

Project Report No. 438

Abstract and Summary

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Optimising fertiliser nitrogen for modern wheat and barley crops

by

R. Sylvester-Bradley¹, D.R. Kindred¹, J. Blake¹, C.J.Dyer¹
and A.H. Sinclair²

¹ADAS Boxworth, Cambridge, CB23 4NN

²SAC, Craibstone Estate, Aberdeen AB21 9YA

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1. Abstract

In each of the three harvest years 2005, 2006 and 2007 ten N response trials were conducted on winter wheat and five on spring barley. Trials were distributed from Kent to Aberdeenshire; each one tested two 'old' (new in the 1980s) and two 'new' (from 2000s) varieties at six N rates from nil to 166% of the amount recommended. For the determination of N optima, grain yields were related to N applied by fitting a linear plus exponential function for each variety and grain N% was described by the better fit of a 'normal with depletion' or a linear function. Mean grain yields with optimum N were 8.69 and 9.98 t/ha for old and new wheat varieties respectively, and they were 5.03 and 5.90 t/ha for old and new barley varieties. In each year and for each species 20% of the trials showed nil or a very small response to fertiliser N. At the other sites differences in N optima of wheat varieties related to their differences in grain yield, the slope being about +20 kg fertiliser N per tonne grain. However, the same did not apply to spring barley varieties for which better N Utilisation Efficiency completely compensated for their better grain yield. The yield response curves indicate that N optima decrease for each point increase in the break-even ratio (the price ratio of fertiliser N to grain) by 11 kg/ha for wheat and by 8 kg/ha for barley. Mean grain N (% DM) with optimum fertiliser N (break-even ratio 6:1) was the same for old and new wheat varieties at 1.98%, whilst it was 2.09% and 1.96% for old and new barley varieties respectively.

The 45 trials provided a test of current recommendations. To maximise average profit from feed grain production, current recommendations (RB209 7th edition published in 2000) had to be increased by 18 kg/ha N for modern wheat varieties and by at least 40 kg/ha N for modern barley varieties. The Field Assessment Method (FAM) used in the recommendations to predict soil N supply (SNS; 'true' values being estimated from grain N at harvest with nil N applied) did not perform satisfactorily either at wheat or barley sites, and recommendations based on the FAM gave no more average profit than use of a fixed N amount at all sites (185 kg/ha N for wheat and 162 kg/ha N for barley). Soil mineral N to 90 cm depth, corrected for over-winter leaching (SMN) was reasonably well related to soil N supply at the wheat sites ($R^2 = 0.52$), with SNS showing equivalence (at least) with estimated SMN amounts, and recommendations based on SMN improved average profit by the value of 15 kg/ha N at the wheat sites. SMN did not relate to SNS at the barley sites, and recommendations based on SMN only improved average profit by the value of 6 kg/ha N.

Results were inconclusive on whether early N applications improved alcohol production from wheat, because the test year (2007) provided inappropriate (dry spring and low-yielding) conditions.

The results have been used to inform the concurrent revision of RB209.

2. Summary

2.1 Project objectives

The aim of the project was ‘To provide evidence of the extent to which optimum amounts of fertiliser N for new, high-yielding varieties of winter wheat and spring barley differ from those for the lower yielding varieties used in the 1980s to develop national fertiliser recommendations (e.g. in RB209)’.

In an extension to the project, an additional objective was set in autumn 2006: ‘To show whether early N timing can increase the efficiency of alcohol production from UK wheat crops’.

2.2 Background

Most of the UK’s arable area is now within Nitrate Vulnerable Zones (NVZs). Defra’s fertiliser recommendations (RB209) and the Scottish equivalent are the ‘standards’ by which N levels are set within NVZs. Cereal growers and the wider cereal industry therefore have a close concern that fertiliser recommendations are based on the best evidence about how financial returns can be optimised.

