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Optimising fertiliser nitrogen for modern wheat and barley crops

by

R. Sylvester-Bradley[1], D.R. Kindred[1], J. Blake[1], C.J.Dyer[1]
and A.H. Sinclair[2]

[1]ADAS Boxworth, Cambridge, CB23 4NN
[2]SAC, Craibstone Estate, Aberdeen AB21 9YA

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Contents

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:

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

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

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

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.

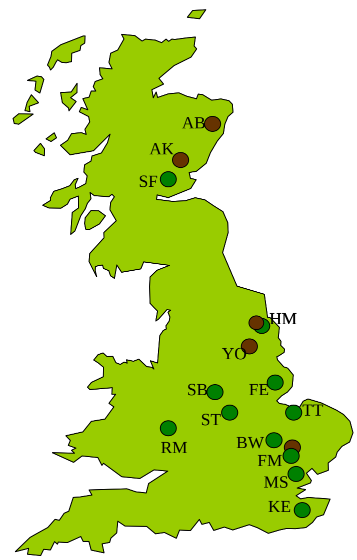

Table 2.1 Varieties used in N response trials from 2005 to 2007, with the number of times each was included.

Variety type	*Wheat*	*Barley*
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.

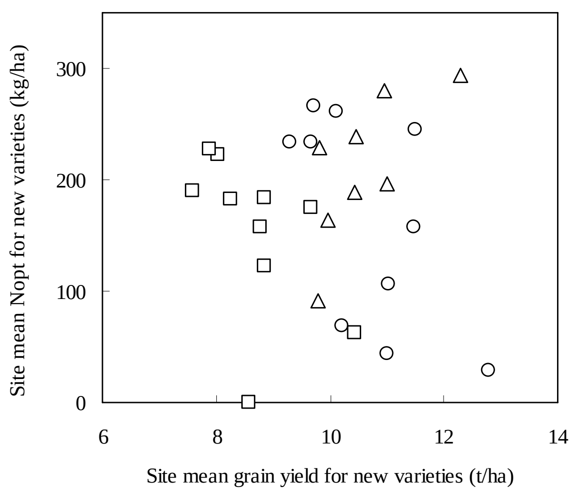

Fig. 2.2. Relationship between mean Nopt at a site and mean grain yield at the same site for wheat trials harvested in 2005 (circles), 2006 (triangles) and 2007 (squares).

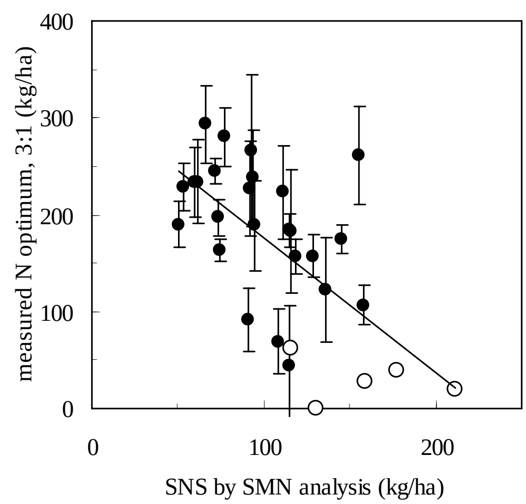

Fig. 2.3. Relationship between mean Nopt at BER 3:1 for modern varieties and SNS determined by soil analysis for SMN over-winter (uncorrected for leaching) for all 30 wheat site-seasons tested in this Project. Open circles indicate sites where the LEXP function did not fit. The fitted line is $y = 314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

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.

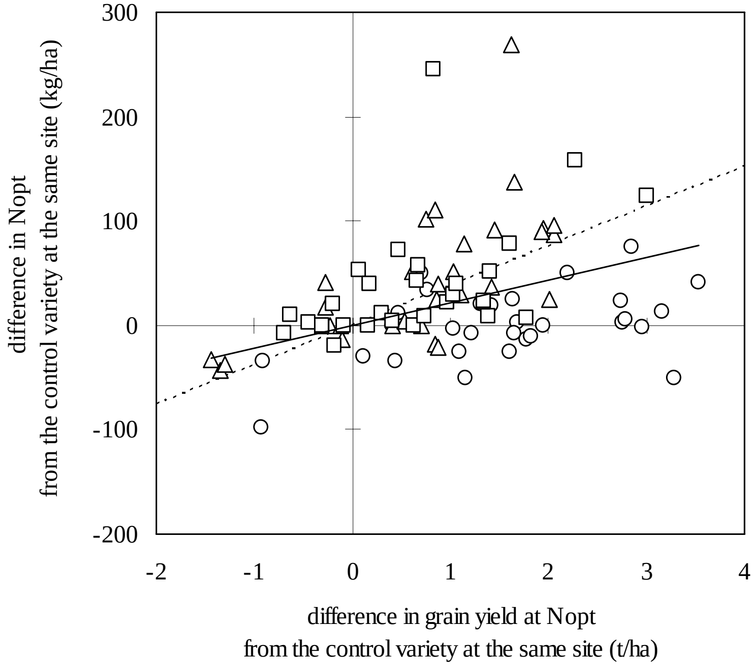

Fig. 2.4. Relationship between the effect of variety on Nopt at a site and the effect of variety on grain yield at the same site for wheat trials in 2005 (circles), 2006 (triangles) and 2007 (squares). R^2 was 0.09**. The slope of the relationship is 21.5 kg fertiliser N per tonne grain yield difference. 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.

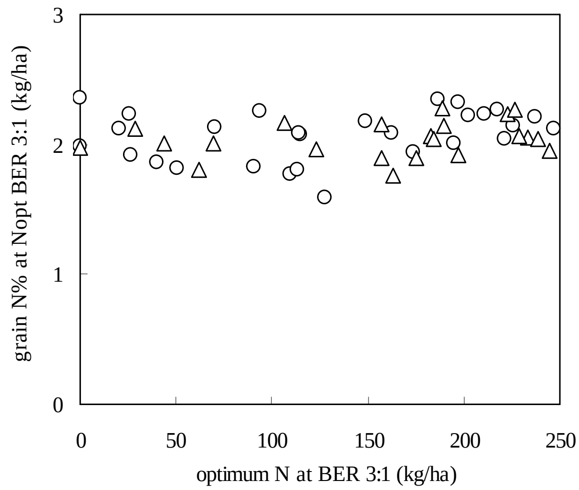

Fig. 2.5. Grain N (% DM) for old (circles) and new (triangles) varieties of wheat in 28 site-seasons.

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%.

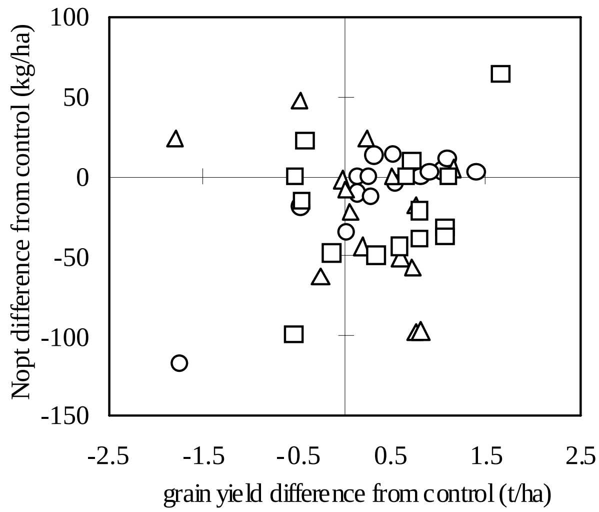

Fig. 2.6 Differences from a control variety in N optimum (BER 3:1) in relation to differences in grain yield at Nopt for spring barley varieties tested in 15 site-seasons: 2005 (circles), 2006 (triangles) and 2007 (squares). $R^2 = 0.04$.

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 Nopt, and the effect of breeding on grain N% in barley.

3. Project objectives and background

3.1 Project objectives

The overall 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).'

Specific objectives (including the project extension – 4.) were:

1. To set up a series of N response experiments in typical conditions (soils & locations) for winter wheat and spring barley.
2. To establish amounts of N fertiliser as the main treatment difference in experiments on winter wheat and spring barley.
3. To fit parallel response curves to yield and grain N data from N response experiments on winter wheat and spring barley, and interpret the significant effects.
4. To show whether early N timing can increase the efficiency of alcohol production from UK wheat crops.

3.2 Background

Nitrogen is commonly regarded as one of the most important inputs for profitable cereal production, the use of N fertiliser typically doubling grain yields of winter wheat (Webb *et al.,* 1998a) and barley (Withers & Dyer, 1990). However, adverse environmental impacts from nitrogen through nitrate leaching, ammonification and nitrous oxide emissions, together with the high financial price of N fertilisers mean that growers should seek to apply the economic optimum rate of fertiliser and not exceed it. Most of the UK's arable area is now within Nitrate Vulnerable Zones (NVZs), whereby restrictions on farm practice apply to minimise risks of nitrate leaching into water courses. 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.

The N requirement of an individual crop is defined as the rate of N fertiliser giving the optimum yield, that is, the point at which the cost of additional nitrogen equals the increased value of grain yield. The requirement depends upon the N available from the soil (dependent on soil type and previous management), the efficiency with which fertiliser N is taken up by the crop (largely dependent on soil type), the shape of the response curve (may be dependent on variety & yield), and the economics of grain price to fertiliser price. Standard nitrogen recommendations (i.e. RB209) are based on data from N response experiments that were largely carried out in the 1980s. However, cereal varieties, management practices and grain yields have changed considerably since then, casting doubt on the relevance of these recommendations for modern cereal crops. For instance, the main wheat varieties in the 1980's 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, yields of wheat and barley have increased by 2.0 and 1.4 t/ha respectively (Defra statistics), but grain N contents have not changed significantly (HGCA Cereal Quality Survey). It follows that crop N demand is likely to have increased by 30-50 kg/ha, and unless N Use Efficiency has improved, it follows that fertiliser N requirements will 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 strategies classed N work 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.

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- Assessment of soil N supplies by look-up tables and by direct soil measurement
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- 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 imprecision in fertiliser recommendations.

There are several important issues and developments that provide the background to this project. These are summarised below, then described in more detail.

1. The price of fertiliser N has increased substantially in recent years due to increasing energy prices. Future prices may increase further. This represents a significant pressure to optimise N use, but also alters the 'breakeven ratio' (kg grain to pay for a kg of N) that is used to define the economic optimum N rate.
2. Nitrate Vulnerable Zones (NVZ) have been designated across large parts of the UK arable area. For land inside an NVZ farmers must comply with the NVZ Action Programme (NVZ-AP) rules (Defra 2002; SEERAD, 2003). Complying with the NVZ-AP rules is a cross compliance Statutory Management Requirement (SMR), and failure to comply can result in a reduction in the Single Farm Payment (SFP). The NVZ-AP rules are being revised, but the current rules require farmers to justify their fertiliser N use for each crop.
3. The recommendations contained in Defra's 'Fertiliser Recommendations (RB209)' (Anon 2000) publication are the recognised industry standard, and are used by the Environment Agency (EA) as the preferred basis for judging compliance of field-level N use with the current NVZ-AP rules in England and Wales. It is important therefore, that these recommendations are maintained fully up to date and relevant to modern growing conditions. The current RB209 recommendations for N use on wheat are based on over 280 experiments, but are now being questioned since these experiments were mostly carried out between 1981 and 1994, and on varieties with a significantly lower yield potential than modern varieties.
4. The emergence of a biofuels market for wheat has large consequences for N fertiliser management. Optimal N strategies are likely to differ considerably for wheat grown for bioethanol than for traditional feed, biscuit or bread-making markets. This is because biofuel processing yields are inversely related to grain protein content (Smith *et al.*, 2006; Kindred *et al.*, 2007a) meaning lower protein grain gives higher alcohol yields per t. In addition, the requirement for 'carbon reporting' of biofuels (RFA, 2008) is likely to place greater emphasis on minimising GHG emissions per t grain; as N fertiliser accounts for up to 80% of the GHG costs of growing wheat there are likely to be pressures to reduce its use (Sylvester-Bradley & Kindred, 2008). HGCA Project 3335 (Kindred *et al.*, 2007b) has already used data collected in the first two years of this project to make initial assessments over how N rates should be adjusted to optimise alcohol yields per ha and greenhouse gas savings. As well as by reducing N rates it may

possible to reduce grain protein (and hence increase alcohol yields) by applying N fertiliser earlier in the season. An extension to this project was approved by HGCA to test this on a subset of sites in the final year of the project.

3.2.1 Trends in wheat production and nitrogen use

National trends in wheat production and nitrogen fertiliser use have been well described by Dampney *et al.* (2007), but the trends are briefly summarised here.

3.2.1.1 Wheat production and markets

Approximately 1.9m ha of wheat is drilled each year in the UK, producing around 15mt of grain. About 70% of the wheat area is sown to non-milling varieties (Fig. 3.1). The majority of these are NABIM Group 3 rather than Group 4 varieties, but there are fewer Group 3 varieties recommended (Table 3.1).

