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

An ADAS study commissioned by NEPIC

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By:

Daniel Kindred
Damian Hatley
David Green
Chris Dyer
Roger Sylvester-Bradley

Contact:

Daniel Kindred
ADAS UK Ltd
Boxworth
Cambridge
CB23 4NN
Tel: +44 (0) 1954 267666
Email: daniel.kindred@adas.co.uk

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For:
John Brady
The North East of England Process Industry Cluster Ltd
Room H224, The Wilton Centre
Wilton, Redcar
Cleveland
TS10 4RF

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Abstract

The opening of the Ensus Bioethanol facility in Teeside creates the opportunity to supply 1 million tonnes of wheat locally for bioethanol production. 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 fertiliser timing can be used by growers to improve biofuel grain quality.

Grain with lower protein content should be worth more to bioethanol processors, as higher yields of alcohol are achieved per tonne of grain. Growers can produce grain with lower protein content by applying less N fertiliser, though this is likely to result in lower grain yields and hence an economic cost to the grower. It may be possible to produce lower protein content grain by applying N fertiliser earlier in the season, without affecting grain yield. It is known that N fertiliser timing effects N uptake and distribution in the crop, with later N applications increasing grain protein content. However, the extent to which applying N earlier can reduce grain protein has not been conclusively tested. Four N response field experiments were set up in 2009 comparing 'normal' with 'medium early' and 'early' N strategies. For each N response trial, fertiliser was applied by hand in spring in 3 split applications, grain yields measured by combine harvester and grain quality tests made, including 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 no effect on grain yield of early N timing at 3 of the 4 sites, but a significant yield advantage of 0.5t/ha for earlier N application at one of the sites, a second cereal site. Early N application did tend to give reduced grain protein hence increased alcohol yield per t, though effects of N timing tended to be relatively small compared to N rate effects (444 to 447 litres/ dry tonne with earlier N timing; 437 to 466 litres/ dry tonne with reduced N rates). Early N timing improved specific weight at the second cereal site, but had no effect at the other 3 sites. There was no effect of N timing on the economic N optima at any site. Alcohol yields per ha were more strongly related to grain yield than to alcohol yield per t, so early N timing only significantly increased alcohol yield per ha at the site where grain yield was increased.

Evidence from this study and previous work suggests that applying the bulk of nitrogen earlier in the season does not compromise yields or quality, and in some cases may be beneficial. Earlier N application can give reduced protein content & increased alcohol yields per tonne, although effects seem to be small compared to differences between N rates. In conclusion, applying N fertiliser earlier should moderately improve grain quality for bioethanol production without impeding grain yield, perhaps giving larger benefits to both grain yield and quality for second wheats. However, the cold and wet 2008/2009 autumn & winter meant crops were very backward in spring 2009; repeating the experiments in a more typical or 'forward' season where lodging risks are more likely would allow these conclusions to be more robustly tested.

Introduction

The North East is set to be 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, which has the potential to use around 1.2 million tonnes of UK wheat per annum. Other large bioethanol plants are also under construction or in planning 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.

These markets combined 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 nitrogen 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

Nitrogen 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 bioethanol production, though its use maintains yields and hence reduces land requirements and pressure on land use change around the world, reducing the consequent carbon emissions (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 nitrogen rate on grain yield and grain protein are generally larger than effects of nitrogen timings. Applying increasingly more nitrogen fertiliser increases grain yields, rapidly at first, but with diminishing returns as N rates increase further: the additional grain yield/ha gained from each extra unit of nitrogen fertiliser applied gets smaller and smaller as N rates increase. Eventually, applying additional nitrogen 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 unit of N fertiliser results in a yield increase which is worth the equivalent amount per ha; applying an additional unit of fertiliser to this will cost more than the extra yield achieved is worth. The optima 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'.

