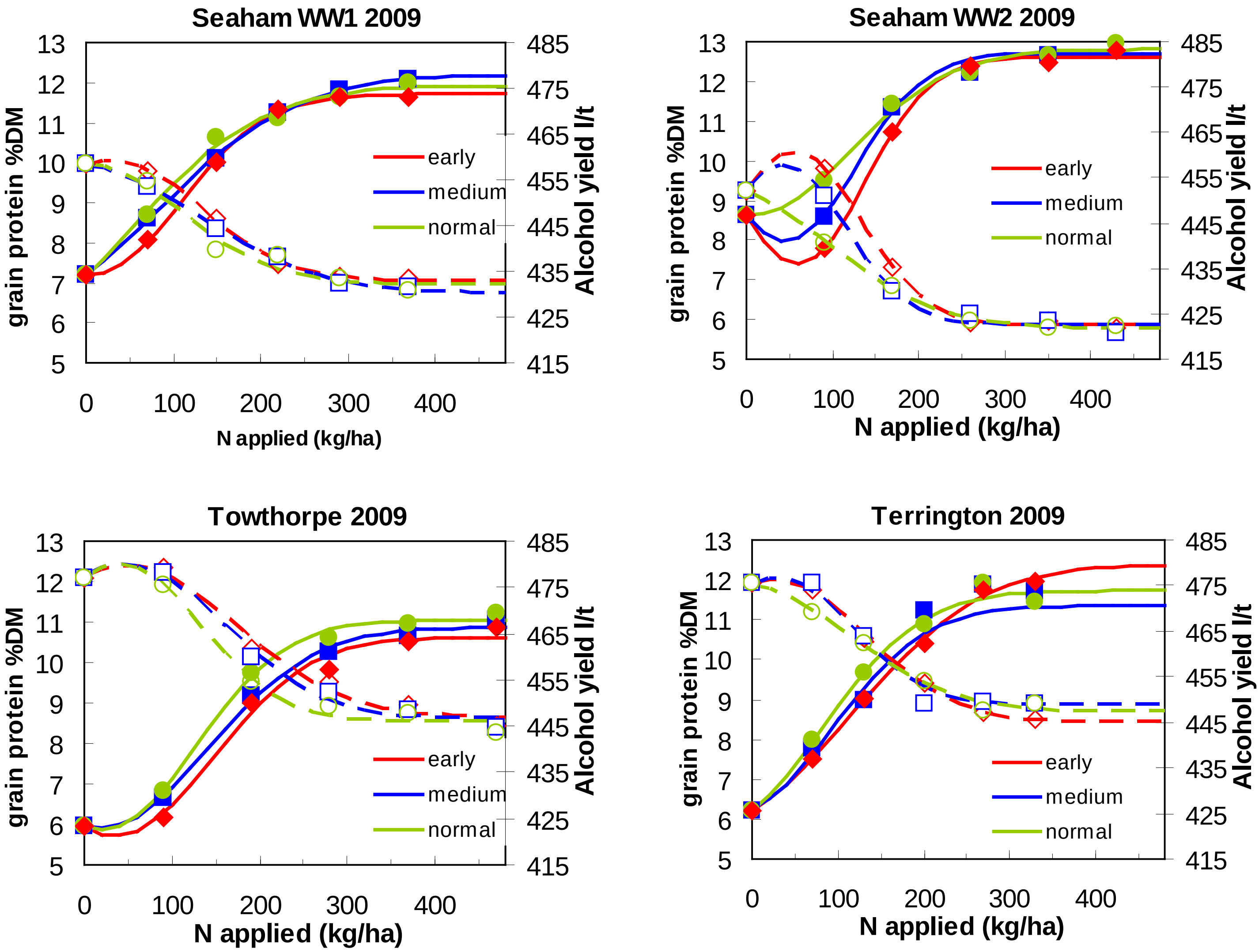

Figure 5: Grain protein (solid line; left axis) and Alcohol yield (broken line; right axis) response to applied N at three N timing strategies (early; medium early & normal) for each of the four trials in 2009