Table 3.1 Winter wheat varieties in NABIM Groups 3 and 4 (from RL for 2007). Varieties in italics were used in the experiments in this project.

Group 3	Zebedee, *Deben, Robigus,* Nijinsky, Claire, Consort, *Riband.*
Group 4	*Glasgow, Oakley,* Humber, *Ambrosia, Istabraq,* Brompton, *Alchemy, Gladiator,* Timber, Napier, Hyperion, Welford, Access, Richmond, Gatsby.

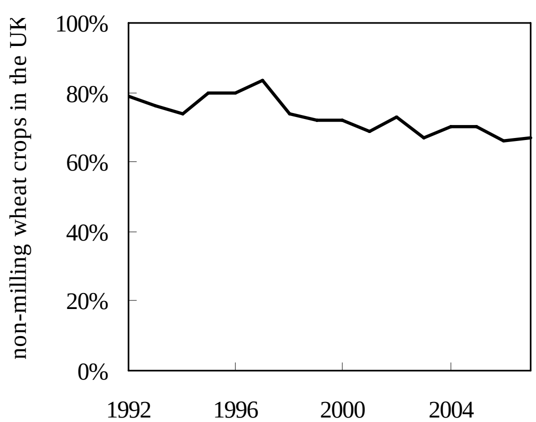


Fig. 3.1 Proportion of 'non milling' wheat crop grown in the UK (BSFP).

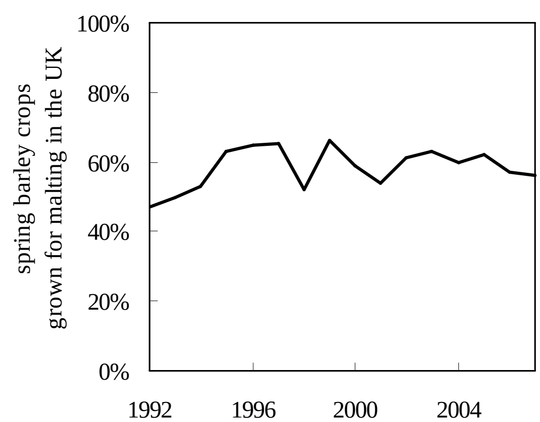


Fig. 3.2 Proportion of spring barley crops grown for malting in the UK (BSFP).

The area of barley grown in the UK has declined, mostly due to less winter crop so the area of spring barley at 0.6 Mha now exceeds that of the winter crop. The majority of this is sown to varieties suitable for malting (Fig. 3.2).

3.2.1.2 Increasing grain yields

Due to varietal improvements and better crop management wheat grain yields have increased since the 1980s. Increases in grain yield of approximately 1% per year were made until the 1990s; there is less evidence of subsequent increases, perhaps because reductions in fixed farm costs have impacted on the quality of crop management. As far as modern winter wheat varieties are concerned it certainly seems that they have a significantly higher yield potential than older varieties as illustrated by changes in the average yield of varieties in Recommended List (RL) experiments (Fig. 3.5), and it is possible that under-use of fertiliser N has been partly responsible for the lack of yield improvement on-farms whilst the genetic potential continued to increase. Overall, since the 1980s, the average national wheat yield has increased from around 6 t/ha to around 8t/ha, and the average yield of feed varieties from the RL experiments has increased from 6.5-8.5t/ha in the 1980s, to around 10 t/ha in the early 2000s.

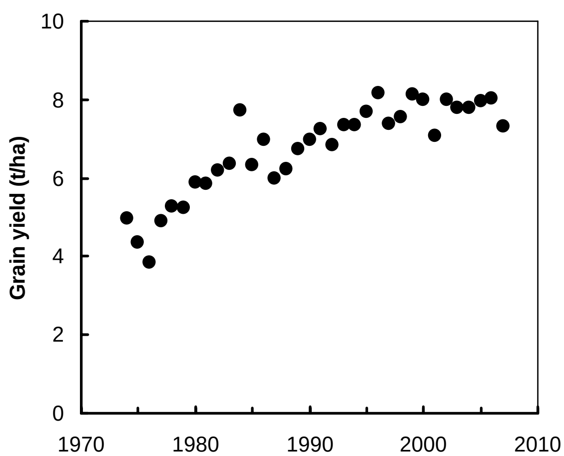


Fig. 3.4 Trend in average annual wheat yields (all varieties)

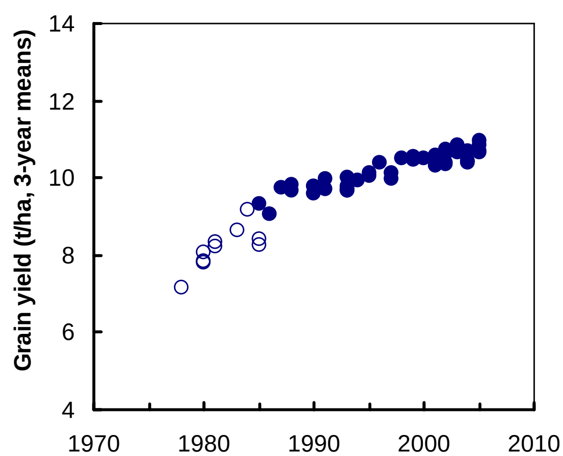


Fig. 3.5 Trend in grain yields of new feed wheat varieties on the Recommended List. (open symbols for varieties tested without fungicides).

3.2.1.3 Grain N concentrations

Most of the N taken up by cereals is transferred to the grain before harvest. Thus grain N concentrations largely reflect the balance between the N supply (from the soil, organic manures and fertiliser) and grain yield. At a fixed N supply higher yields tend to dilute grain N, and grain N concentration falls. Data from the annual HGCA Cereal Quality Survey (Figure 3.7a) show significant year to year variation in protein levels along these lines (high yielding years tend to be low protein years (Figure 3.7b). However, although a decrease would be expected (because average grain yields have increased whilst fertiliser N applications have remained constant since 1983) there is no clear indication of a trend towards lower protein contents in recent years.

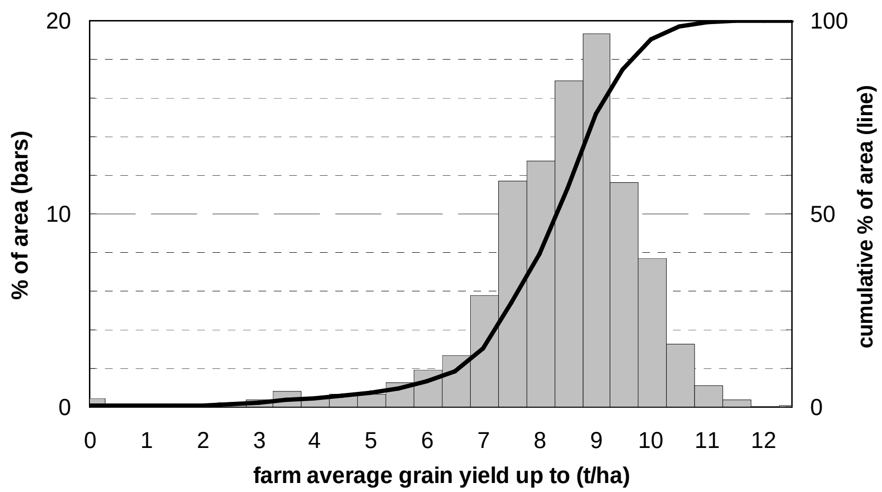


Figure 3.6 Distribution of farm-average yields in 2005

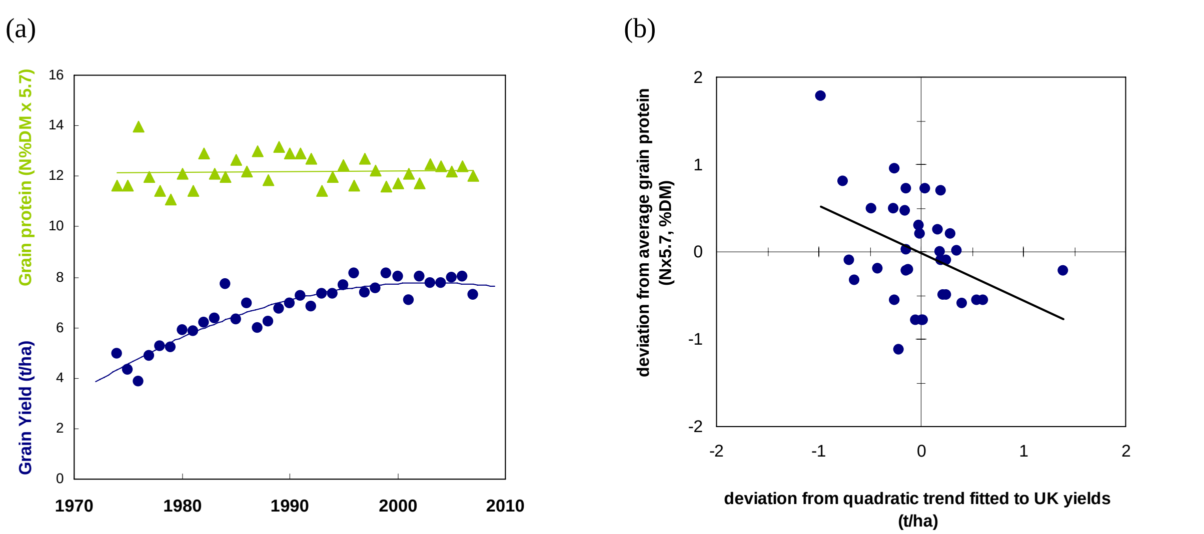


Figure 3.7 (a) Trends and (b) seasonal variation in grain yield (from Defra statistics) and grain protein content (N% x 5.7 from the HGCA Cereal Quality Survey) for winter wheat in the UK.

3.2.1.4 Increasing offtake of crop N in wheat

The national trend for the offtake of N in grain can be calculated from data for the annual average yield and grain protein content (Figure 3.8). This has increased from a mean of 118kg/ha (1980-1989) to 136kg/ha (1990-1999) and 140kg/ha (2000-2005). Assuming a constant value of 75% for the nitrogen harvest index (NHI, the proportion of total above-ground crop that is harvested), the equivalent figures for N in the total above ground crop (grain and straw) would be 157, 181 and 187kg/ha – an increase of 30kg/ha (19%) between the 1980s and early 2000s. In theory, based on a 60% recovery of fertiliser N, 50kg/ha of extra fertiliser N would be needed to meet this higher requirement for the total above ground crop N.

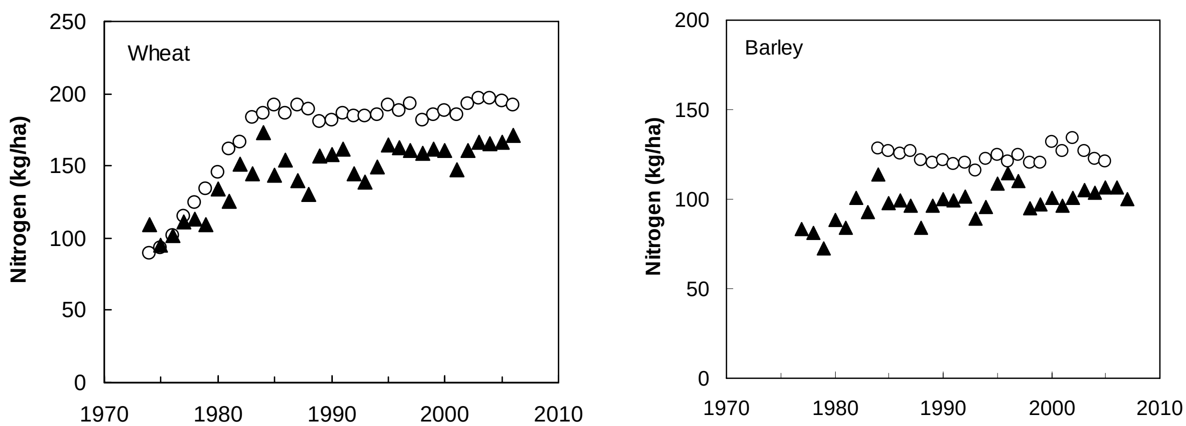


Figure 3.8 Trends in N removed in grain and straw (triangles, estimated from data used in Figures 3.4 and 3.7) and fertiliser N applied (circles, BSFP) for wheat and barley in the UK.

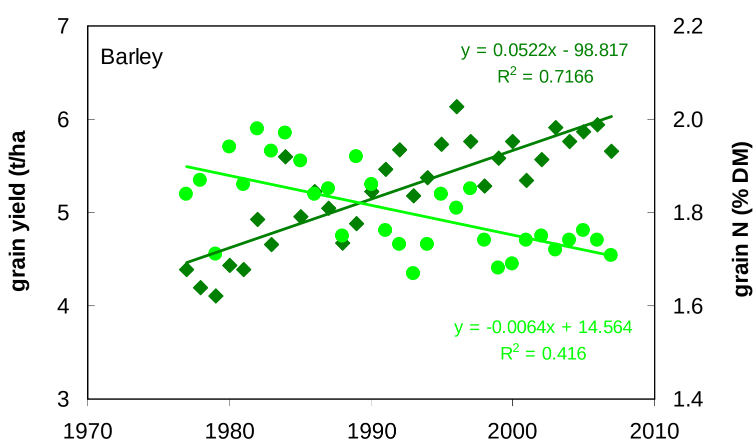


Figure 3.9 Trends in national farm average grain yield (diamonds; Defra stats.) and grain N concentrations (circles; data from HGCA Cereal Quality Survey) for barley (winter & spring) in the UK.