There has 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 this 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 than grain yield because nitrogen fertiliser increases grain protein contents, and higher grain proteins gives lower bioethanol yields per ton 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 in fact 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 nitrogen 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, to our knowledge, no N response experiments have been conducted recently between North Yorkshire and Southern Scotland. There is evidence that nitrogen 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 nitrogen 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 Project 3084 compared 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 nitrogen earlier encourages the nitrogen 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, nitrogen is applied to wheat crops in two or three split applications. Often around 40kg/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 at the earlier applications.

Nitrogen timings were not explicitly examined by Clarke et al. (2008) because there is very little 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 nitrogen 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.

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 will be necessary to confirm that 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 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

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. 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, so it is 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).

The soil mineral nitrogen content of the soil was measured to determine the likely optimum nitrogen rate for the crop (Anon., 2000) , with the nitrogen treatments then calculated to span the optimum, ranging from zero N, 1/3 of recommended, 2/3 of recommended, recommended nitrogen, 4/3 of recommended and 5/3 of recommended.

Three N timing strategies (conventional, medium and early) were tested for each of the 5 with-N rates, with up to half of the nitrogen 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 1), with the remainder of the N split equally between the two later application dates.

Table 1: N rate splits for the three N timing treatments

	Mid -February – early March	April to early May**
Conventional	20%*	80%
Medium	33%	66%
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.*

Table 2: Site Details for the four experiments

	Towthorpe	Vicarage	18 Acre	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	26/09/08	19/11/08	24/10/08	26/09/08

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.

Nitrogen 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 GG0005 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). Nitrogen optima for grain yield were determined using a break- even ratio of 6:1 (grain price assumed to be £97/t, Ammonium nitrate (34.5% N) price £200/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.

Grain yield

High or reasonable yields were achieved at all sites, ranging from 8t/ha in the second wheat position at 18 acre to 14 t/ha at Towthorpe (Figure 1). The optimum nitrogen rate for grain yield varied from a fairly low 112kg N/ha at Vicarage to a very high 393 kg/N/ha at 18 acre (the only second wheat included in the study). Yields from the 18 acre site at zero N rates were very low at less than 2 tonnes per ha, resulting from very low soil N reserves (soil mineral N in autumn was only 17kg/ha). N Optima at Terrington and Towthorpe were 223 and 300 kg/ha respectively. The measured optima were reasonably close to the expected optima at all sites except Vicarage Field, where it was less than expected. The yield obtained at the optimum N rate varied from 8.2t/ha at 18 acre to 13.9t/ha at Towthorpe, Vicarage yielded 10.2t/ha and Terrington 12.4 t/ha.