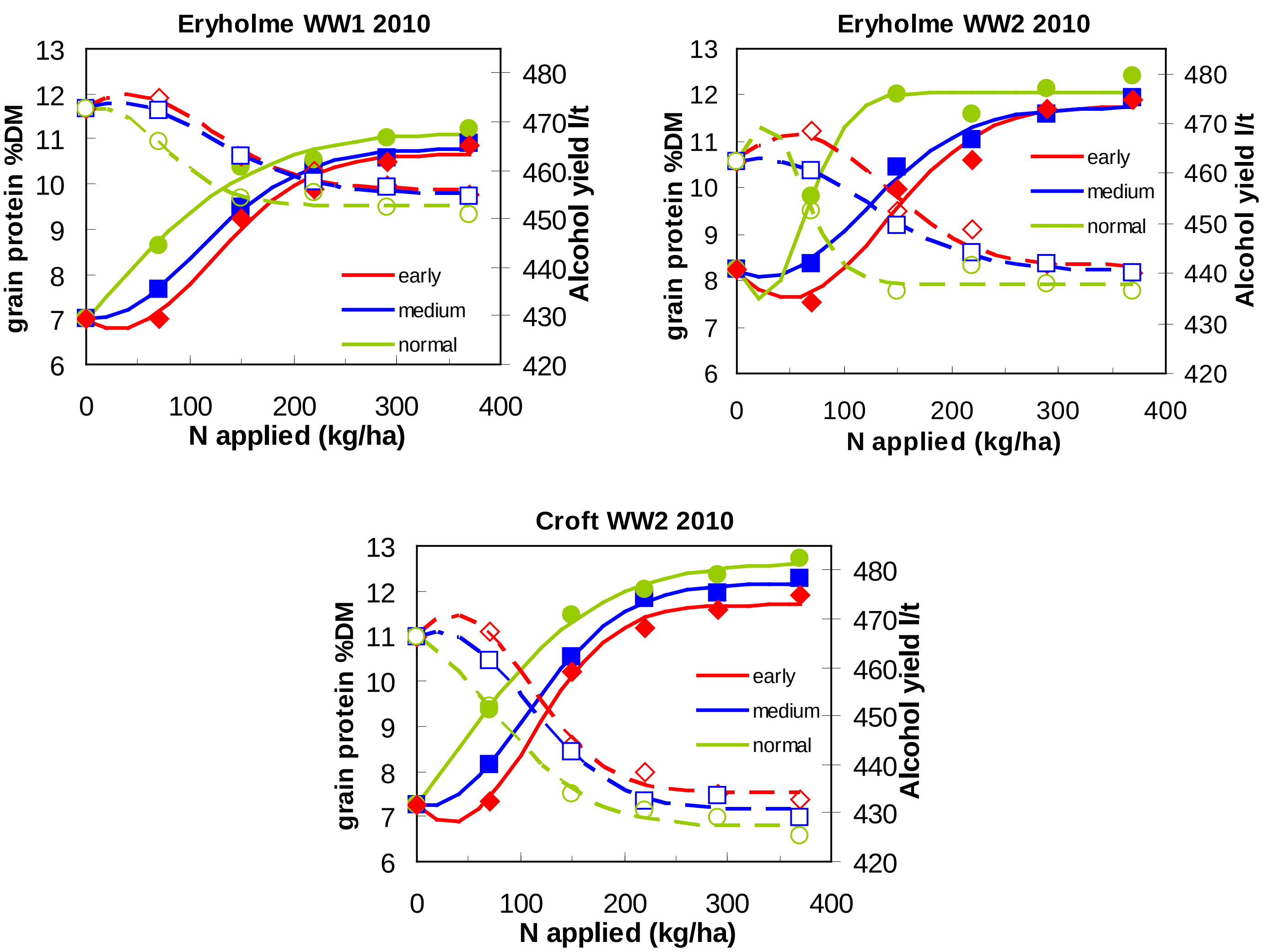

Figure 6: Grain protein (solid line; left axis) and Alcohol yield (broken line; right axis) response to applied N at three N timing strategies (early; medium early & normal) for each of the four trials in 2010

Alcohol yield (litres/ dry tonne) generally mirrored grain protein effects, though substantial differences were apparent between sites relative to differences in protein content. Across sites alcohol yields declined with increasing N application from 466l/t to around 438l/t. Across sites and N rates early N timing increased alcohol yield significantly (p<0.001) from 444.1l/t at 'normal' timing to 447.6 l/t at medium and 449.1 l/t with early timing (SED = 0.45). N timing also interacted with N rate (p<0.001), with differences in N timing being greatest at the lowest N rates. Within each site, significant differences between timings were seen at one site in 2009 (Seaham WW2 (p=0.012)) and all three sites in 2010 (P<0.001).

Considering protein and alcohol yield at the economic optimum for yield, Table 4 shows grain protein to be lower at the early N timing than the normal timing in every experiment, significantly so in 4 of the 7 sites and alcohol yield was higher in 6 of 7 sites, significantly so in 5 of 7 sites.