3.2.1.5 Trends in spring barley yields and nitrogen concentrations

National data for barley – both winter and spring – show yields increasing, but by less than for wheat. Comparable data for grain N concentration show a decreasing trend. This may partly be due to the increasing yield, or to the (slight) decrease in fertiliser N applied, but it may also be due to the decreasing area of barley that is grown hence the increasing proportion of the crop that is grown for malting.

3.2.1.6 Static nitrogen fertiliser use

The average application rate of fertiliser N to winter wheat increased rapidly in the 1970s and early 1980s, but it has stayed at around 190kg/ha since 1983 (Figure 3.9). For winter and spring barley the increase in N use in the 1970s was less dramatic, and it ceased a little earlier – in about 1980. There was a further small (~10 kg/ha) increase in N use on both spring and winter barley in about 2000 that didn't occur on wheat. This has diminished since, concurrent with increases in the price of fertiliser N.

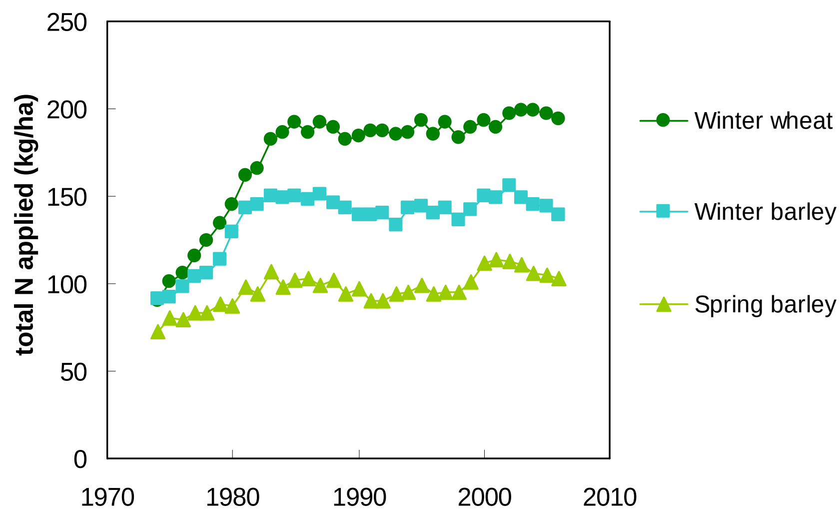


Fig. 3.10 Long term trends in the average rate of fertiliser N use on cereal crops in Great Britain (BSFP). Data exclude Scotland prior to 1994.

3.2.2 Nitrogen prices and economic optimum N rates

Current RB209 recommendations are for N amounts that should be (given perfect prediction) optimum economically. This represents the point on the nitrogen response curve where the cost of using more N would not be covered by the value of the extra crop output produced. Current RB209 recommendations for wheat are based on a ratio of 3:1 (3 kg grain is needed to pay for 1 kg of N) which has been appropriate up until the early 2000s (Figure 3.11). In recent years however, fertiliser N prices have increased so that the appropriate 'breakeven ratio' for purposes of calculating the economic optimum has been well above 3:1. Figure 3.12 shows the breakeven ratio for different prices of ammonium nitrate and grain. In 2008, ammonium nitrate prices are approaching £350 per tonne and with wheat grain at £135 per tonne this gives a ratio of a little over 7:1. The slope or curvature of the yield response curve affects the size of the adjustment that is needed to accommodate changes in the break-even ratio. Hence it will be important to explore whether this has changed with newer varieties.

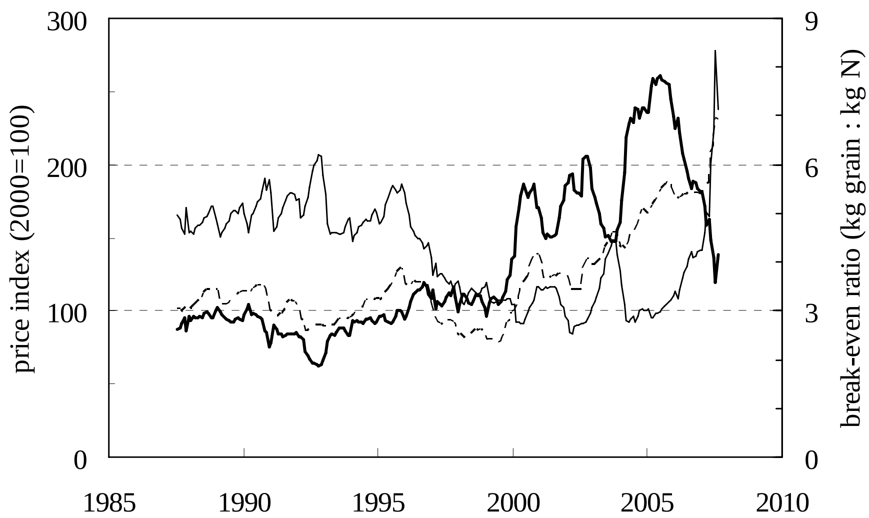


Figure 3.11 Trends in nitrogen price index (dashed) grain price index (fine) for feed wheat, and the consequent break-even ratio (bold) since the 1980s.

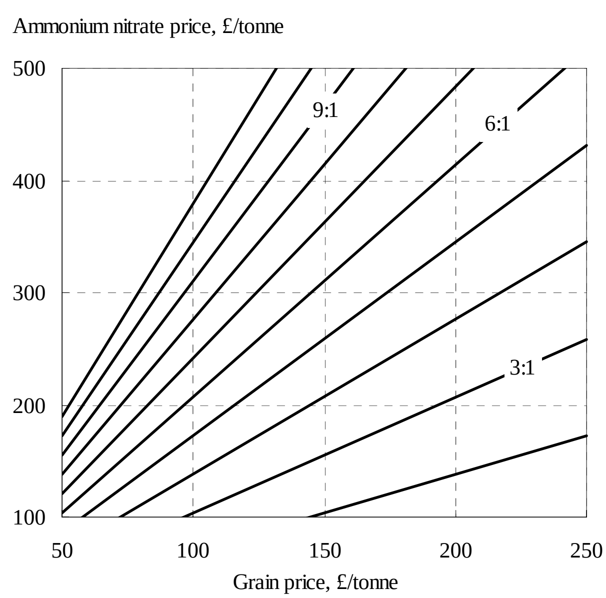


Figure 3.12 Price Ratios according to different prices of fertiliser N (ammonium nitrate) and grain.

3.2.3 Compliance with the Nitrate Vulnerable Zone (NVZ) Action Programme rules

In December 2002, approximately 55% of England, 3% of Wales, 13% of Scotland and parts of Northern Ireland were designated as NVZs. Land within an NVZ must be managed according to the specific NVZ-AP rules that have been set by each devolved Government. Through 2006-8, all NVZ-AP rules throughout the UK have been under revision. A key element of the current rules is that the use of fertiliser N should not exceed the crop requirement, taking account of crop uptake and the soil N supply from crop residues, soil organic matter and organic manures. Farmers need to be able to justify their N use decisions. For NVZs in England, Wales and Northern Ireland, the 7th edition of RB209 is cited as *'…one authoritative source but not the only information source that you can use …'* (Defra 2002). Nevertheless, the RB209 recommendationa are commonly used by the compliance inspectors (the EA in England and Wales) as the initial reference point on which to judge compliance.

The current nitrogen recommendations in RB209 for winter wheat are based on over 280 nitrogen response experiments carried out over the last 30 years or more, mostly funded by Defra and HGCA (Dampney, 2000). However, most of these experiments were carried out between 1981 and 1994 using varieties with a significantly lower yield potential than modern varieties, and this has raised doubts about the validity of the current RB209 recommendations. These recommendations are not directly adjusted for yield although advice is given to adjust the recommended N rate for grain yield using past information for the grain N (protein) concentrations. Use of grain N is a proxy for yield, as increasing yield will usually result in a lower content. Critical values are given that would be expected if economic optimum N rates have been applied for grain yield:- 2.0% N (11.4% protein) for feed wheat, and 2.2% N (12.5% protein) for bread making wheat.

It should be noted that where N optima decrease due to increases in the breakeven price ratio, then these critical values will also reduce.

3.2.4 N management for biofuel production

About 700,000 tonnes of Group 3 wheats are used by the distilling industry. During the course of the research described here there were also increasing prospects of an emerging bioethanol industry. The optimum amount of fertiliser N for ethanol production is likely to differ from that for feed production because fertiliser N affects grain N concentration and there is a strong negative relationship between grain N and alcohol yield (HGCA Research Review No. 61; HGCA Project Progress 14). Measurement of grain N% allows estimation of optimum amounts of fertiliser N for alcohol production as well as for grain yield. Whether such optima would apply in practice depends on the willingness of alcohol producers to pay a premium to growers for grain of a particular quality.

N applications are generally made earlier for malting barley than for feed barley and later for milling wheat than for feed wheat. It is expected that wheats for alcohol production will benefit from earlier N applications than do feed wheats. However, there is little recent information on effects of timing N applications on wheat yield, and virtually no information on effects on alcohol yield. So there is a need to confirm wheat's response to varying N timing, particularly for regions in the south where wheat has seldom been grown for distilling.

To be sure about N timing effects N rates must also be right for alcohol production (litres/ha), or at least it must be known how the N rate differs from the optimum. This is because timings giving less efficient N uptake will appear best if N rates are super-optimal. Therefore it is best to test N timings at several N rates. In the last year of the work described here (2006-7) additional plots were established to test the effects of N timing. A potential disadvantage of early N timing is that lodging will become more prevalent so it was important to assess this, as well as effects on grain yield and quality.

4. Experimental design, materials and methods

4.1 Experiment design and treatments

Experiments were set up to determine the economic optimum N rates for different varieties of winter wheat and spring barley. Each experiment compared 2 'modern' varieties with 2 'old' varieties at a range of six N fertiliser rates, ranging from nil to about 166% of the RB209 recommended rate. There were 10 sites per year for winter wheat and 5 sites per year for spring barley, in the harvest years of 2005, 2006 and 2007. Depending on available space experiments either had a randomised block design with guard plots either side of each plot, or a split-plot design with N rate as the mainplot and variety as the sub-plot with guard plots either side of each main plot. Minimum plot size was 12m by 2m and there were 3 replicates per block. Plots were drilled by Oyjord plot drill.

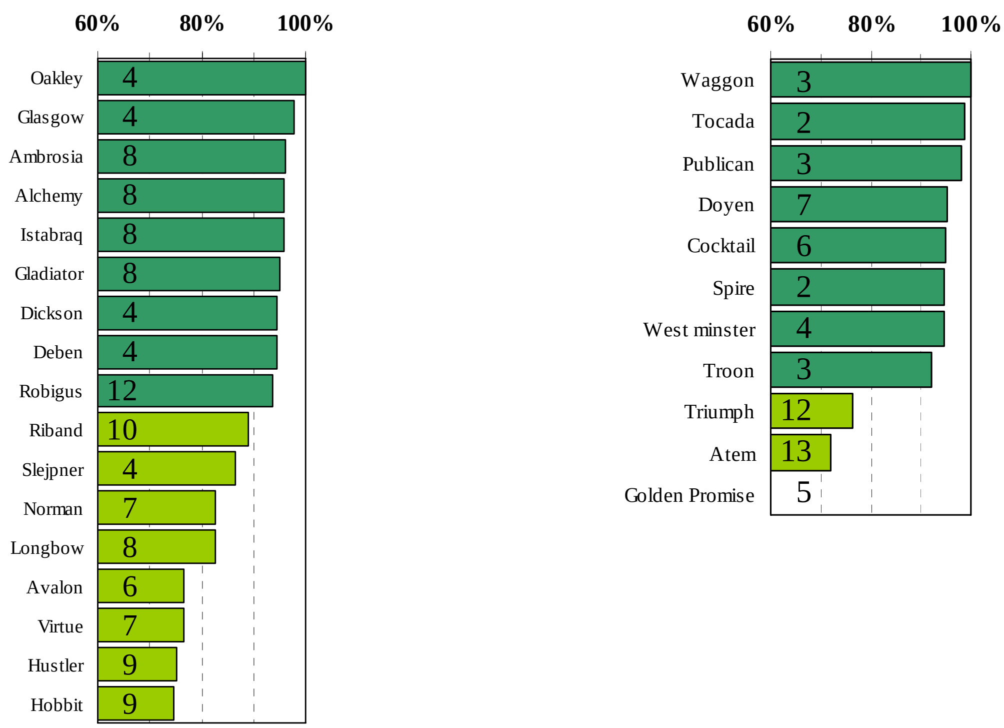


Figure 4.1. Winter-wheat (left) and spring-barley (right) varieties (new – dark green; old – light green) used in this study, showing their estimated yields in RL trials relative to the highest yielding variety (Oakley & Waggon respectively), and the number of site-seasons at which they were tested. An estimate of RL yield for Golden Promise was not available.