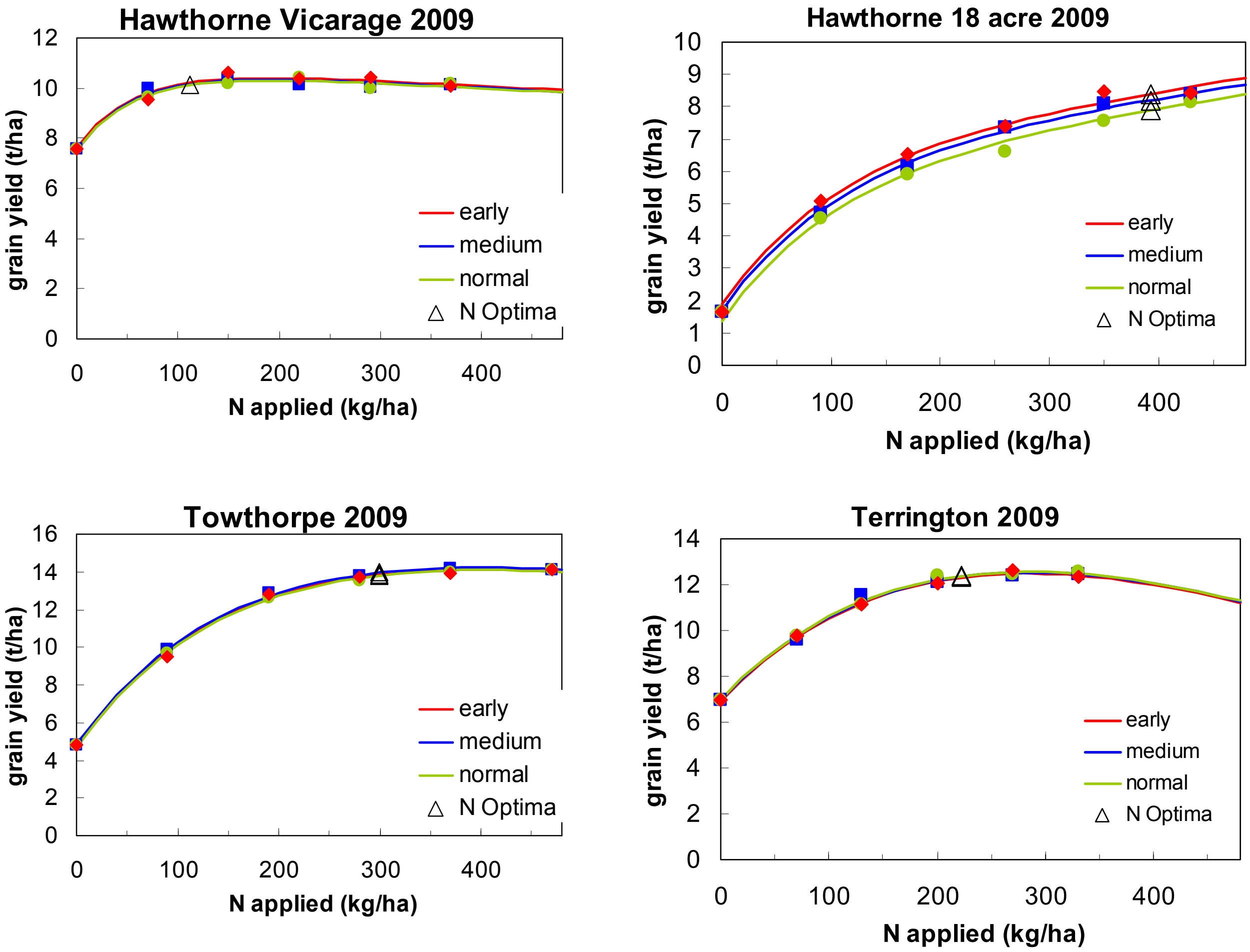

Figure 1: Grain yield response to applied nitrogen at three N timing strategies (early; medium early & normal) for each of the four trials; triangles show N optima for grain yield.

Timing of N application had no significant effect on grain yield except at the 18 acre field (p=0.051) where early N application had a substantial positive effect of 0.5t/ha yield over normal timing. This large yield effect in the second cereal position suggests large positive effects of early nitrogen on tillering and rooting ameliorating the effects of take-all disease.

Grain protein and alcohol yield.

Applying nitrogen increased grain protein levels at all sites from ~8% of dry matter (DM) or less to a maximum of around 12% DM at most sites, and 11% DM at Towthorpe (Figure 2). Across sites and N rates early N timing significantly ($p<0.001$) reduced grain protein content (10.3% early; 10.5% medium; 10.7% normal; SED 0.09% DM). Within sites, significant N timing effects were found at Towthorpe and 18 Acre ($p<0.001$) with a significant interaction between nitrogen rate and timing at 18 Acre ($p=0.002$) where early timing at very low N applications produced much lower protein.