Table 4. Grain protein and Alcohol yield at the N optima for yield for different timing strategies at each site

	N optima	***Grain Protein %DM***				***Alcohol Yield l/dry t***			
Site	***kg N/ha***	***Early***	***Medium***	***Normal***	***SED***	***Early***	***Medium***	***Normal***	***SED***
2009									
Seaham WW1	*112*	9.1	9.4	9.7	*0.13*	451.9	449.1	447.5	*1.01*
Seaham WW2	*393*	12.6	12.7	12.8	*0.12*	422.6	422.7	421.9	*1.33*
Towthorpe	*300*	10.3	10.5	10.9	*0.11*	451.1	449.4	446.7	*1.04*
Terrington	*223*	11.0	10.9	11.3	*0.35*	450.5	451.1	451.9	*2.05*
2010									
Croft	*263*	11.6	12.0	12.4	*0.08*	434.6	431.4	427.9	*0.72*
Eryholme WW1	*209*	10.1	10.3	10.7	*0.07*	458.4	458.0	452.9	*0.57*
Eryholme WW2	*339*	11.8	11.7	12.0	*0.10*	441.7	440.8	438.0	*0.92*
mean	*263*	*10.9*	*11.1*	*11.4*		*444.4*	*443.2*	*441.0*	

Alcohol Yield (l/ha).

Figures 7 and 8 show that N effects on alcohol yield per ha tend to be dominated by grain yield rather than alcohol yield per tonne. Alcohol production was more than doubled by applying N at Towthorpe, Croft and Eryholme WW1 and trebled at Seaham WW2 and Eryholme WW2.

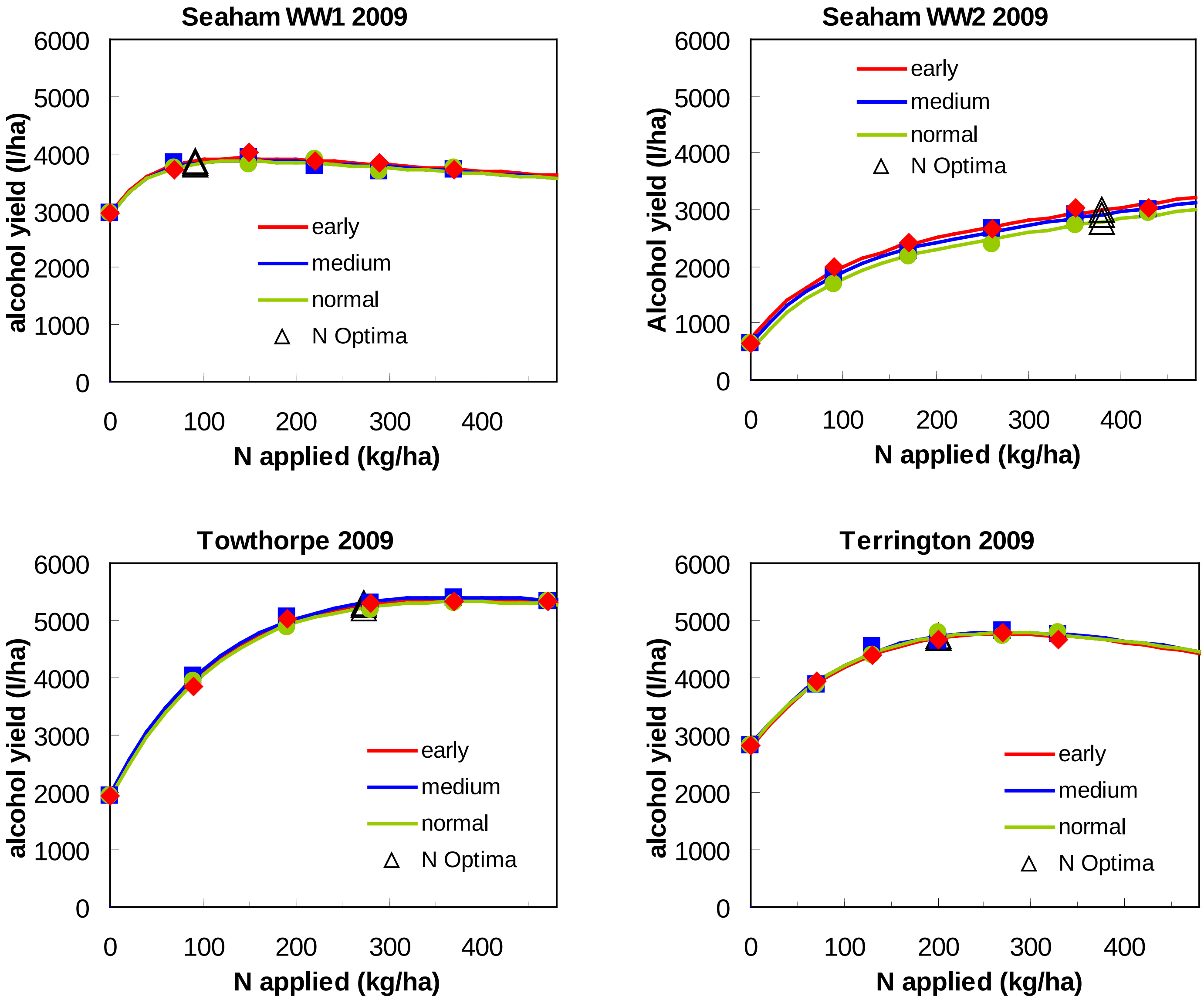

Figure 7: Alcohol yield (litres per hectare) response to applied N at three N timing strategies (early; medium early & normal) for each of the four trials. Triangles show N optima for grain yield.