4.1.1 Varieties

The ‘modern’ varieties were chosen to give the highest yields, according to the Recommended List. The ‘old’ varieties were chosen to reflect varieties of relatively low yield potential, typical of those used in the experiments that underpin RB209. Spring barley varieties were chosen to give a balance between malting and feed types. The varieties used were different at different sites and different years, though some varieties were maintained throughout the 3 years. Details of the varieties used are given in Figure 4.1, and full details of each of the sites are given in the appendix.

In addition to these varieties, in five of the winter wheat experiments in 2006 and 2007 (Rosemaund, Boxworth, Terrington, High Mowthorpe, Kent and SAC) the variety Xi19 was also included under Defra project IS0223. Data from the Xi19 plots are not presented here. Also, in 2007, extra varieties Mascot and Marksman were included at Terrington and High Mowthorpe, but again, data are not presented here.

4.1.2 Nitrogen treatments

At each site, 6 N rates were tested ranging from zero to 370kg/ha N depending on the site. The recommended ‘optimum’ N rate was determined from RB209 recommendations in conjunction with measurement of soil N supply by soil mineral nitrogen analysis in autumn or spring (see section 4.2.1), and Sinclair (2002) for SAC trials. This optimum N rate was set as N level 4, so that N levels 1 to 6 were 0, 33%, 66%, 100%, 133% and 166% of the recommended rate respectively. Nitrogen applications were as ammonium nitrate (34.5% N). N amounts for each plot were calculated, weighed and spread to include the full plot width (equivalent to plot centre to plot centre) plus half of any adjacent guard plot. Fertiliser was spread by hand by experienced staff, or at some sites by carefully calibrated plot spreader.

4.1.2.1 Nitrogen splits for winter wheat

N applications for the winter wheat experiments were split to give 40 kg/ha in early March and the remainder split between GS31 and GS32, as described in Table 4.1. The exceptions to this were where treatments gave a total N rate less than 70kg/ha whereby one application was made at GS31, or where the remaining N rate after the first split was less than 60kg/ha, whereby only two applications were made, 30 or 40kg in early February and the remainder at GS31.

In addition to these N treatments, additional N timing treatments were included at some sites in 2006 and 2007 under Defra Project IS0223 for the Xi19 plots to test late-N applications representative of bread making wheat using ammonium nitrate and foliar urea. Results from these treatments are not presented here.

Table 4.1. Nitrogen treatments and timings for different RB209 and SAC 'recommended' N rates. 1st timing relates to early March, 2nd timing to GS31 and 3rd timing to GS32.

Rec N rate		**120** *kg N/ha*				**140** *kg N/ha*				**150** *kg N/ha*			
		timings				*timings*				*timings*			
Treatment	*prop*	**Total**	*1st*	*2nd*	*3rd*	**Total**	*1st*	*2nd*	*3rd*	***Total***	*1st*	*2nd*	*3rd*
N1	0.0	**0**	*0*	*0*	*0*	**0**	*0*	*0*	*0*	**0**	*0*	*0*	*0*
N2	0.3	**40**	*0*	*40*	*0*	**50**	*0*	*50*	*0*	**50**	*0*	*50*	*0*
N3	0.7	**80**	*40*	*40*	*0*	**90**	*40*	*50*	*0*	**100**	*40*	*60*	*0*
N4	1.0	**120**	*40*	*40*	*40*	**140**	*40*	*50*	*50*	**150**	*40*	*55*	*55*
N5	1.3	**160**	*40*	*60*	*60*	**190**	*40*	*75*	*75*	**200**	*40*	*80*	*80*
N6	1.7	**200**	*40*	*80*	*80*	**230**	*40*	*95*	*95*	**250**	*40*	*105*	*105*

Rec N rate		**180** *kg N/ha*				**200** *kg N/ha*				**220** *kg N/ha*			
		timings				*timings*				*timings*			
Treatment	*prop*	***Total***	*1st*	*2nd*	*3rd*	***Total***	*1st*	*2nd*	*3rd*	***Total***	*1st*	*2nd*	*3rd*
N1	0.0	**0**	*0*	*0*	*0*	**0**	*0*	*0*	*0*	**0**	*0*	*0*	*0*
N2	0.3	**60**	*0*	*60*	*0*	**70**	*30*	*40*	*0*	**70**	*30*	*40*	*0*
N3	0.7	**120**	*40*	*40*	*40*	**130**	*40*	*45*	*45*	**150**	*40*	*55*	*55*
N4	1.0	**180**	*40*	*70*	*70*	**200**	*40*	*80*	*80*	**220**	*40*	*90*	*90*
N5	1.3	**240**	*40*	*100*	*100*	**270**	*40*	*115*	*115*	**290**	*40*	*125*	*125*
N6	1.7	**300**	*40*	*130*	*130*	**330**	*40*	*145*	*145*	**370**	*40*	*165*	*165*

4.1.2.1.1.1 Extra N timings for alcohol yield

Additional treatments were added at six sites in the 2007 harvest year to test whether alcohol yields could be improved by advancing the timing of N application. The N timing treatments tested whether applying more than 40 kg/ha (one third or one half of the total nitrogen rate) at the 1st timing (in early March) would reduce grain N content or increase grain yield. An extra 6 N treatments were applied to one variety at each trial, the variety chosen being a potential distilling variety (Alchemy or Glasgow). For this one variety additional N treatments were applied for the 3 highest N rates, with 33% or 50% of the N applied early for each rate (see Table 4.2..

4.1.2.2 Nitrogen splits for spring barley

The total nitrogen amounts were split between two timings for the spring barley experiments. The first half was applied between sowing and 3rd leaf stage but not before 16th February or after 15th March. The second half was applied at early stem extension, at least 3 weeks after the first application, but not before April or after 7 May.

Table 4.2. N fertiliser application splits for additional alcohol yield treatments in 2007

	Rec N rate	**150** *kg N/ha*				**180** *kg N/ha*				**220** *kg N/ha*			
			timings				*timings*				*timings*		
Treatment	*% early*	**Total**	*1st*	*2nd*	*3rd*	**Total**	*1st*	*2nd*	*3rd*	**Total**	*1st*	*2nd*	*3rd*
N10	33%	**150**	*50*	*50*	*50*	**180**	*60*	*60*	*60*	**220**	*70*	*75*	*75*
N11	50%	**150**	*80*	*70*	*0*	**180**	*90*	*45*	*45*	**220**	*110*	*55*	*55*
N12	33%	**200**	*70*	*65*	*65*	**240**	*80*	*80*	*80*	**290**	*100*	*95*	*95*
N13	50%	**200**	*100*	*50*	*50*	**240**	*120*	*60*	*60*	**290**	*150*	*70*	*70*
N14	33%	**250**	*80*	*85*	*85*	**300**	*100*	*100*	*100*	**370**	*120*	*125*	*125*
N15	50%	**250**	*130*	*60*	*60*	**300**	*150*	*75*	*75*	**370**	*190*	*90*	*90*

4.1.2.3 Agronomic treatments

All experiments received 30 kg/ha of Sulphur as magnesium sulphate (Keiserite 23%S or Epsom salts 10%S), potassium sulphate (18%S) or calcium sulphate (Gypsum: 16-18%S), not as as ammonium sulphate or Douple Top. All other crop management inputs were according to commercial farm practice to ensure that other nutrients were not limiting, and to control weed, pest, disease and lodging incidence.

4.2 Assessments

For each site, the following information was collected:

- Description of soil type
- Previous 3 years cropping history
- Previous fertiliser and organic manure use

4.2.1 Soil Mineral N analysis

Each block of each experiment was sampled for soil mineral N analysis, with at least 6 cores taken per block, these being divided into 0-30, 30-60 and 60-90cm horizons. Sampling of the winter wheat sites was generally done in autumn (November) and sampling of spring barley sites in spring, between 2-5 weeks after sowing. Soil samples were frozen as soon as possible after being taken, and despatched to the Lab. (Eurofins, Wolverhampton) where they were analysed for ammonium-N and nitrate-N. Topsoil samples were also analysed for total N% by Dumas, and topsoil samples from one rep were also analysed for pH, P, K & Mg.

Crop N at the time of soil sampling was assessed using Table 4.3; crude visual estimates were made of average plant density and average stage of tillering for each variety in each replicate to estimate crop N (kg/ha) according to the categories in Table 4.3.

The Soil Nitrogen Supply (SNS) was calculated as total of nitrate and ammonium-N (0-90cm) plus crop N, and this was used to determine economic optimum N requirements by soil type using RB209.

Table 4.3. Key for estimating crop N (kg/ha) at the time of soil sampling.

<table>
<tr><th rowspan="2">Stage of tillering</th><th colspan="4">Plant density (per m^2)</th></tr>
<tr><th><80</th><th>80-140</th><th>150-250</th><th>>260</th></tr>
<tr><td>seedling</td><td rowspan="5">Consult study director about aborting trial.</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>up to 3 leaves</td><td>5</td><td>5</td><td>5</td></tr>
<tr><td>1-2 tillers</td><td>5</td><td>5</td><td>15</td></tr>
<tr><td>3-5 tillers</td><td>15</td><td>15</td><td>30</td></tr>
<tr><td>over 5 tillers</td><td>30</td><td>30</td><td>50</td></tr>
</table>

4.2.2 Crop assessments

At each N application, site visit and harvest a crop assessment form was completed to record any details of pests, disease or weeds. At harvest, a lodging assessment was made by recording the percentage areas affected by leaning (displaced by 9º and less than 45º from the vertical) and lodging (displaced by greater than 45º from the vertical).

Plots were harvested by plot combine. Plot length and widths were measured to calculate yield on the basis of harvested widths as one path width (up to a maximum of 45 cm) plus the plot width (number of rows x row spacing). Grain moisture content was determined to adjust yields to 85% DM. A 200g subsample of grain was taken from each plot for grain N% determination.

At sites used in Defra project Is0223 grab samples were taken at harvest to determine nitrogen harvest index. Data from these measurements are not presented here.

4.3 Statistical analysis

4.3.1 Analysis of variance

Each experiment was analysed for grain yield and grain nitrogen concentration as either a randomised block design with 3 blocks of a 6 by 4 factorial, or as a split-plot design with N rate as the main plot and variety as the sub-plot. The analyses test for differences between varieties, differences between N rates and for the interaction between varieties and N rates, i.e. whether the response to N was different for each variety.

The apparent recovery of fertiliser N in grain was calculated as follows, then statistically analysed omitting plots of the control treatment as these were always zero:-

$$\text{Apparent recovery (\%)} = \frac{\text{Grain N offtake (treatment)} - \text{Grain N offtake (control)}}{\text{Rate of fertiliser N applied}} \times 100$$

4.3.2 Grain yield response curves and deriving economic optimum (Nopt) rates

The method adopted to fit yield response curves and to derive Nopt rates was broadly the same as that used to underpin the current RB209 recommendations (Anon 2000). This assumed that yield increases due to fertiliser N, diminish successively as the N rate increases. There is a choice of mathematical functions that can describe such responses (e.g. quadratic, linear over quadratic, exponential, linear plus exponential). Most of these functions provide good descriptions of most experimental datasets, though for individual experiments one function may well be better than another. However, when analysing more than one experiment, it is desirable that one function is chosen for all data, so that comparisons between experiments can be made on a common basis. Following a comparison of approaches by George (1984), the linear plus exponential (LEXP) function has been used as the standard method, and is the basis for determining recommended N rates in RB209. Hence, the LEXP function shown below has been used for fitting data from the experiments reported here.

$$y = a + b.r^{\mathrm{N}} + c.\mathrm{N}$$

where *y* is yield in t/ha at 85%DM, N is total fertiliser N applied in kg/ha, and *a*, *b*, *c* and *r* are parameters determined by statistical fitting. These parameters have no distinct meaning and can be correlated with each other, e.g. fitting sometimes gives large positive values of *a* with large negative values of *b*. However, if interdependence between the parameters is appreciated it is often useful to recognise features of the responses with which each parameter tends to be associated. These are as follows:

a: a measure of the asymptote, or maximum achieved yield.

b: the change in yield from the maximum if no fertiliser N was applied. Thus *a*+*b* always gives the fitted yield with no N applied.

c: the slope of the response well beyond the region of maximum curvature. Where large N rates cause increasing yield loss (e.g. due to lodging), this parameter value tends to be increasingly negative.

r: the shape of the response in the region of maximum curvature. This value tends to be larger for flatter response shapes and smaller for sharper response shapes (i.e. those with a more distinct shoulder).