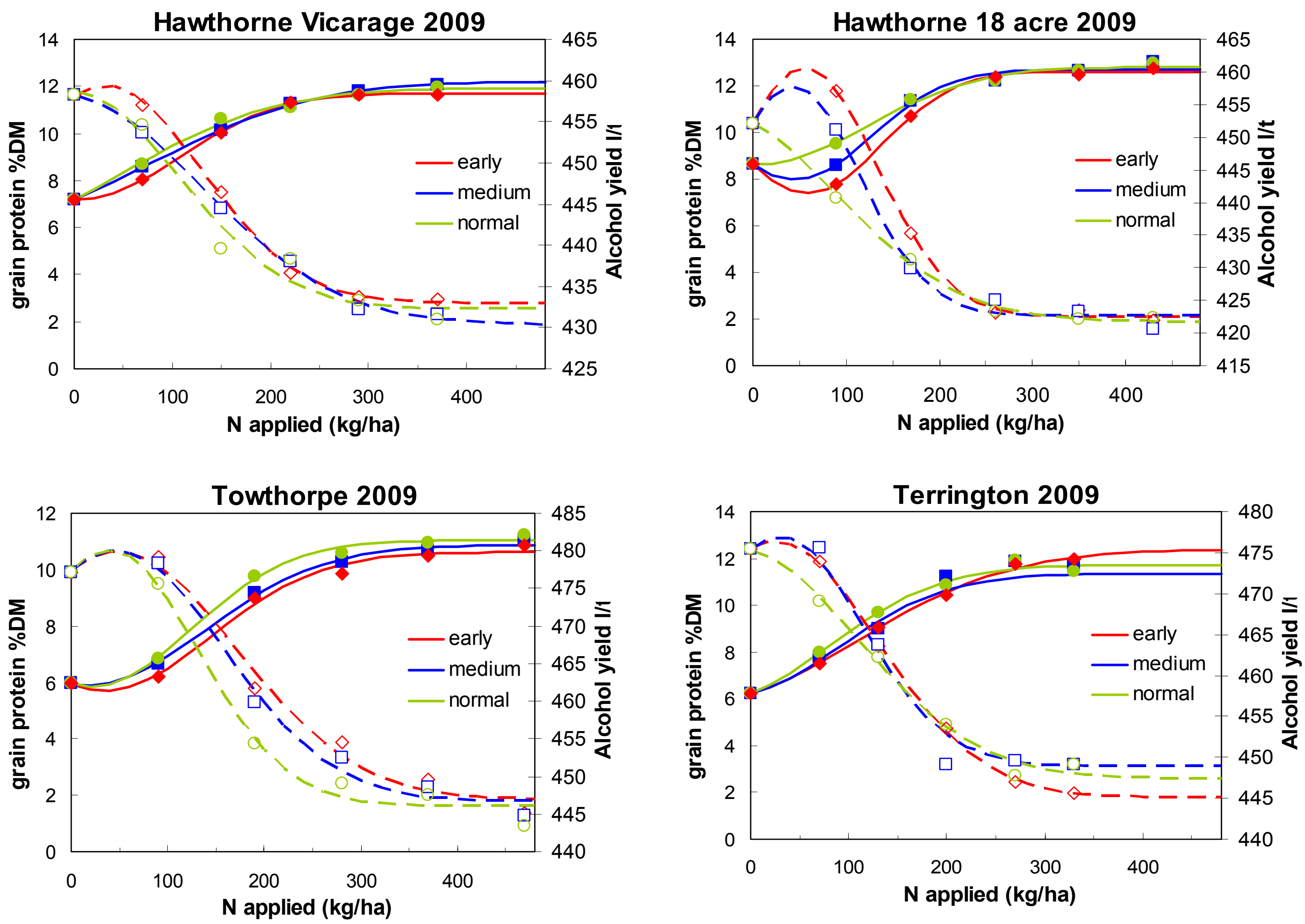

Figure 2: Grain protein (solid line; left axis) and Alcohol yield (broken line; right axis) response to applied nitrogen at three N timing strategies (early; medium early & normal) for each of the four trials.

At the economic optima grain protein was reduced by early N timing at all sites (Table 3), but most substantially at Vicarage and Towthorpe where protein was reduced by 0.6%DM.