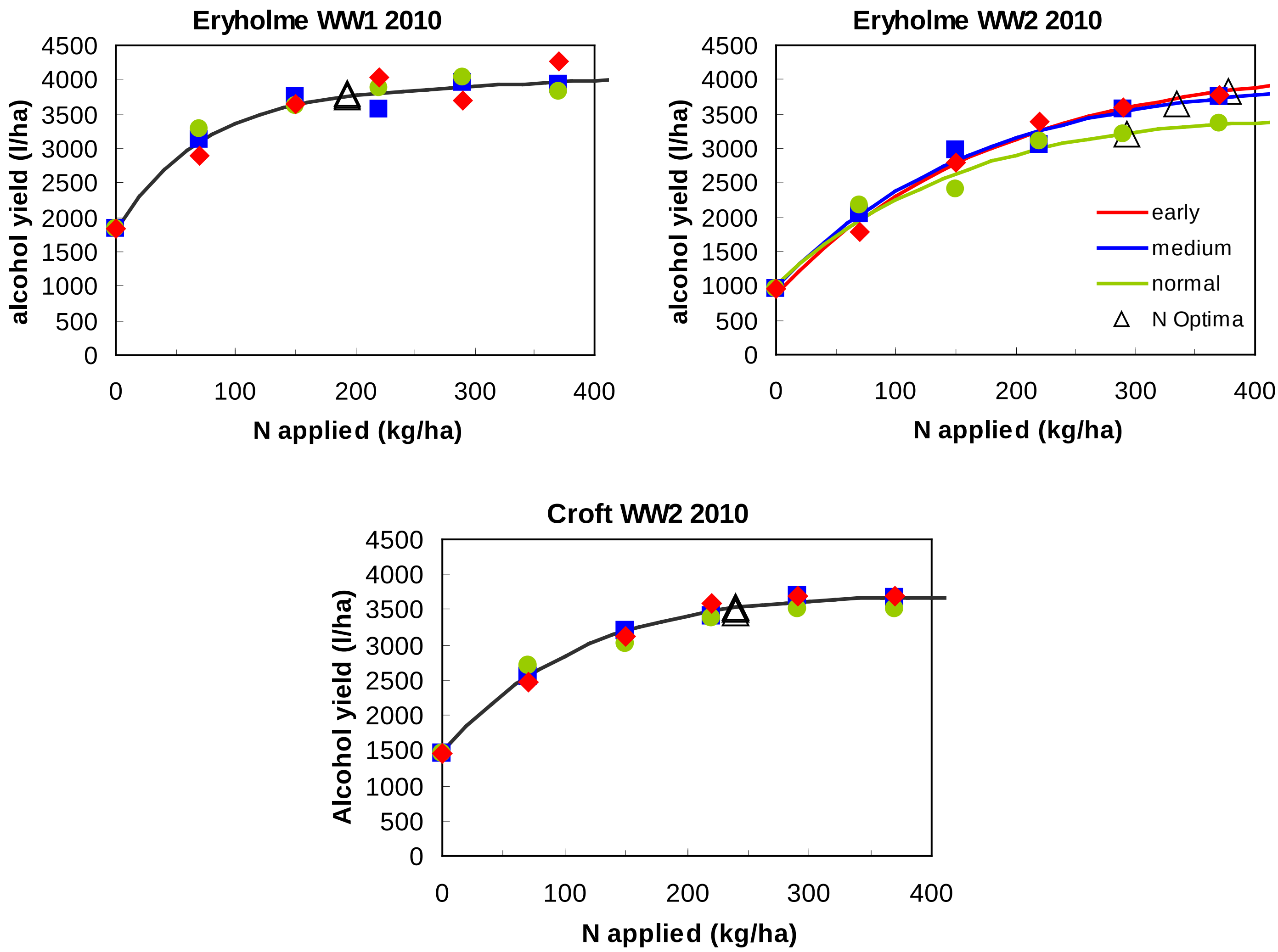

Figure 8: Alcohol yield (litres per hectare) response to applied N at three N timing strategies (early; medium early & normal) for the trials in 2010. Triangles show N optima for grain yield.

Within sites, the effect of N timing on alcohol yield per ha was only significant at the second wheat sites Seaham WW2 (p=0.044) and Eryholme (p<0.001) where early timings produced greater alcohol yield, due to the greater grain yields with the earlier timings at these sites. Analysing across all sites, early N timing did significantly increase alcohol yield per ha (p=0.009), except at the lowest N levels (p=0.023 for the N x timing interaction). Overall, at the 'recommended' N level (Level 4) alcohol yield per ha was 3925 for the early timing compared to 3796 for the normal timing (SED = 67.7).