The fitting process does not use common values of parameters between sites or seasons, thus it is assumed that responses were unique to a site. In order to determine Nopt for each variety at each site the LEXP function was fitted using a ‘Parallel curve’ approach. This involved a four-stage procedure:

i) Fit a common curve to all varieties (i.e. keeping *a, b, c* and *r* constant for all varieties at a site).

ii) Fit separate curves for each variety, with a common response but different intercepts (i.e. varying *a* but keeping *b, c* and *r* constant).

iii) Fit separate curves for each variety allowing *a*, *b* and *c* all to vary (i.e. just keeping *r* constant).

iv) Fit separate curves for each variety, allowing all parameters to vary.

In a few instances where the fitted value of *r* was outside the range 0.8299-0.9999, the curves were refitted with *r* fixed at 0.990. The sums of squares explained at each stage was calculated, and a test was made of the improvement in fit over the previous model. If there was no significant improvement between two stages, then the previous model was taken as the best description of the data. In general, fitting at stage 3 was most satisfactory for wheat and barley data, hence for all sites where LEXP fitted satisfactorily, Nopt was determined according to Stage 3.

Estimates of Nopt values were derived from the fitted LEXP parameters as follows:

$$\text{Nopt} = [\ln(k-c)-\ln(b(\ln(r)))]/\ln(r)$$

where *k* is the breakeven price ratio between fertiliser N (p/kg) and grain (p/kg). Breakeven ratios were studied over a range from 3 to 10. Standard errors (se) of each Nopt value were determined for each method of fitting the data (individual and parallel curve approaches). The yield at each Nopt rate (Yopt) was calculated from the fitted parameters.

At sites where there was only a small response to fertiliser N or no significant response, and LEXP did not fit satisfactorily, the assumption was made that the economic N amount must be either nil or small. Nopt was taken to be nil when the response from nil (treatment N1) to treatment N2 did not exceed the LSD, it was taken as the first applied amount (N2) when the difference between N2 and N1 did not exceed the LSD, and so on. These data were not used in the study of effects of Break-Even Price Ratio on Nopt.

4.3.2.1 Grain N (or protein) response curves

Grain protein concentrations on a dry matter basis are conventionally calculated by multiplying grain N concentrations by 5.7. Grain N results here are presented as grain N, without multiplying by 5.7. A response curve was fitted independently to each set of grain N data for each variety. Either a Normal Type curve with Depletion (NTD) or a straight line (SL) function was used, depending on which fitted the data better. This was decided by comparing the Residual Mean Squares (RMS) for the two fits. The one with the smaller RMS was selected. The function for the NTD curve is:-

$$y = d + c.\exp(-\exp(-a.(N - b)))$$

where y is grain N (%), a, b, c and d are fitted parameters determined by fitting, and N is applied N (kg/ha).

The function for the SL function is:-

$$N\% = a + b.N$$

Grain N% values were derived for selected Nopt values.

Alcohol processing yields (APY) – litres of alcohol per tonne of dry grain – were calculated from grain N concentrations using the relationship

$$APY = 520 - \text{grain N\%} \times 5.7 \times 7.2$$

as reported in HGCA Research Review 61. Alcohol yields – litres per hectare – were then calculated by multiplying APY by dry grain yield.

5. Results and Discussion

Key results from the experiments are described in the following section. Individual data and response curves with statistics for each experiment are given in the Appendix.

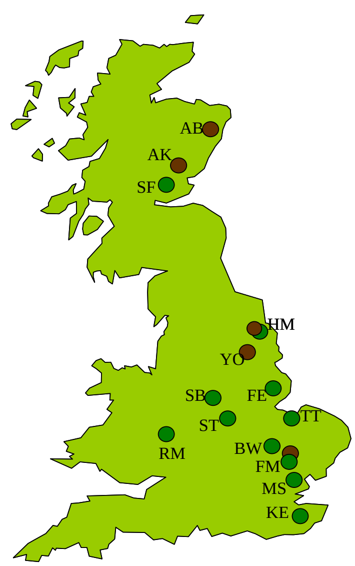
5.1 Weather & Growing conditions

5.1.1 Distribution and Soil types

The distribution of wheat and barley trials is shown in Fig. 5.1. One wheat site and two barley sites were established in Scotland each season. The remainder were in England, predominantly on the East, but with trials at ADAS Rosemaund representing the west of the country. Spring barley trials and most wheat trials were conducted at the same sites each season. Wheat trials were conducted for only the first season at Forgandenny, Stoughton and Edlington. These were replaced by trials at Laurencekirk, Fowlmere and Metheringham respectively in the 2nd and 3rd seasons.

Fig. 5.1. 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.



Wheat sites were established predominantly on clay soils or medium soils (Table 5.1.), whilst the sites chosen for barley trials were generally on lighter soils.

Table 5.1. Representation of soil types in N response trials on winter wheat (30) and spring barley (15).

	Wheat	Barley
Light sands or shallow over sandstone	1	2
Medium soils or shallow over rock#	8	4
Deep clay soils	12	0
Deep fertile silty soils	3	4
Shallow over chalk	5	2
Shallow over limestone	1	3

#(not chalk, limestone or sandstone)

5.1.2 Previous crops

There was a wide range of crops preceding the trials (Table 5.2.). Only 6 of the wheat trials were in a take-all prone situation. No serious take-all was recorded.

Table 5.2. Representation of previous crops and SNS Index classes (refined as in the 7th edition of RB209) in the N response trials on winter wheat (30) and spring barley (15) reported here.

Previous crop	*Wheat sites*	*Barley sites*
Sugar Beet	1	1
Linseed	1	0
Winter barley	0	1
Spring barley	1	4
Winter Oats	5	1
Winter wheat	4	4
Spring wheat	1	0
Spring beans	2	1
Peas	2	1
SOSR	2	0
WOSR	11	0
Set aside	0	2

SNS Index	*Wheat sites*	*Barley sites*
0	1	2
1	10	9
2	9	1
3	4	1
4	6	2
5	0	0
6	0	0

More than half of the wheat sites and four of the barley sites were established after legumes or oilseed rape crops where significant N residues could be expected.

5.1.3 Seasonal growing conditions

All three seasons were warm compared to long-term average weather. Conditions for establishment of winter wheat and spring barley were generally satisfactory in all three seasons, and no trials were aborted at that stage.

The three winters were quite different in terms of rainfall, with 2004-5 being dry, 2005-6 being very dry and 2006-7 being relatively wet (Fig. 5.1.). Thus it was expected that N residues from previous cropping etc. would be greater than normal in the first two seasons, and perhaps rather less than normal in the third season.

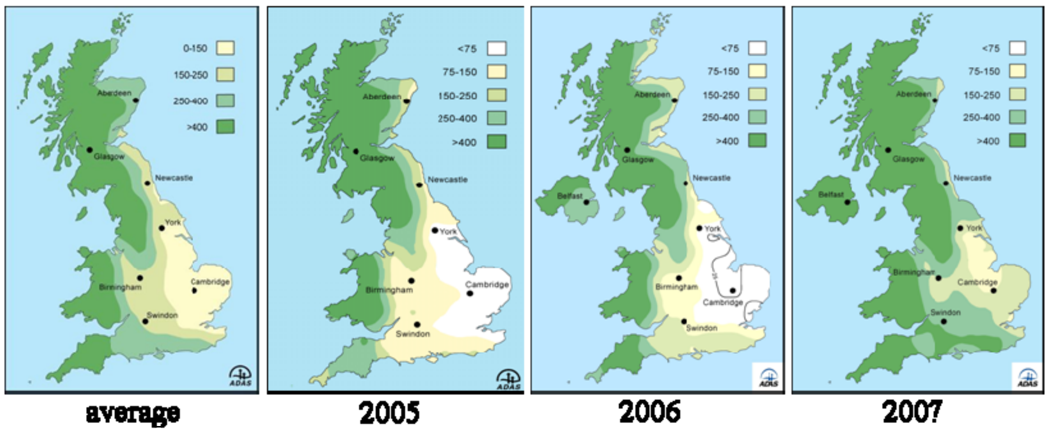


Fig. 5.1. Over-winter rainfall in an average year and for the winters before each of the harvest years of this research project. In comparison with the average the winters before 2005, 2006 and 2007 harvests were dry, very dry and wet respectively.

Spring rainfall was adequate for uptake of fertiliser N in the first two seasons, although May was relatively cold in 2005. In the third season there was very little rainfall over SE and E England during April, and N uptake was delayed until a heavy rainfall later in May.

Table 5.3. Solar radiation (estimated from sunshine hours) during fixed thermal periods in Eastern UK (% normal), national average grain yields (t/ha) and average yields of modern varieties in all trials (t/ha) for wheat and spring barley in the three seasons of N response experiments described here

	Solar radiation		National average yield		Trial average yield	
	Ear formation (May)	Grain-fill (June-July)	Winter wheat	Spring barley	Winter wheat	Spring barley
2005	100%	93%	7.96	5.40	10.68	6.17
2006	99%	98%	8.04	5.33	10.85	6.65
2007	80%	77%	7.30	5.32	8.68	5.49

In 2005 conditions for grain yield formation (in June & July) were warm without being particularly sunny. In 2006 it was both warm and sunny during June and July but there was double average rainfall in August. In 2007 it was dull and very wet over much of the country during grain formation, warm in June but cool in July. No year was particularly prone to lodging, although lodging occurred at the higher N rates at 4 sites in

2006 and one site in 2007. National average yields were generally in keeping with the weather patterns in June and July, considering low temperatures and bright conditions both to be positive for yield (Table 5.3.).

Concerning harvest, the 2007 weather pattern contrasted with that of 2006. Harvest in 2006 was early and unaffected by rain until mid August. The 2005 harvest was more normal and largely unaffected by wet weather.

5.2 Winter Wheat Experiments

All ten trials each year reached the stage of harvest, although not all trials showed significant responses to fertiliser N. The results will now be described in detail, examining soil N supplies first, followed by grain yields and responses to fertiliser N.

5.2.1 Soil N Supplies (SNS)

Soil N supply (SNS) assessed by soil analysis and crop assessment varied from 50 kg/ha at Fowlmere 2007 after winter oats with 0.16% total N in the topsoil to 211 kg/ha at Kent in 2006 after oilseed rape, and with 0.3% total N in the topsoil. Previous cropping, soil type and over-winter rainfall, combined in the Field Assessment Method (FAM) defined in RB209 was not a satisfactory predictor of SNS as assessed by soil and crop analysis in these trials (Fig. 5.2.). If anything, the FAM tended to over-estimate SNS by soil analysis.

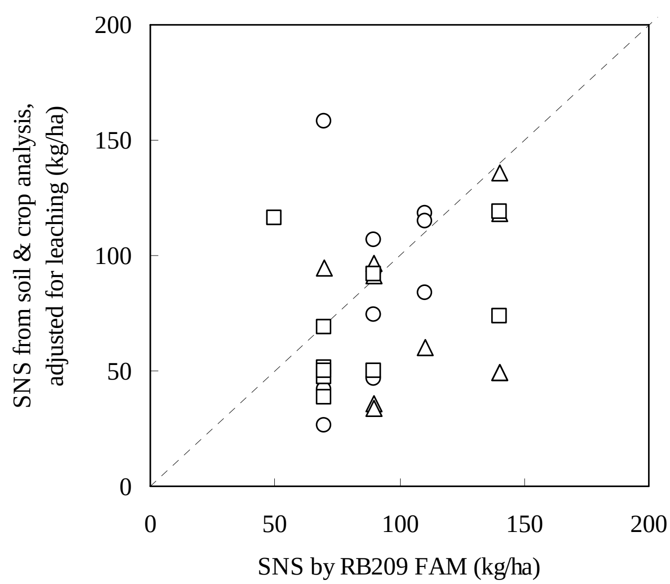


Fig. 5.2. Comparison, for the winter wheat trial sites of SNS determined by soil analysis plus crop assessment, corrected for over-winter leaching, with SNS determined by the Field Assessment Method given in RB209. The dotted line shows perfect agreement.

SNS by analysis related better to total topsoil N than to previous cropping (Fig. 5.3.). The levels of topsoil N measured here, varying from 0.14 to 0.70%, are equivalent to a range of soil organic matter from 2.5 to 12%; surprisingly 25% of the wheat plus barley sites had more than 0.3% total N (equivalent to more than 5% SOM). Total N analysis is relatively cheap, so it would seem worth investigating its wider use to support assessment of soil N supplies.

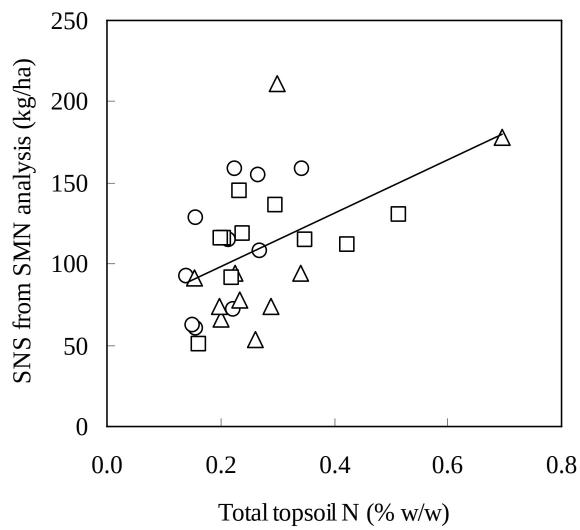


Fig. 5.3. Relationship between SNS and total topsoil N for wheat trials harvested in 2005 (circles), 2006 (triangles) and 2007 (squares). R^2 was 0.24.