Most of the data used to develop the current recommendations were collected in the ‘80s, for instance the main wheat varieties were Hustler, Galahad, Avalon, Longbow and Norman, and the main barley varieties were Triumph & Atem. Since then, there has been a complete change in varieties being widely grown and yields of wheat and barley have increased by 2.0 and 1.4 t/ha respectively (Defra statistics). It follows that crop N demand is likely to have increased by 30-50 kg/ha and, unless N Use Efficiency has improved, and it follows that fertiliser N requirements may have increased by 50-80 kg/ha.

The latest (7th) edition of RB209 was dated 2000 (and 2002 in Scotland); both documents have been in the process of revision through the last two years of the work reported here. In anticipating this revision it was recognised that a large increase in N fertiliser requirements was unlikely to be sanctioned without direct evidence.

As well as new varieties, husbandry changes are also likely to have affected N requirements in recent years, for instance, there have been reductions in seed rates, greater use of minimal tillage, and significant changes in the fungicides used. It will be important to assess N requirements of new varieties under the conditions in which they are now commonly grown.

For the major crops N levels in national fertiliser recommendations are generally set according to optima determined from simple response experiments: with five or more N levels, including nil. HGCA research on N in the 1990s generally studied integration of nitrogen with other inputs and issues concerned with N timing, and it was only in recent years that HGCA research strategies deemed work on N responses as a high priority. Thus there was little direct evidence available on N optima of modern varieties of the main cereal

crops (wheat winter and spring barley) before this work began. HGCA funded 9 site-seasons of work on group 1 & 2 varieties of winter wheat (HGCA Projects 2579 & 2700; Dampney *et al.*, 2006), but neither of these projects provided sufficient evidence of optimum N requirements for revision of national fertiliser recommendations.

N response experiments are of significant industry-interest, and can be conducted easily. A multiple site approach was therefore adopted. However, interpretation requires careful statistical analysis using curve fitting to determine differences in optimum amounts between varieties, and to examine other aspects of current fertiliser recommendations, for example:

- Assessment of soil N supplies by look-up tables or by direct soil measurement
- Apparent equivalence between soil mineral N and subsequent N capture by unfertilised crops
- Equivalence of soil N and fertiliser N
- Effects of soil type on fertiliser N recovery
- Associations between maximum yields and optimum N amounts
- Associations between grain N concentrations and optimum N amounts
- Dependence of optimum N amounts on grain and fertiliser prices
- Implications for profit and for N residues of inaccuracy and imprecision in fertiliser recommendations.

2.3 Experiments and Data Processing

In each of the three harvest years 2005, 2006 and 2007 ten N response trials were conducted on winter wheat and five on spring barley. Trials were after a range of previous crops and on a range of soils distributed from Kent to Aberdeenshire (Fig. 2.1); each tested two ‘old’ (new in the 1980s) and two ‘new’ (from 2000s) varieties (Table 2.1) at six N rates from nil to 167% of the amount recommended. Total N amounts were split between three applications with ~20% applied early (in March) and the rest split equally between two applications around GS31. In the 3rd year additional N timing treatments of 50% early and 33% early were used to test whether this increased alcohol yield.

Soil mineral N was determined at each site over-winter for wheat and in spring for barley. For the determination of N optima, grain yields were related to N applied by fitting a linear plus exponential function (LEXP) for each variety and grain N% was described by the better fit of a Normal Type curve with Depletion (NTD) or a linear (LIN) function, each specified as follows:

$$\text{LEXP:} \quad Y = a + b.r^N + c.N$$

$$\text{NTD:} \quad G = d + c.\exp(-\exp(-a.(N - b)))$$

$$\text{LIN:} \quad G = a + b.r^N + c.N$$

where Y is yield in t/ha at 85%DM, G is grain N% at 100%DM, N is total fertiliser N applied in kg/ha, and a , b , c , d and r are parameters determined by statistical fitting. N optima (Nopts) were expressed at a N:grain break-even price ratio (BER) of 3:1 for consistency with previous work, except when examining price effects directly.

Differences within sites between N optima of varieties were related to differences between grain yields of varieties. Site data were collated to allow determination of N recommendations at each site. The economic performance of these recommendations was determined by calculating the unrealised profit – the profit lost due to the recommended N rate differing from the N optimum.