Table 3. Grain protein at the N optima for different timing strategies at each site

N Timing	***18 acre***	***Vicarage***	***Towthorpe***	***Terrington***
Early	12.6	9.1	10.3	11.0
Medium	12.7	9.4	10.5	10.9
Normal	12.8	9.7	10.9	11.3

Alcohol yield (litres/ dry tonne) generally mirrored grain protein effects, though substantial differences were apparent between sites relative to differences in protein content, reducing with increasing N rate from 452 l/t to 422 l/t at 18 acre, 458 to 433 l/t at Vicarage, 477 l/t to 445 at Towthorpe and 475 to 449 l/t at Terrington, across sites averaging to a reduction from 437 l/t with nil-N applied to 466 l/t at the highest N rate ($P<0.001$). Across sites and N rates early N timing increased alcohol yield significantly ($p=0.002$) from 444.4l/t at 'normal' timing to 446.4 l/t at medium and 447.1 l/t with early timing (SED = 0.70). N timing also interacted with N rate ($p=0.042$), with differences in N timing being greatest at the lowest N rates. Within each site, significant differences between timings were only recorded at 18 acre ($p=0.012$) where there was also a significant interaction between N and timing (0.011). Alcohol yields at the optimum N rate at each site (Table 4 below), show that whilst N timing effects on alcohol yield at the optima are absent at 18 acre and Terrington, improvements in alcohol yield with early timing of over 4l/t were achieved at Vicarage and Towthorpe.

Table 4. Alcohol yields (l/t) at the N optima for different timing strategies at each site

N Timing	***18 acre***	***Vicarage***	***Towthorpe***	***Terrington***
early	422.6	451.9	451.1	450.5
medium	422.7	449.1	449.4	451.1
normal	421.9	447.5	446.7	451.9

Alcohol Yield (l/ha).

Figure 3 shows 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 and trebled at 18 acre.