Crop N uptake without fertiliser N is indicative of the availability of soil N to the crop throughout its life. Grain N (kg/ha) represents the majority of crop N uptake. The ratio between grain N and total crop N (i.e. the N harvest index) was measured in a sub-set of the wheat trials reported here. Detailed results will be reported elsewhere (under Defra Project IS0223), but there was relatively little variation (see Section 5.2.4) so estimates of crop N uptake can be made with reasonable accuracy just by assuming N harvest index was 0.75.

There was no significant relationship between SNS determined by the FAM of RB209 and nil N uptake estimated from grain N (kg/ha). However, SNS determined by soil analysis showed a significant relationship (R^2=0.28), which became highly significant (R^2=0.52; Fig. 5.4.) when the autumn-sampled results were corrected for over-winter leaching according to the over-winter rainfall using a simple leaching model (E.I. Lord, personal communication). The relationship showed a positive intercept of about 40 kg/ha, equivalent to the average amount of crop N expected to be derived from atmospheric deposition (Webb *et al.*, 2004), and the slope was 1.2 kg/kg. Hence the amount of N taken up by the unfertilised crop was always as large or larger than the amount estimated over-winter from soil mineral N analysis.

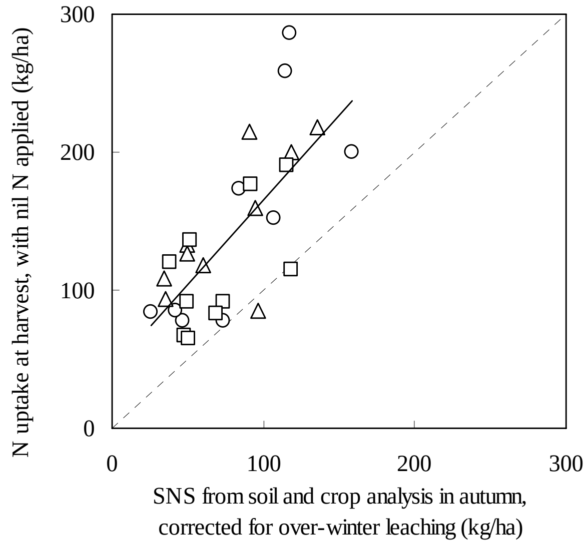


Fig. 5.4. Relationship between SNS derived by soil analysis and crop N uptake by wheat with nil N applied in 2005 (circles), 2006 (triangles) and 2007 (squares). y = 42 + 1.22.x ; R^2 = 0.52.

5.2.2 Grain yields

5.2.2.1 Site & Season

Optimum grain yields in these trials were generally good at about 10 t/ha (Table 5.4). As shown in Table 5.3, 2007 was a lower yielding season than 2005 and 2006, probably due to its dull grain filling period.

Table 5.4. Mean grain yields of modern varieties (t/ha) at each winter wheat site in the three seasons of N response experiments described here.

Wheat sites	**2005**	**2006**	**2007**	**Mean**
	Mean grain yield at optimum N, t/ha			
SAC Forgandenny	11.51			**11.51**
SAC Laurencekirk		11.01	8.85	**9.93**
ADAS High Mowthorpe	10.11	10.45	8.04	**9.53**
Farmacy, Edlington	11.47			**11.47**
Farmacy, Metheringham		12.28	8.56	**10.42**
Univ. Nott., Sutton Bonington	11.03	10.44	10.42	**10.63**
ADAS Terrington	9.30	12.29	8.25	**9.95**
ADAS Boxworth	10.22	9.81	8.76	**9.60**
Agrovista, Stoughton	12.78			**12.78**
Masstock, Fowlmere		9.78	7.57	**8.68**
ADAS Rosemaund	9.72	10.94	9.67	**10.11**
Masstock, Stebbing	9.67	9.97	7.87	**9.17**
ADAS Kent	11.00	11.55	8.85	**10.47**
Mean	**10.68**	**10.85**	**8.68**	**10.07**

There were no obvious consistent differences between the yields at the 13 different locations used for the winter wheat trials, once the seasonal effect had been taken into account.

5.2.2.2 Variety

The relative performance of the varieties chosen for these trials, and particularly the lower yields of older varieties, was evident except that the newest and highest yielding varieties from the RL (Oakley & Glasgow) were only tested in 2007, which was the lowest yielding season. Hence these varieties appeared at a disadvantage, particularly Oakley which seemed to be grown at lowest yielding sites in 2007. Overall it was expected (from past RL data) that the old varieties of wheat grown here would yield 84% of the newer varieties. In the event, they yielded slightly better than this, at 87% of the newer varieties. Of the older varieties Longbow appeared to yield noticeably better than would be expected from RL data.

5.2.3 Responses of grain yield to fertiliser N

For modern varieties, the responses in grain yield to application of fertiliser N ranged from near nil (0.2 t/ha) to 6.7 t/ha. The mean response over all sites was 2.9 t/ha – 30% of grain yield – probably smaller than would be ideal for testing differences in responsiveness between varieties, but representative of the distribution of responses in the country as a whole, given that the distribution of sites according to SNS by analysis was not different from that shown by national studies (e.g. HGCA Wheat Growth Guide 2nd Edition Page 14).

The six sites where lodging occurred were Kent 2005, Rosemaund, Laurencekirk, Fowlmere and Stebbing in 2006 and High Mowthorpe in 2007. In most cases the lodging only occurred with the largest amounts of applied N and it occurred more with old varieties than new varieties. None of these lodging sites had a particularly large SNS (the maximum was 115 kg/ha), and only two of these sites (Kent 2005 and Fowlmere 2006) showed a small response to fertiliser N.

About two of the ten sites in each season showed a response of less than 1 t/ha to applied N. It is just possible that this occurred because the host farmers spread fertiliser N over their trial but, in cases where this was suspected (i.e. Stoughton 2005, Kent 2005 & 2006, Metheringham 2006 & 2007, Sutton Bonington 2007), close questioning of relevant staff and examination of the data has lead us to believe that this did not happen, and that this does not explain large nil-N yields and small yield responses. All of these sites had above average SNS by analysis, both before and after correction for leaching. Given that the distribution of SNS in these trials (Table 5.2) was similar to that nationally, sites with small responses have not been excluded from the cross-site analysis. However, it was difficult to fit a curve to the yield data from these sites, and therefore difficult to be certain about the optimum amounts of N, except to say that they were probably small or nil.

5.2.3.1 N optima and variety yield

The LEXP function with constant R parameter fitted satisfactorily for all varieties for 24 of the 30 sets of wheat data – the R^2 of the fit was 77% on average, and ranged from 37% to 95%. At the remaining six sites Nopt was either taken from an independent LEXP curve (with floating R) or was taken to be nil or 40 kg/ha depending on whether there was a significant response between N1 (nil) and N2. Nopt determined from LEXP curves were expressed at a break-even price ratio of 3:1 for consistency with previous work. The effect of other BERs will be discussed in Section 5.2.3.3.

Average Nopt for each site ranged from nil to 260 kg/ha (294 kg/ha excluding old varieties); for some individual varieties Nopt exceeded the maximum level tested 370 kg/ha. The median site Nopt was 152 kg/ha overall, and was 154, 151 and 134 kg/ha in 2005, 2006 and 2007 respectively. There did not appear to be any relationship between grain yield and Nopt across sites, although it is apparent that the average Nopt in 2007 was less than the other two, higher-yielding, seasons (Fig. 5.5).

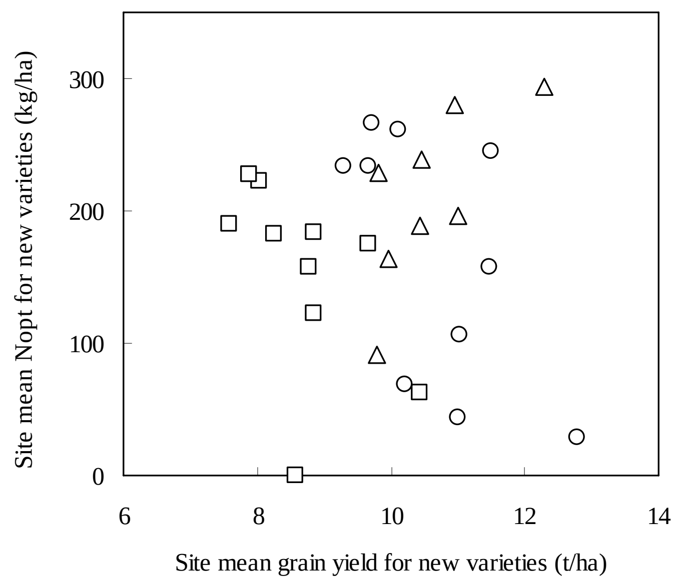


Fig. 5.5. Relationship between mean Nopt at a site and mean grain yield at the same site for wheat trials harvested in 2005 (circles), 2006 (triangles) and 2007 (squares).

Average Nopt was 129 and 164 kg/ha for ‘old’ and ‘new’ varieties respectively, giving a difference of 35 kg/ha. It is desirable to have a basis by which to interpret this apparent variety effect, since there is no way of using such a distinction (between varieties introduced in the 1980s and the 2000s) predictively. The obvious association is with the greater yields of the newer varieties. Since the yield advantage of newer varieties was not always evident in each trial, the yield-Nopt association has been examined without specific note of the age of the varieties. Hence an old variety was selected (arbitrarily) at each site, then the differences in Nopt of each other variety from the control were compared to the differences in yields (at

Nopt). The resulting relationship (Fig. 5.6) shows a very loose but highly significant (P=0.01) positive slope of about 20 kg fertiliser N per tonne of variety yield difference. The relationship was more noticeable in 2006 and 2007 than 2005.

A slope of 20 kg/t is about half that expected if fertiliser was required to fully sustain an extra tonne of grain production. At an average concentration of 2% N in grain DM, 1 tonne grain at 85%DM contains 17 kg. Some additional straw and chaff is also likely to be associated with the extra grain, giving a total extra amount of N in the crop of about 23 kg. Since fertiliser N is normally used with only 60% efficiency (Bloom *et al.* 1980), the extra amount of fertiliser N expected to be associated with an extra tonne of grain would be about 38kg. The relationship in Fig. 5.6 is not precise but it seems likely to have a slope of less than 38 kg/t, particularly in 2005; thus it seems that breeders, in making yield improvements to wheat varieties between the 1980s and the 2000s, have probably improved their N Use Efficiency as well as their grain yield.

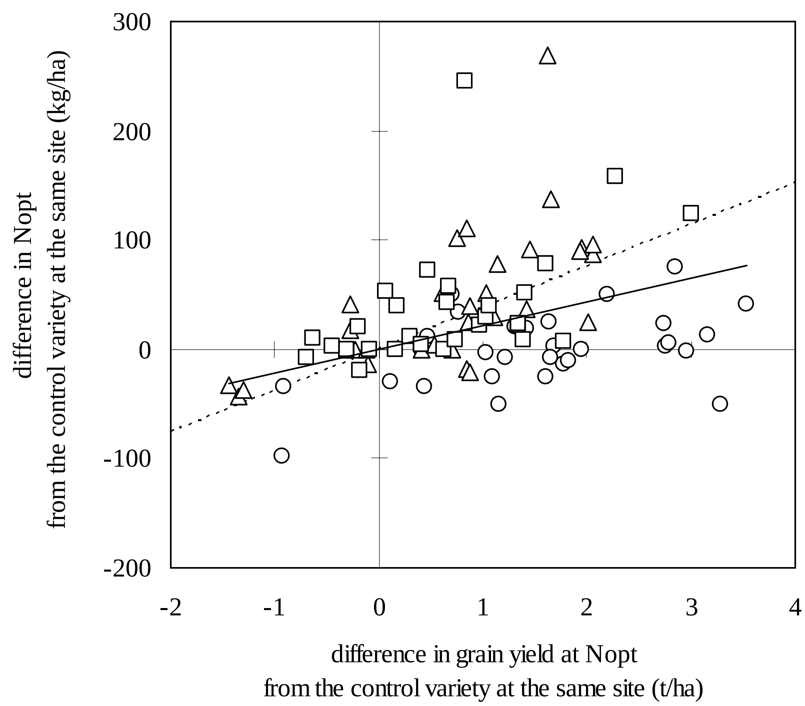


Fig. 5.6. Relationship between the effect of variety on Nopt at a site and the effect of variety on grain yield at the same site for wheat trials labelled as in Fig. 5.5. R^2 was 0.09**. The slope of the relationship is 21.5 kg fertiliser N per tonne grain yield difference. The dotted line shows a slope of 38 kg/t, as expected if the N Use Efficiency of new varieties were no better than old varieties.

This finding appears to conform with the findings of Foulkes *et al.* (1998) who studied a dataset developed and provided by Levington Agriculture, and found that breeding wheat for greater yields had been associated with improvement of apparent recovery of fertiliser N. N recovery will be examined in a subsequent section.