N timing only affected the shape of the response to N fertiliser of alcohol production per ha at one site, the Eryholme 2nd wheat site, where the N optima for alcohol production was higher with the earlier N timing, reflecting the results for grain yield at this site.

N optima for alcohol yield per ha were between 3 and 19% lower than optima for grain yield (Table 6), within the range found previously (Kindred *et al*., 2007; Clarke *et al*., 2008), though the average reduction of 9% found here is slightly lower than that reported previously, of around 12%.

Table 6. Economic optimum N rates for grain yield and alcohol yield per ha at each of the 4 sites

Site	N optima for Grain yield	N optima for Alcohol yield	% reduction in optima
2009			
Seaham WW1	112	91	19%
Seaham WW2	393	379	4%
Towthorpe	300	273	9%
Terrington	223	201	10%
2010			
Croft	263	240	10%
Eryholme WW1	209	193	8%
Eryholme WW2 early	388	377	3%
Eryholme WW2 medium	345	335	3%
Eryholme WW2 normal	297	292	2%
mean	264	245	9%

Other Quality Parameters - Specific Weight.

There were large differences in specific weight between sites, and a general trend for specific weight to increase with N application ($p<0.001$). Specific weights were low in some of the experiments in 2009, perhaps reflecting the wet summer and late harvest in the North East in this year, especially at Seaham. Specific weights were higher on the fertile silts at Terrington in 2009 and were higher in 2010 (Table 8). Overall there was no consistent or significant effect of N timing on specific weight across sites, though significant N timing effects were seen at Seaham WW2 ($p=0.051$; early = 70.6, medium = 70.1, normal = 69.8), and the first wheat site at Eryholme ($p<0.001$; early = 76.3, medium = 76.7, normal = 77.0) (Figure 7). It is not expected that such small differences in specific weight would have any material impact on processing yield or efficiency.

Table 7. Specific weight at each site with zero, recommended level and highest level of N fertiliser, averaged across N timings.

Site	0N	Recommended N (RB209)	high N	Mean
2009				
Seaham WW1	67.7	67.8	72.1	*67.5*
Seaham WW2	67.7	70.6	72.1	*70.0*
Towthorpe	61.4	61.5	61.8	*61.5*
Terrington	68.6	73.5	73.8	*72.5*
2010				
Croft	71.6	77.5	77.6	*76.2*
EryholmeWW1	72.3	77.3	78.0	*76.4*
Eryholme WW2	69.1	74.9	75.3	*73.9*
Average	*69.1*	*74.9*	*75.3*	*73.1*

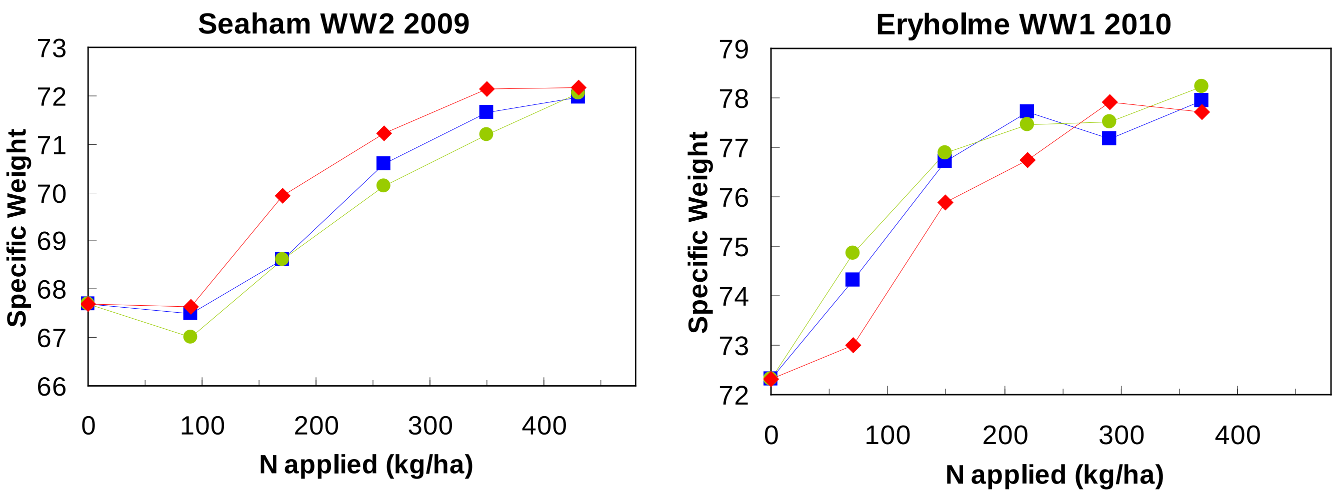

Figure 9: The effect of N applied at three N timing strategies (early (red); medium early (blue) & normal (green)) on the specific weight of grain at the two sites where timing effects were significant.