Fig. 2.1. Distribution of N response trial sites for wheat (green) and barley (brown) in England & Scotland.

SAC Aberdeen AB, SAC Laurenckirk AK, SAC Forgandenny SF, ADAS High Mowthorpe HM, NDSM York YO, Farmacy Edlington FE, Univ. Nottingham Sutton Bonington SB, Agrovista Stoughton ST, ADAS Rosemaund RM, ADAS Boxworth BW, ADAS Terrington TT, Masstock Fowlmere FM, Masstock Stebbing / Barnston MS, ADAS Kent KE.

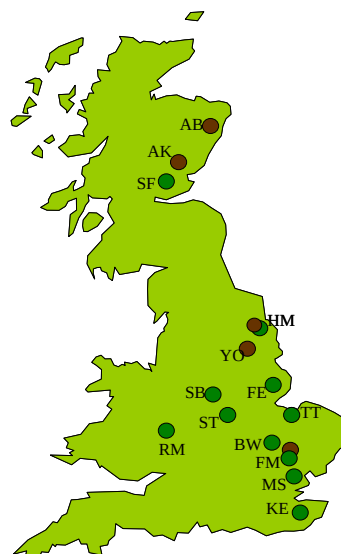


Table 2.1 Varieties used in N response trials from 2005 to 2007, with the number of times each was included.

<i>Variety type</i>	<i>Wheat</i>	<i>Barley</i>
Old	Riband 10, Slejpner 4, Norman 7, Longbow 8, Avalon 6, Virtue 7, Hustler 9, Hobbit 9.	Triumph 12, Atem 13, Golden Promise 5.
New	Oakley 4, Glasgow 4, Ambrosia 8, Alchemy 8, Istabraq 8, Gladiator 8, Dixon 4, Deben 4, Robigus 12.	Waggon 3, Tocada 2, Publican 3, Doyen 7, Cocktail 6, Spire 2, Westminster 4, Troon 3.

2.4 Results and Conclusions

The growing seasons of 2005 and 2006 had warm weather conditions but with radiation receipts similar to the long term produced good yields (means of new wheat varieties were 10.7 and 10.9 t/ha respectively); 2007 had a dry spring and a dull wet summer, resulting in lower yields (mean 8.7 t/ha).

2.4.1 Winter Wheat

The range of soil N supplies (SNS) estimated by soil mineral N (SMN) was 50-211 kg/ha to 90 cm depth and related better to total topsoil N% than to previous cropping. These estimates, corrected where appropriate for over-winter leaching, related reasonably well ($R^2=0.52$) to crop N offtake with nil N applied i.e. they provided a useful prediction of crop capture of soil-derived N.

There were no consistent differences in yields between sites used in more than one season. Overall, old varieties yielded 87% of new varieties and the mean response to N was 2.9 t/ha, but responses ranged from 0.2 t/ha to 6.7 t/ha. Lodging occurred at six of the thirty trials, predominantly at high N rates and with the old varieties. About two out of the ten trials in each year showed only slight response to applied N and did not offer a test of differences in responsiveness of varieties. Responses at the other sites were related to SNS (Fig. 2.3) but not to site yield (Fig. 2.2), except lower Nopts were associated with the lower yields in 2007.

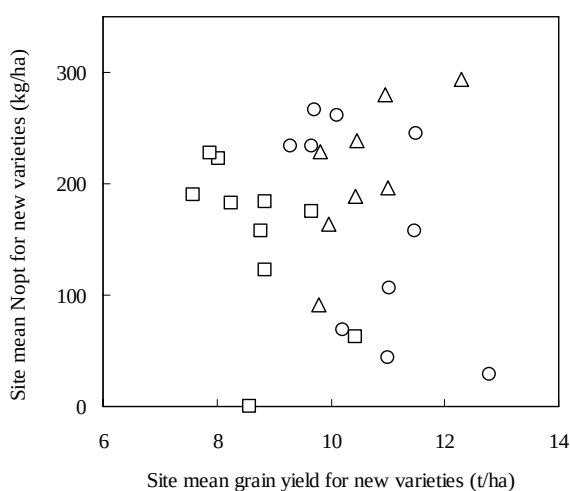


Fig. 2.2. Relationship between mean Nopt at a site and mean grain yield at the same site for wheat trials harvested in 2005 (circles), 2006 (triangles) and 2007 (squares).