5.2.3.2 Absolute performance of RB209 predictions

The 30 sites tested here are reasonably representative of the conditions in which wheat is grown in the UK, and they therefore offer a good test-bed for N recommendation systems. Since soil N supply was assessed by measurement as well as by FAM (previous cropping, soil type and over-winter rainfall), it is possible to compare the performance of the two systems, and modifications to them. The only element of existing recommendations that is not directly testable here is the use of past grain N% data from each farm to gauge the extent to which past fertiliser N strategy has been compatible with past yields – past grain N% data were not obtained from host farmers.

It has already been seen that SNS by direct measurement was a much better predictor of nil-N uptake than SNS by the FAM. When it came to predicting Nopts, the same was true (Fig. 5.7), however, even with soil analysis, the relationship showed considerable imprecision. It might be supposed that variation in site yield would account for some of this imprecision but unfortunately, even if the site-to-site yield variation had been known with perfect foresight, there was no common adjustment (kg N per tonne grain) that would have improved the precision of the recommendations.

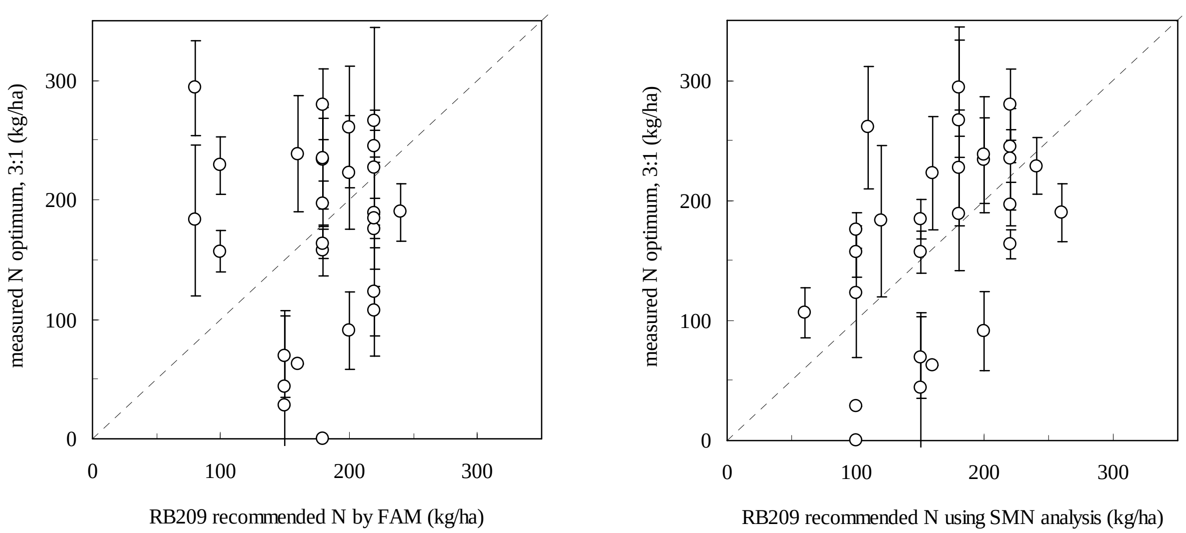


Fig. 5.7. Average Nopts for ‘modern’ varieties in relation to N recommendations based on FAM (left) or soil analysis (right) for 28 wheat trials harvested in 2005 to 2007. The relationship was not significant with FAM, but was significant with soil analysis (R^2=0.25).

There therefore remains a question of whether adjustment for grain yield variation, or grain N% (as a surrogate for yield variation), is worthwhile. Clearly, as part of yield variation, knowledge of the different yields of varieties improves the precision of recommendations. However, the differences between concurrent varieties (i.e. those on the RL for each season) is only of the order of 1 t/ha, so the adjustment for concurrent varieties should be less than 20 kg/ha N in most circumstances. It seems more appropriate that recommendations should be adjusted on a long term basis: as a new generation of varieties supersedes the previous generation, so the published recommendations can be revised to accommodate the new requirements.

5.2.4 Effect of break-even ratio on N optima

In purely commercial terms, the best strategy will be to fertilise each field to the point where any further expense on fertiliser will not be covered by additional returns from extra grain produced. This point is Nopt. However Nopt will depend on the purchase price of the fertiliser and the sale price of the grain. The ratio between these two prices defines the point at which further expense on fertiliser is not worthwhile – the Break-Even Ratio (BER). Fig. 3.12 shows BERs for combinations of grain and fertiliser prices and Fig. 3.11 shows BERs that have been experienced over recent years for feed wheat. Clearly there have been big and frequent changes nationally over recent years, and changes are likely to have been even more significant at a farm level. It is therefore important for farmers to know the extent to which they should be adjusting fertiliser applications on account of changes in BER.

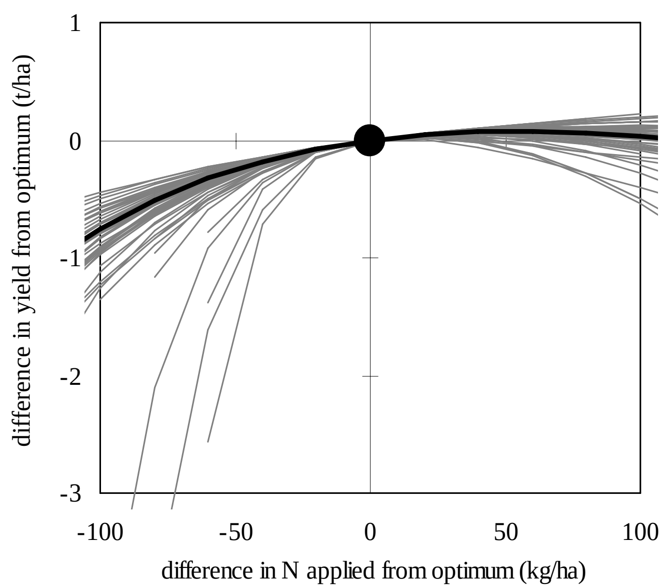


Fig. 5.8. Forty seven response curves from wheat trials in 2005-7, all for individual modern varieties where R^2 for LEXP was >0.5 and Nopt<Nmax (grey lines), all co-located at the optimum (BER 3:1; black circle), and a 'standard' curve giving yield effects close to the average of all responses (bold line).

Adjustment for changes in BER will depend on the curvature of the N response in the region of Nopt. Fig. 5.8 shows curves from all the modern varieties for which LEXP provided a good fit (R^2>0.5), with all curves co-located at their optima at BER=3. The variation in curve shape is relatively small, so a 'standard' curve is presented from which it is possible to explore appropriate adjustments to Nopt according to changes in BER. The responses with sharper curvature tended to be those for which Nopt was small, hence determination of curve shape was less reliable.

In practice it may be more appropriate to consider an alternative 'average' curve, which may have a different degree of curvature. This is because the performance of recommendations, as described for RB209 above, is imperfect. It must be assumed that any N decision or recommendation will have a significant level of imprecision, and that each fertiliser decision must attempt to optimise commercial performance from a number of fields which will have unavoidable degrees of under- and over-fertilisation. Hence a sub-group of 25 response curves was taken from the 51 above, each having similar RB209 recommendations for fertiliser N (180 to 240 kg/ha; Fig. 5.9). The range of Nopts for these curves was 87-321 kg/ha; the mean and median were 216 and 233 kg/ha respectively. An 'average' curve was fitted to the average yields from these curves, which gave an 'average Nopt' of 222 kg/ha.

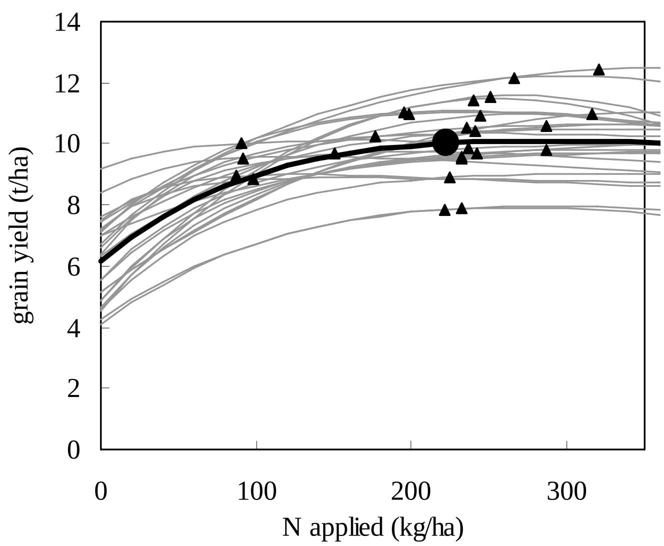


Fig. 5.9. Twenty five response curves from wheat trials in 2005-7, all for individual modern varieties where R^2 for LEXP was >0.5, Nopt<Nmax and the RB209 recommendation was between 180 and 240 kg/ha N (grey lines), and an 'average' curve (bold line) fitted to their average yields, giving an 'average Nopt' of 222 kg/ha N (black circle).

The 'standard' and the 'average' curves determined above proved to be so similar that they gave very similar adjustments for changes in BER. Hence the effect of imprecise N use on adjustment for BER can be discounted and, although the adjustment for BER clearly decreases as BER increases (Fig. 5.10), this effect is small enough to be ignored (given all the other imprecision in setting N amounts), and an average adjustment for one unit change in BER can be derived of 10.8 kg/ha fertiliser N. The apparent universal relevance and simplicity of this adjustment will be very useful in promoting in the industry appropriate adjustment of N use for price changes.

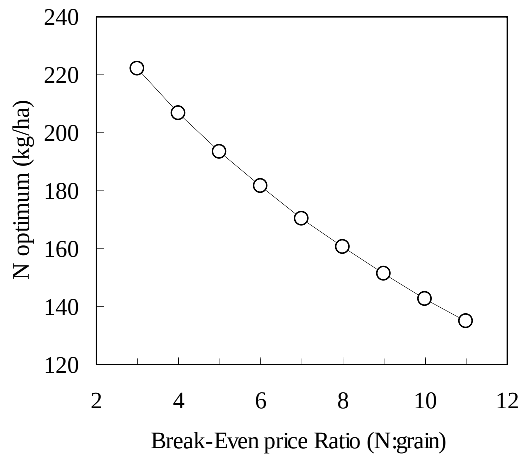


Fig. 5.10. Effect on Nopt of Break-Even price Ratio between N and grain for an 'average' N response curve derived from 24 responses of modern wheat varieties each at a site where the N recommended by RB209 was 160-240 kg/ha N.

5.2.4.1 Grain N% at optimum N

Despite the wide variation in Nopt, there was no relationship between Nopt and grain N% at Nopt (Fig. 5.11). The average grain N at Nopt (BER 3:1) for old and new varieties was 2.06% and 2.05% respectively, and the variation in grain N% was relatively small. This supports the approach taken in RB209, where grain N% is used to indicate whether fertiliser N has been optimal for grain yield.

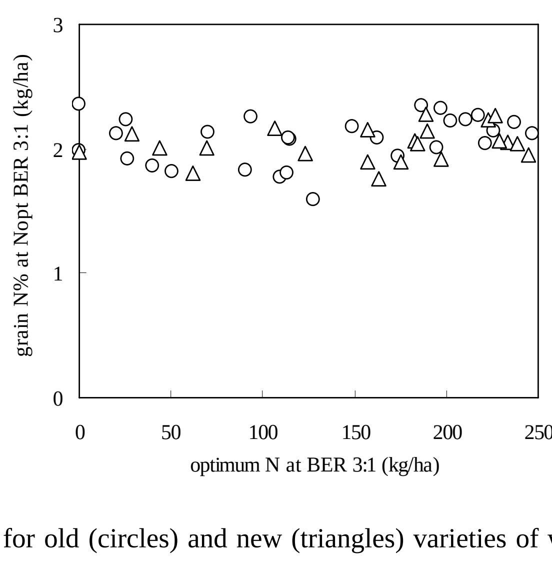


Fig. 5.11 Grain N (% DM) for old (circles) and new (triangles) varieties of wheat in 28 site-seasons from 2005 to 2007.

Since grain N% was quite sensitive to N applied in the region of Nopt, the average grain N% at Nopt depended on the BER at which Nopt was determined (Table 5.5). At current BERs of 5-7 it appears that the current guideline of 2% in RB209 is about right. The range of grain N% at Nopt given in Table 5.5. shows that it would not be appropriate to judge accuracy of N use on a farm without averaging a number of fields and examining trends over a number of seasons. It could be very misleading to assume that grain N% at Nopt should be close to 2% on every field.

Table 5.5. Mean, maximum and minimum grain N (% DM) at Nopt in each of 28 wheat N response trials from 2005-2007 according to different Break-Even Ratios.