Thousand Grain Weight

As well as differences between sites (Croft = 47g; Eryholme WW1 = 51g; Eryholme WW2 =50g) there was a significant effect of N rate and timing on grain weight in 2010 ($p<0.006$ for the interaction), with grain size increasing with N fertiliser and early timing giving slightly smaller grains. Smaller grains with early N timing might be expected as early applications of N stimulate tiller production and survival, (especially if uptake of later applied N is delayed due to dry conditions), leading to more ears per m^2; if later N applications are to lead to similar grain yields then compensation must occur through grain number per ear or through grain size. The differences in grain size between treatments seen in these experiments are unlikely to give any meaningful difference in the alcohol processing yield or efficiency.

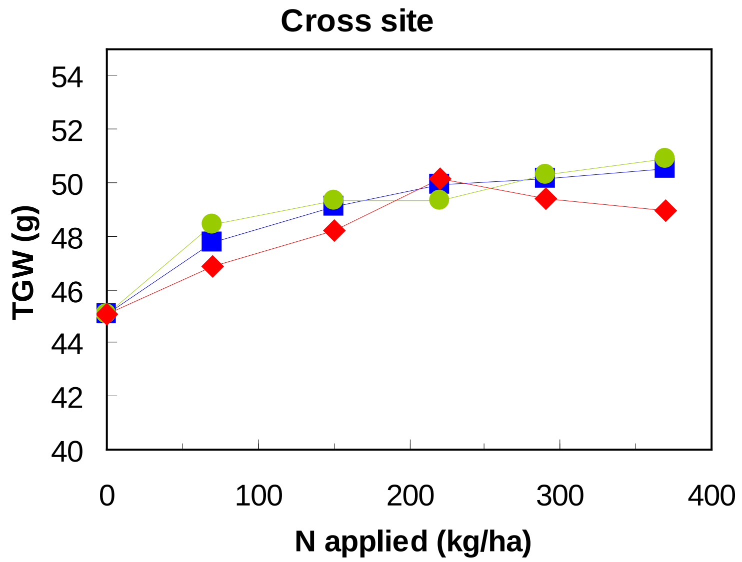

Figure 10: The effect of N applied at three N timing strategies (early; medium early & normal) on the thousand grain weight (TGW) averaged across three trial sites in 2010.

Conclusions

This series of experiments was set up to explore whether earlier N timings could improve value of wheat grain to bioethanol processors without grain yield. The results from the 7 experiments in 2008 and 2009 have shown that applying N fertiliser earlier can give useful improvements to alcohol yield per tonne without compromising grain yield (Table 8). Indeed, significant increases in alcohol yield per tonne were recorded in 6 of the 7 sites. Whilst the magnitude of the N timing effect is relatively small in relation to differences seen between sites, varieties and N rates, it seems that early timing can improve alcohol yields by around 4 l/t fairly consistently. Such a difference may be worth more than £1 per tonne grain to the bioethanol processor from increased revenues, after any negative effects on quantity of DDGS is accounted for. Although the additional value is small on a per tonne basis, if such timing effects are consistent and give no yield, management or financial penalty to the farmer, there is the potential for adoption of early N timing to give benefits in improved bioethanol production of more than £1 million per annum.

Tabe 8 *Summary of effects of N timing on grain yield, alcohol yield (AY) and alcohol production per ha from 3 years of trials.*

Year	Site	Effect on yield		Effect on AY l/t		Effect on AY l/ha	
2007 (HGCA funded trials)	**Boxworth**	*+0.09 t/ha*	*ns*	*+3 l/t*	*ns*	*+62 l/ha*	*ns*
	High Mowthorpe	*+0.19 t/ha*	*ns*	*+2 l/t*	*ns*	*+98 l/ha*	*ns*
	Terrington	*-0.07 t/ha*	*ns*	*+1 l/t*	*ns*	*-25 l/ha*	*ns*
	Rosemaund	*+0.05 t/ha*	*ns*	*-2 l/t*	*ns*	*+5 l/ha*	*ns*
	Kent	*-0.20 t/ha*	*ns*	*-1 l/t*	*ns*	*-94 l/ha*	*ns*
2009	**Seaham WW1**	+0.10 t/ha	*ns*	*+2 l/t*	*ns*	*+52 l/ha*	*ns*
	Seaham WW2	*+0.52 t/ha*	**	*+4 l/t*	*	*+200 l/ha*	***
	Towthorpe	+0.02 t/ha	*ns*	*+4 l/t*	***	*+40 l/ha*	*ns*
	Terrington	-0.07 t/ha	*ns*	*-1 l/t*	ns	-25 l/ha	*ns*
2010	**Croft**	+0.04 t/ha	*ns*	*+8 l/t*	***	*+65 l/ha*	*ns*
	Eryholme WW1	-0.14 t/ha	*ns*	*+5 l/t*	***	*-15 l/ha*	*ns*
	Eryholme WW2	*+0.64 t/ha*	**	*+7 l/t*	***	*+185 l/ha*	***