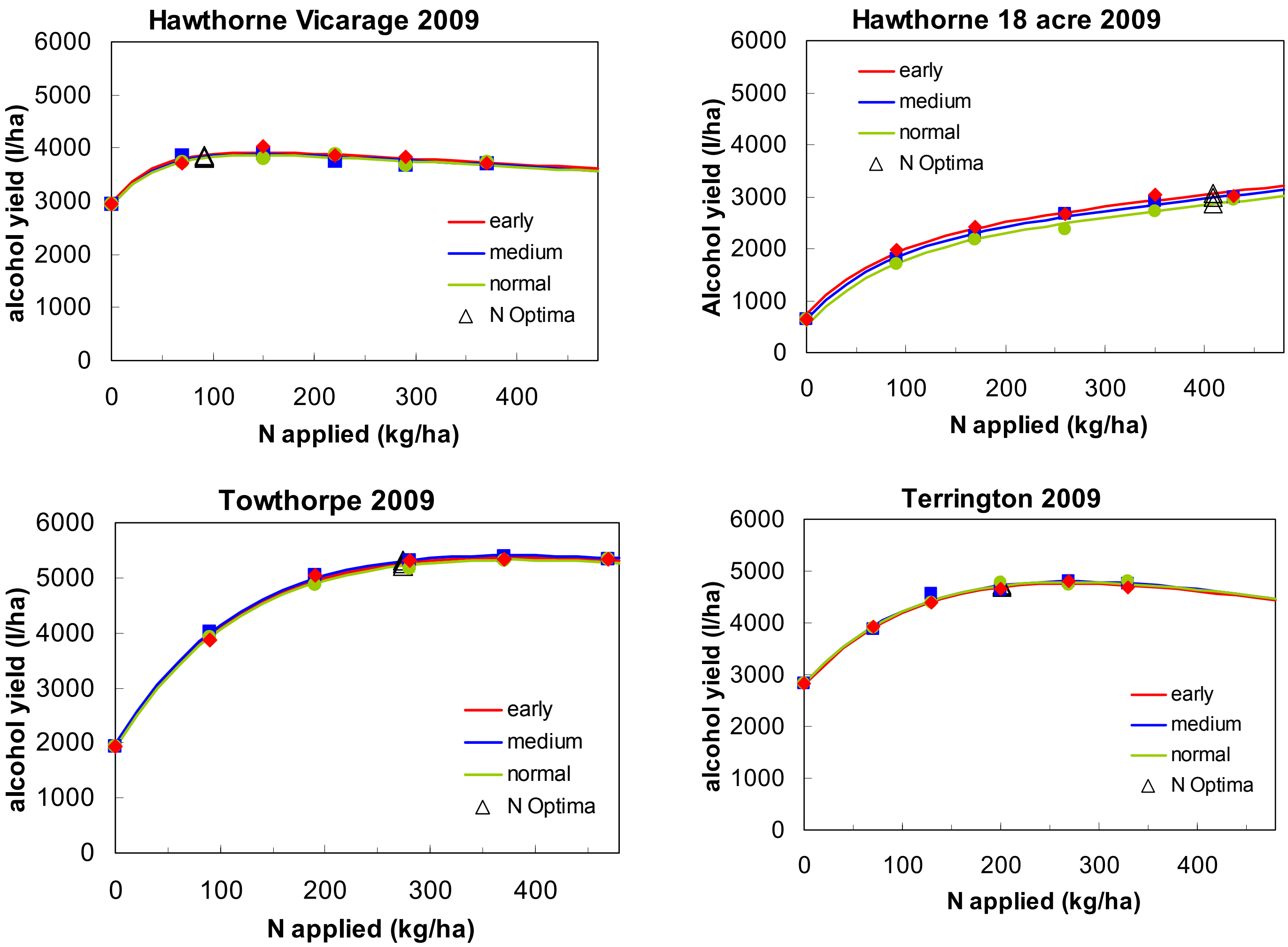

Figure 3: Alcohol yield (litres per hectare) response to applied nitrogen at three N timing strategies (early; medium early & normal) for each of the four trials. Triangles show N optima for grain yield.

The effect of N timing on alcohol yield per ha was only significant at 18 acre (p=0.044) where early timings produced greater alcohol yield, due to the greater grain yields with the earlier timings at this site. Across sites N timing did not significantly affect alcohol yield per ha (p=0.138).

N optima for alcohol yield per ha were between 4 and 18% lower than optima for grain yield (Table 5), within the range found previously (Kindred et al., 2007; Clarke et al., 2008) where a difference of around 12% has been reported on average. No significant effect of N timing on N optima for alcohol yield per ha was found.

Table 5. 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**
18 acre	393	379	4%
Vicarage	112	91	18%
Towthorpe	300	273	9%
Terrington	223	201	10%

Specific Weight.

There were large differences in specific weight between sites, and a general trend for specific weight to increase with N application. Specific weights were generally low in these experiments, reflecting the late establishment and backward nature of crops in the North East region in this season. The highest specific weights were on the fertile silts at Terrington (68.6 to 73.8 kg/hl with increasing N) and lowest on the shallow soil at Towthorpe (61.5, no significant N rate effects). Vicarage (65.7.01 to 67.6 kg/hl) and 18 acre (67.7 to 72.1 kg/hl) were intermediate. N timing only had a significant effect on specific weight at 18 acre (p=0.051), where early N application produced grain with a higher specific weight than medium and normal timings (Figure 4).