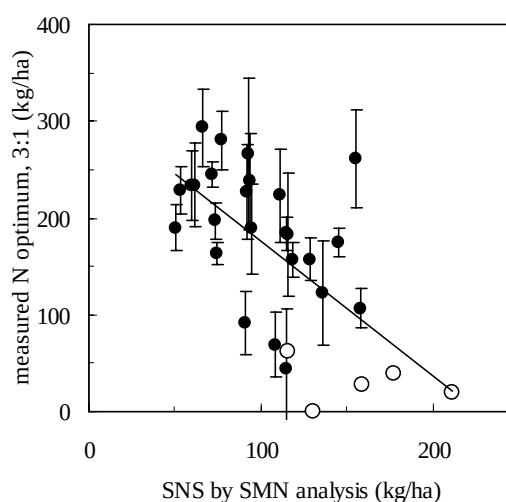


Fig. 2.3. Relationship between mean Nopt at BER 3:1 for modern varieties and SNS determined by soil analysis for SMN over-winter (uncorrected for leaching) for all 30 wheat site-seasons tested in this Project. Open circles indicate sites where the LEXP function did not fit. The fitted line is $y = 314 - 1.39x$; $R^2 = 0.40^{***}$.

However, there was a clearer and more consistent association between the Nopt of different varieties within a site and their differences in grain yield (Fig. 2.4). The slope of this relationship was about 20 kg N per tonne grain yield. It is deduced that, since the extra fertiliser N expected to be needed to support 1 tonne of extra productivity is ~38 kg, breeders have not only increased grain yield of modern wheat varieties but they have also increased N Use Efficiency. Analysis of grain N data confirmed that recovery of applied N was 48% for

new varieties compared to 44% for old varieties. However, there was no change in grain N% at Nopt, indicating that there had been no concurrent improvement in N Utilisation Efficiency.

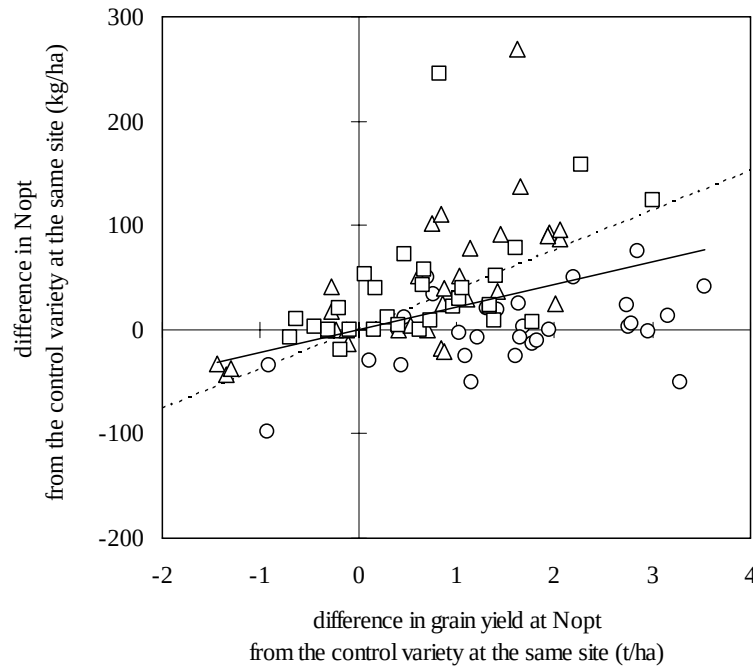


Fig. 2.4. Relationship between the effect of variety on Nopt at a site and the effect of variety on grain yield at the same site for wheat trials in 2005 (circles), 2006 (triangles) and 2007 (squares). R^2 was 0.09**. The slope of the relationship is 21.5 kg fertiliser N per tonne grain yield difference. The dotted line shows a slope of 38 kg/t, as expected if the N Use Efficiency of new varieties were no better than old varieties.