No evidence has been found from these experiments, or from previous similar experiments in 2007 (Sylvester-Bradley *et al*., 2008), that applying a larger proportion of N fertiliser early in spring damages yields or quality. However, it must be noted that all 3 years in which experiments have been conducted have been characterised by dry springs, and hence low lodging risks and low risks of greater leaching loss of early applied N. The potential increased lodging risk from applying N earlier in the season remains untested. From visual observations of the experiments in 2010, it was clear that the canopies of plots receiving early N were thicker having more shoots than plots receiving the same quantity of N applied ‘normally’. Such crops are likely to be more susceptible to lodging, though no lodging was seen in any of the trials in 2009 & 2010. Such differences in the canopy also show the compensatory potential of wheat in producing grain yield; despite normal N timing plots in 2010 having fewer ears per m^2 and generally looking thin, they generally achieved almost the same grain yield as the thicker early N plots, by compensating for the reduced number of ears with an increased grain size.

It should be noted that applying a greater proportion of N early may increase the risk of fertiliser N being lost from the soil by leaching or denitrification, both because soils are likely to be wetter and experience more drainage, and because supply of N will exceed demand for N by the crop at this time, as growth is slower. Losses of fertiliser N in spring are generally small, averaging 16% predominantly due to denitrification (10%) rather than leaching (6%) (Powlson *et al*., 1992; Addiscott, 1996). The loss of this spring applied N is related to the rainfall experienced in the 3 weeks after application, is likely to be greater on sandy than on more retentive clay or silt soils, and is likely to be greater where applications are in excess of crop demand. Powlson *et al*. (1992) give the equation N Loss (%) = 5 + 0.264 x mm rainfall in the 3 weeks following application. Where rainfall in the 3 weeks following application exceeds 100mm then N losses may amount to 30% of the applied N. Rainfall following early N applications in 2009 was low (21mm for whole of March), but March rainfall in 2010 was moderately above average (68mm), giving the potential for perhaps 19% of applied N to be lost from early N applications in 2010. Despite this however, N recovery of N from the early treatments was as great for the 'early' treatments as for the 'normal' later applied treatments, at least at the higher N rates. Impacts on N recovery, grain yield and grain protein of greater early N applications in wetter springs remain untested.

Two of the three second wheat sites tested in this project showed a large (>0.5 t/ha) yield benefit from increasing the proportion of N applied early. Soil mineral N levels in both these sites were very low, typical of a second wheat situation, and small applications of early N is recommended to second wheats for this reason, and to help stimulate tillering and rooting to help ameliorate Take-all effects. The results from these experiments suggest a strong possibility that a greater proportion of N should be applied early to second wheat crops in general than is currently recommended. This certainly warrants further investigation, as if yield improvements of 0.5 t/ha could be achieved on 2/3rd of second cereal crops across the country the benefit to the arable industry could run to more than £15 million per year.

Overall, it would seem safe to advise growers that a greater proportion of N fertiliser can be applied earlier to the crop if they are seeking to improve the utility of their grain for alcohol production, so long as lodging and leaching risks are deemed to be minimal. It is possible that N fertiliser losses and lodging problems could be increased in wetter springs, but this is untested. For second wheats, growers can be advised that a yield benefit may accrue as well as an improvement in alcohol yield. However, further work is required before advice to use more early N can be given confidently in situations where lodging may be a substantial risk. It is suggested that further experiments are conducted, ideally in seasons with large crops after winter and wet springs, thus being more conducive to lodging. To provide robust results, even in the absence of lodging, crop measurements can be made of the various factors that influence lodging risk (eg stem strength, root plate spread, height) and modelled to quantify the lodging risk (Berry *et al*., 2003).

Whether growers should alter the way they grow their crops to supply the bioethanol (or potable alcohol) market will depend on the relationship with the processor. There are three main areas in which growers can influence the value of their grain to a bioethanol processor: variety choice, N fertiliser application rate and N fertiliser application timing. Whilst no premiums or other mechanisms exist for high alcohol yield grain, there is little incentive for growers to produce grain for bioethanol any differently than producing grain for animal feed; ie aiming for high yields whilst optimising input costs. Mechanisms that reward growers for producing high alcohol crops could benefit both growers and the bioethanol industry.