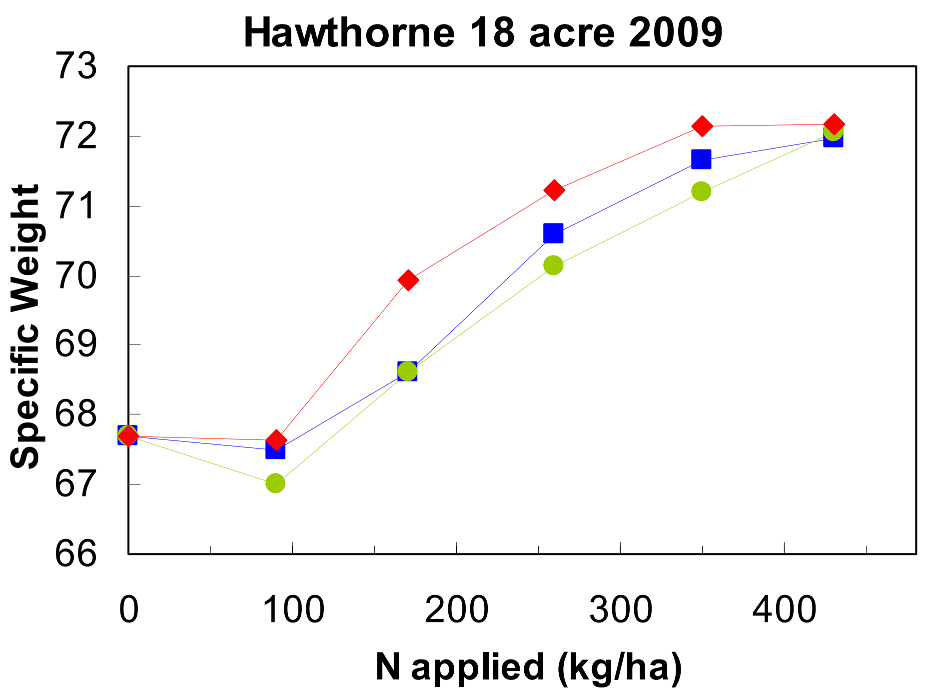

Figure 4: The effect of nitrogen applied at three N timing strategies (early; medium early & normal) on the specific weight of grain at the Hawthorne 18 acre site.

Conclusions

No evidence has been found from these experiments, or previous experiments (Sylvester-Bradley et al., 2008), that applying a larger proportion of nitrogen fertiliser early in spring damages yields or quality. Indeed, in the case of second wheats it seems that early N applications can actually benefit yield substantially, perhaps due to reduction in Take-all effects. This effect warrants further investigation.

Applying a greater proportion of nitrogen early in the season does seem to reduce grain protein and increase alcohol yields per tonne fairly consistently across sites. However, the magnitude of this effect is small compared to differences in alcohol yield seen between sites, varieties and N application rates. The increase in alcohol yield that may be expected from earlier N timing is around 3-4 litres per dry tonne wheat grain. Such a difference is unlikely to be worth much more than £1 per t to the bioethanol processor from increased revenues, especially when the negative effects on quantity of DDGS is accounted for. However, 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 around £1 million per annum. Before widespread advice could be given to growers to apply a greater proportion of N early, a greater evidence base is required. In particular it will be important to test the effects of early N timing in years when crops are larger and more developed in early spring, giving a greater risk of early N applications exacerbating lodging risk later in the year, potentially damaging yields & quality.

The experiments conducted at Hawthorns are useful in starting to build evidence for N optima in the North East region; very few N response experiments have been conducted in the North East in recent years. The very low SMN measured on 18 acre field (17kg N /ha), low unfertilised crop N uptake (30 kg N/ha) and exceedingly high N optima (393 kg N/ha) may lend some credence to the thought that N requirements in the North East are closer to the fertiliser recommendations generated in Scotland than those in England. However, the N optima at Vicarage field (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 nitrogen from this soil during spring, although soil measurement of potentially mineralisable N did not suggest a large amount of N would be mineralised.

Further N rate & N timing experiments should be considered in the North East to strengthen the evidence for advising growers on appropriate N strategies for bioethanol production. The cold and wet 2008/2009 autumn & winter meant crops were very backward in spring 2009; repeating the experiments in a more typical or ‘forward’ season where lodging risks are more likely would allow these conclusions to be more robustly tested. ADAS can use a validated method of calculating lodging risk from measurements of the crop which can be used to estimate the effects of N timing on lodging risk even when lodging doesn’t occur in the field. The large improvement in yield from early N application in the second cereal position warrants further investigation, as this could have significant implications for the growing of second wheats across the board, not just for bioethanol production.

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