Average RB209 recommendations based on the 7th edition (2000) were ~20 kg/ha less than average Nopts for modern varieties. In keeping with the poor performance of the FAM in predicting uptake of soil-derived N, N recommendations based on the FAM showed no improvement in economic performance compared to applying a fixed N rate at each site. However, economic performance of N recommendations based on SMN analysis was reasonable, saving the value of 15 kg/ha N compared to applying a fixed N rate at each site.

A comparison of the shape of the response curves showed reasonable consistency between varieties and sites, hence a single rate of adjustment seemed appropriate to accommodate price variations. This was to reduce amounts of applied N by 11 kg/ha for each point change in BER (e.g. from 4:1 to 5:1).

There was confirmation that grain N concentrations at Nopt are relatively stable (Fig. 2.5), and that as a consequence, assuming an average is taken over several fields and seasons, they offer a means of monitoring

how closely on-farm N use matches economic N requirements. Grain N at 2% would seem to indicate N use similar to Nopt at BER 6:1.

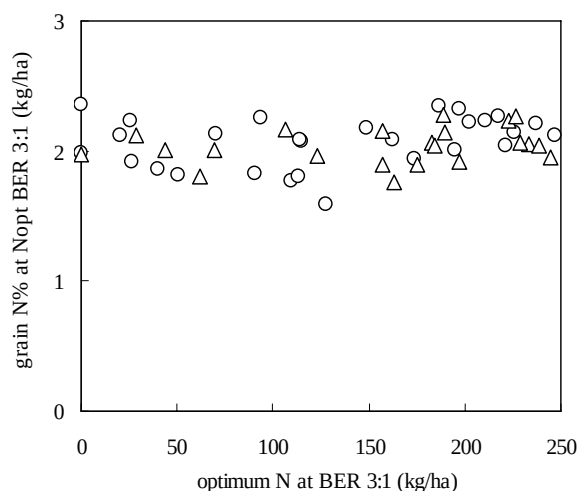


Fig. 2.5. Grain N (% DM) for old (circles) and new (triangles) varieties of wheat in 28 site-seasons.

The dry spring and low yielding conditions in 2007 proved unsatisfactory for testing whether early N applications would increase alcohol production, and it is concluded that this work should be repeated.

2.4.2 Spring Barley

SNS assessed by soil analysis varied from 23 to 224 kg/ha for the spring barley sites, and as for the wheat sites the variation related better to total topsoil N% than to previous cropping. However, no predictor of SNS accounted for a significant amount of variation in N offtake at harvest with nil N applied.

There was a wide range of soil types and previous crops represented in the sites. Those in Scotland gave largest yields and a site at York gave consistently low yields. There was an association between these yields and Nopt, however there were insufficient sites to test whether farm yield would provide a useful component of Nopt prediction.

In contrast to results for wheat, there was no evidence for a relationship between the yield differences between varieties (within a site) and differences between varieties in Nopt, despite yield differences within a site being up to 2 t/ha (Fig. 2.6).

The 'average' response curve determined for barley in the same way that it was for wheat proved to be rather 'sharper' in shape than the wheat curves. Thus the average adjustment for one unit change in BER was a little less than for wheat at 8 kg/ha fertiliser N.

Grain N% at Nopt increased a little as Nopt increased, suggesting further investigation is required before it can be recommended as a good indicator of optimal N use. Grain N% at Nopt also differed significantly

between old and new barley varieties at 2.09% and 1.96% respectively, indicating that as barley breeders had improved grain yields they had also improved N Utilisation Efficiency. Grain N% of new malting varieties at Nopt was highly variable (range 1.7 to 2.3%) so a reduction of at least 80 kg/ha from Nopt would have been required to ensure that most crops had grain N less than 1.75%.