These experiments are useful in starting to build evidence for N optima in the North East region; where very few N response experiments have been conducted in recent years. Very low soil mineral N levels in spring were measured on four of the five sites in the North East, and N optima were considerably higher than expected on two of these four sites; the two second wheat sites (393kg N/ha Seaham WW2; 335kg N/ha Eryholme WW2). Low unfertilised crop N offtakes were measured on the second wheat sites (30kg/ha Seaham WW2; 42kg/ha Eryholme WW2) corroborating the low soil mineral N measurements. However, the N optima at Seaham WW1 (112kg N/ha) was considerably lower than would be expected from soil N supply measured in spring. The yield and protein of the unfertilised crop at harvest indicates that around 115kg N/ha was supplied from the soil, compared to 66kg/ha measured in the soil, suggesting that there was substantial mineralisation of N from this soil during spring, although soil measurement of potentially mineralisable N did not indicate a large amount of N would be mineralised.

Clearly results from 5 site-seasons is too small a sample to provide firm recommendations about N rates for the North East as a whole, but this limited evidence suggests that N optima in the North East may be higher than would be predicted from generic English recommendations in RB209. Alternatively, the relatively high N optima seen in this study may just reflect the two years in which the experiments have been undertaken; both 2009 and 2010 had dry springs which may have restricted uptake of fertiliser N. Further experiments in the region would be useful to assess whether fertiliser N requirements are well predicted by RB209, or whether responses are better predicted by Scottish recommendations. Overall, the use of soil mineral N testing on these sites has proved useful in explaining differences in N optima between sites.

References

Addiscott, T. (1996). Fertilizers and Nitrate leaching. In *Agricultural Chemicals and the Environment*, eds. R. E. Hester and R. M. Harrison), pp. 1-26. London: Royal Society of Chemistry. http://www.rsc.org/ebooks/archive/free/BK9780854042203/BK9780854042203-00001.pdf

Agu, R. C. Bringhurst, T. A. & Brosnan, J. M. (2006). Production of grain whisky and ethanol from wheat, maize and other cereals. *Journal of the Institute of Brewing* **112**, 314-323.

Anon (2000). *Fertiliser Recommendations for Agricultural and Horticultural crops*. (Seventh Edition). MAFF (now DEFRA) Reference Book 209. London: HMSO.

Anon. (2008) Genstat 12th Edition. VSN International Ltd.: Hemel Hemstead, UK.

Berry, P. M. (2003). A calibrated model of wheat lodging compared with field measurements. *Agricultural and Forest Meteorology* 119, 167-180.

Clarke, S., Kindred, D., Weightman, R. M. and Sylvester-Bradley, R. (2008). *Growing Wheat for Alcohol and Bioethanol Production in the North East*: An ADAS report commissioned by One North East and North East Processing Industries Cluster.

Kindred, D. Smith, T. C. Sylvester Bradley, R. Ginsburg, D. & Dyer, C. (2007). Optimising nitrogen applications for wheat grown for the biofuels market. In *Project Report No. 417* London: HGCA.

Kindred, D. Verhoeven, T. Weightman, R. Swanston, J. S. Agu, R. C. Brosnan, J. & Sylvester Bradley, R. (2008a). Effects of variety and fertiliser nitrogen on alcohol yield, grain yield, starch and protein content, and protein composition of winter wheat. *Journal of Cereal Science* **48**(1), 46-57.

Kindred, D., Weightman, R. M., Clarke, S., Agu, R. C., Brosnan, J. M. and Sylvester-Bradley, R. (2008). Developing wheat for the biofuels market. Aspects of Applied Biology 90. Biomass and Energy Crops III, 143-152.

Kindred, D., Weightman, R., Roques, S. and Sylvester-Bradley, R. (2010). Low nitrogen input cereals for bioethanol production. Aspects of Applied Biology 101 Non Food Uses of Crops 101, 37-44.

Powlson, D. S., Hart, P. B. S., Poulton, P. R., Johnston, A. E. and Jenkinson, D. S. (1992). Influence of soil type, crop management and weather on the recovery of N-15-labeled fertilizer applied to winter-wheat in Spring. *Journal of Agricultural Science* **118**, 83-100.

Smith, T. C. Kindred, D. R. Brosnan, J. Weightman, R. Shepherd, M. & Sylvester-Bradley, R. (2006). Wheat as a Feedstock for Alcohol Production. *HGCA Research Review 61* London: HGCA.

Swanston, J. S. Smith, P. L. Gillespie, T. J. Brosnan, J. M. Bringhurst, T. A. & Agu, R. C. (2007). Associations between grain characteristics and alcohol yield among soft wheat varieties. *Journal of The Science Of Food And Agriculture* **87**(4), 676-683.

Sylvester-Bradley, R. Kindred, D. R. Blake, J. Dyer, C. & Sinclair, A. (2008). Optimising fertiliser nitrogen for modern wheat and barley crops. In *Project Report No. 438* London: HGCA.