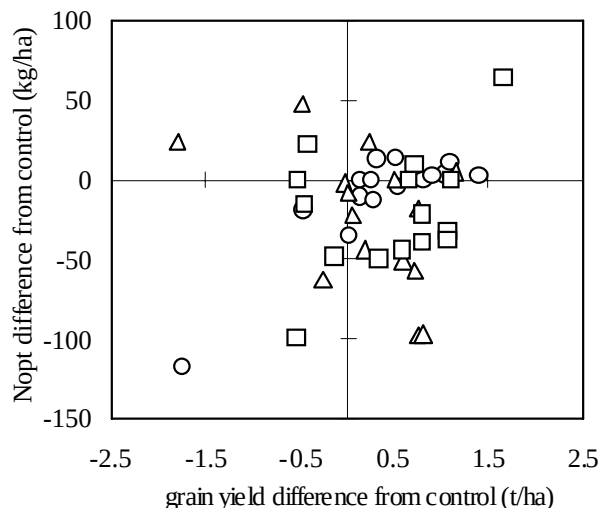


Fig. 2.6 Differences from a control variety in N optimum (BER 3:1) in relation to differences in grain yield at Nopt for spring barley varieties tested in 15 site-seasons: 2005 (circles), 2006 (triangles) and 2007 (squares). $R^2 = 0.04$.

Economic performance of RB209 recommendations indicated that increases of 40 kg/ha N (if based on FAM) or 66 kg/ha N (if based on SMN) to about 165 kg/ha would be required to maximise profit (BER 3:1). However careful judgement would be required to optimise N recommendations according to economic conditions i.e. fertiliser and grain prices and premiums available through the malting market. Overall, there was little difference in the economic performance of N recommendations based on FAM, SMN or a fixed rate.

2.5 Recommendations

Suggestions for further research are as follows:

- There is much scope for further improvements in N Use Efficiency of both wheat and barley. These will depend on a better understanding of the genetical and physiological basis of recent improvements. In support of NUE improvement, it is likely that a sub-set of RL trials should be conducted with more than one N rate. Data from this project could be used to explore how such trials should be designed, how they should be interpreted, and what costs there might be for the testing programme and what the economic implications might be for the industry as a whole.

- A comparison of NUE of different cereal species could provide a key to best strategies for NUE improvement. Breeding was shown here to have improved NUE in wheat and barley by different mechanisms, whilst oats and triticale have reputations for high NUE particularly through high N capture. Routes to better NUE may well be revealed by direct comparisons of species, with thorough monitoring.
- The most widely used method of judging soil N supplies – the Field Assessment Method – has been shown to perform very poorly in this work. The current HGCA project RD-2007-3425 ‘Establishing best practice for predicting SNS’ will be very important in improving and promoting the use of SMN analysis.
- Since SMN is being determined under HGCA project RD-2007-3425 both in autumn and spring it will be important that the need for and the best method for interpreting these is resolved.
- Given the imprecision of N recommendations, over-fertilisation is inevitable in some cases, and may cause lodging. It will be important for yield-maximisation to know whether this can be prevented, and how.
- The work in 2007 on optimum N timing for alcohol production was inconclusive and needs to be continued in further seasons. Indeed there is general uncertainty in the industry about optimum N timing for modern cereal varieties.
- Data from this project provide an opportunity to deduce general rules on optimising N for alcohol production and to mitigate greenhouse gas emissions from cereal production.
- Given the high prices of ammonium nitrate and other conventional N fertilisers, the industry needs a comparison for N products including various alternative sources of N such as calcium cyanamide, TwinN, calcium ammonium nitrate, and various inhibitors of urease and nitrification.
- Conclusions need to be drawn on any compromise between environmental and economic repercussions of N fertiliser use. To achieve this it will be important that these data are combined with data collected under Defra funding on the N residues after a sub-set of these sites.
- Use of grain N% to monitor on-farm optimal N use has been partially supported by evidence from this project but it will be important in current HGCA Project RD-2007-3436 ‘Using grain N % as a signature for Good N Use’ to examine whether particular effects found here can also be found in the wider dataset now being collated. These include the effect of rotation on grain N% in wheat, the increase in grain N% in barley with increasing N_{opt} , and the effect of breeding on grain N% in barley.