	BER 3:1		**BER 6:1**		**BER 9:1**	
Variety type	*Old*	*New*	*Old*	*New*	*Old*	*New*
Mean grain N%	2.07	2.05	1.99	1.97	1.93	1.91
Max grain N%	2.36	2.28	2.36	2.20	2.36	2.13
Min grain N%	1.59	1.76	1.48	1.67	1.40	1.58

In previous work on grain N% at Nopt effects have been found of variety type (milling vs feed) and soil type. Data were not appropriate to explore such effects here, but a further project (HGCA Project 3436) will study a much wider dataset, including data from barley and oilseed rape, and the report will be available in 2009. If this work confirms that grain N% is a good guide of optimal N use, it should be possible to use data from the HGCA Cereal Quality Survey (Fig. 3.7a) to decide whether average N use by UK farmers is optimal on average, a question for which there has been no good answer hitherto.

5.2.5 Economic performance of N recommendations

Given the apparently poor performance of recommendation systems in predicting true Nopts (Fig. 5.7) it is important to consider the value of adopting one recommendation system rather than another, and the economic implications of striving to improve N recommendations. In particular it is useful to quantify the economic benefit of undertaking soil N analysis as part of the N decision making process.

Fig. 5.12 illustrates the economic performance of RB209 recommendations using SMN analysis for modern varieties. Only those responses are shown where the LEXP function fitted the data reasonably well (R^2>0.5) and where the Nopt at BER 3:1 was within the range of N levels tested. Unrealised profit is expressed in terms of fertiliser N equivalents; whilst the price of ammonium nitrate is around £345/tonne these results translate directly to £/ha. However, the volatility of fertiliser prices may well mean that the results will need to be converted according to the price of fertiliser N, in order that these data remain meaningful into the future.

The individual responses in unrealised profit show losses due to both under-fertilising and over-fertilising, with generally greater losses below the optimum than above the optimum. Small imprecision in N use (say

N use within 40 kg/ha of Nopt) could, in a few cases, cause economic losses larger than the value of 100 kg/ha N. However, most losses from small imprecision were much smaller than this (average 35 kg/ha N due to under-fertilising and 21 kg/ha due to over fertilising). Larger imprecision (say N use differing by 100 kg/ha from Nopt) generally caused economic losses of the order of the value of 100 kg/ha N, or larger. Hence, there is clear importance in minimising major imprecision in N decisions.

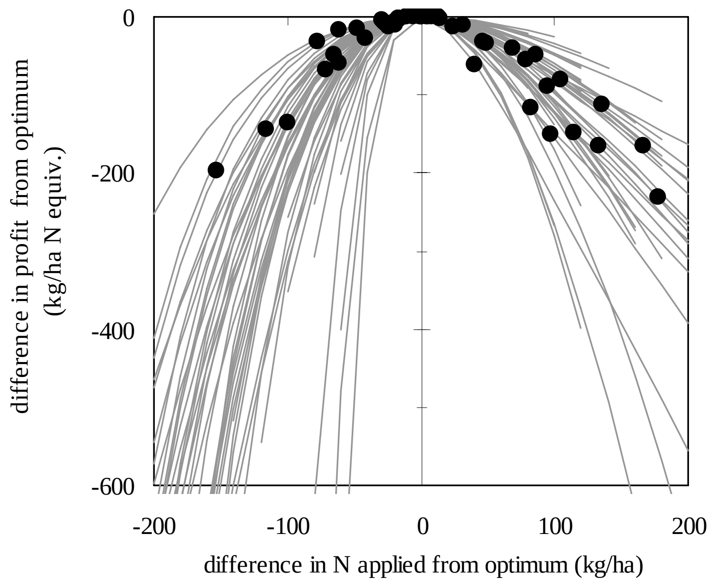


Fig. 5.12 Effect on unrealised profit of N applications differing from the optimum N level (3:1) for 47 response curves from wheat trials in 2005-7, all for individual modern varieties where R^2 for LEXP was >0.5 and Nopt<Nmax. Black circles indicate amounts recommended for the circumstances of each response curve, according to RB209 7th edition, using SMN analysis, and adding 25 kg/ha N (which minimised the overall average unrealised profit).

Given the effect on profit of deviating from Nopt, both accuracy (being right on average) and precision (correctly anticipating field-to-field variation) will be important in maximising the effectiveness of any N decision or recommendation system: N recommendations for the subset of data illustrated in Fig. 5.12 needed to be adjusted by adding 25 kg/ha N in order to minimise the average unrealised profit for all sites. The resultant average unrealised profit was 50 kg/ha N equivalent. Without this adjustment to the recommendations average unrealised profit was 58 kg/ha 'N equivalent'. The greater lost profit of the unadjusted recommendations arose for two reasons; 1) on average they were inaccurate (13 kg/ha less than the average N optimum); 2) Imprecision in the recommendations is more costly when under-fertilising than over-fertilising, making it worth over-fertilising by 12 kg/ha N. This last effect has never been formally recognised or taken into account in recommendations. The inaccuracy of recommendations derived from the RB209 7th edition is likely to have arisen in part because, for this dataset, they had to be set without adjustment for past yields or grain N%. Given that these responses were all for modern wheat varieties the inaccuracy is probably associated with the genetic improvement of grain yield since the 7th edition was published.

The economic implications of using recommendations based on the Field Assessment Method (FAM) from RB209 as opposed to SMN analysis can be seen in Table 5.6. All but two site-seasons were used in this comparison, including those with small or zero Nopt values, for which the LEXP function often did not fit particularly well. The two excluded sites were those with a clear positive response to applied N but where LEXP did not fit, thus leaving determination of Nopt very uncertain. As a control, the two recommendation approaches (based on FAM or SMN) were each compared with use of a single fixed N recommendation at every site regardless of circumstances. This N rate was set at 185 kg/ha, which minimised the average unrealised profit across all sites.

Table 5.6. Summary data from comparing economic performance of recommendation systems for the 28 site-seasons where optima could be determined (omitting Metheringham & Kent 2006).

	Units	Maximum	Minimum	Median	Mean
Nopt at BER 3:1	*kg/ha*	294	0	186	173
Grain yield at Nopt	*t/ha*	12.78	7.57	9.89	9.94
N recommended by FAM[1]	*kg/ha*	258	98	198	196
N recommended by SMN[1]	*kg/ha*	278	78	188	183
N difference at 185 kg/ha N[2]	*kg/ha*	185	-109	-1	12
N difference at Nrec by FAM	*kg/ha*	198	-196	23	23
N difference at Nrec by SMN	*kg/ha*	127	-133	-6	10
Yield change at 185 kg/ha N[2]	*t/ha*	0.19	-0.79	-0.19	-0.21
Yield change at FAM-N	*t/ha*	0.20	-2.22	-0.10	-0.23
Yield change at SMN-N	*t/ha*	0.12	-0.98	-0.09	-0.17
Unrealised profit at 185-N	*kg/ha N equiv.*	350	1	55	81
Unrealised profit at FAM-N	*kg/ha N equiv.*	545	0	38	98
Unrealised profit at SMN-N	*kg/ha N equiv.*	301	0	44	66

[1] adjusted by +18 kg/ha N to minimise mean unrealised profit of recommendation based on SMN.

[2] 185 kg/ha N was set to minimise mean unrealised profit.

As seen in Figs 5.5. & 5.7, the site mean Nopts ranged from nil to 294 kg/ha, and the overall mean Nopt was 173 kg/ha. There was no N recommendation of nil, and recommendations ranged up to 278 kg/ha (including the 18 kg/ha increase found necessary in order to minimise average unrealised profit[1] and explained by a

[1] This adjustment differs from the adjustment of 25 kg/ha N derived from data presented in Fig. 5.12 because a larger dataset has been used, involving more sites with Nopts at or close to nil.

universal genetic improvement of grain yields since RB209 was published). Under- and over-recommendation reached almost 200 kg/ha N for the FAM, was slightly less using the fixed N rate, and was least for the SMN approach. The differences between recommendation approaches in over-predictions of Nopt are not only significant economically, but they are also very relevant to the risks of causing disproportionate effects on N pollution through nitrate leaching, and possibly also nitrous oxide emission.

There was a yield range between site-seasons of almost 5 t/ha but, as explained already (Section 5.2.3.2), no improvement in precision could have been achieved even if site yields had been known in advance, because there was no relationship between yield variation and Nopt variation between sites. The effects on grain yield of using the fixed N amount or recommended rates rather than Nopt were generally quite small, on average less than 0.25 t/ha, but they included a 2.2 t/ha loss at ADAS Terrington 2006 where Nopt was under-predicted by 196 kg/ha N using the FAM. As shown in Fig. 5.12, the levels of unrealised profit resulting from following recommendations (or using fixed N) were not normally distributed – unrealised profits were very small in most site-seasons, whatever the recommendation approach, but a few of the unrealised profits were large. It is these large effects that had the main influence on the overall economic performance of a particular recommendation approach, hence the recommendation approach that was best able to recognise the large effects – i.e. the SMN-based approach – was that which performed best overall, giving an average unrealised profit to the value of 66 kg/ha fertiliser N. Surprisingly, the approach based on FAM performed worse (by an average of the value of 17 kg/ha N) than using a fixed rate of 185 kg/ha N. This was largely because the FAM predicted 131 kg/ha too much N at the University of Nottingham in 2005, and 196 kg/ha too little N at ADAS Terrington 2006. In the Terrington case, the fixed N approach avoided most of the marked shortfall in grain yield that accompanied the under-prediction, and in the Nottingham case the fixed N approach reduced the over-fertilisation by 53 kg/ha N, and reduced the yield shortfall by 0.5 t/ha.

5.2.6 Crop recovery of soil & fertiliser N

Grain N offtake was measured in these trials, but straw N offtake, hence total N uptake and apparent N recovery, was only measured in a subset of the trials (under Defra project IS0223). Examination of the NHI data shows it to decrease only slightly due to an increase in fertiliser N of 200 kg/ha, e.g. from 0.73 to 0.69 at ADAS Terrington in 2007. Hence, it is possible to assume that the variation in N harvest index (NHI) was small, and that the variation in grain N offtake (kg/ha) provides a reasonable representation of variation in *total* apparent N recovery of soil and fertiliser N by the crop, as was reviewed previously for the older UK varieties by Bloom *et al.* (1988).

Fig. 5.13a shows that apparent recovery of soil N (i.e. grain N with nil fertiliser applied) was very similar for the new varieties and for the old varieties, with the new varieties showing slightly better recovery in most cases. Mean grain N offtake for the 29 sites where grain N was measured with nil N applied was 98 and 103 kg/ha for old and new varieties respectively.

The same comparison is made in Fig. 5.13b but with optimum N applied. A further six sites were omitted here because they had small Nopts, hence gave results essentially the same as with nil N applied. In this case grain N offtake by old varieties was on average 24 kg/ha less than by new varieties. Part of this difference was due to the greater Nopts of the new varieties. However, the apparent N recovery in grain (additional N recovered at Nopt from recovery at nil N, divided by Nopt) for old varieties was 44% compared to 48% for new varieties. These values relate approximately to 56% and 63% apparent recovery of fertiliser N into the whole crop respectively by old and new varieties. Hence there appears to be no evidence here that breeding for yield has decreased recovery of soil N as suggested by Foulkes *et al.* (1998), and these data support the conclusion of Foulkes *et al.* (1998) that breeding for yield has brought associated improvements on apparent recovery of fertiliser N.

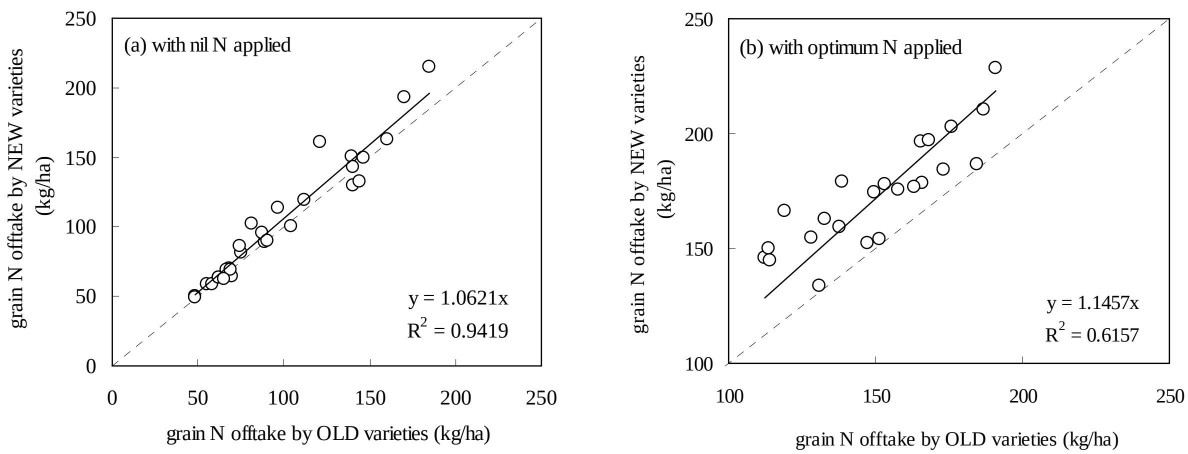


Fig. 5.13. Average grain N offtake for 'modern' varieties at a site in relation to average grain N offtake by 'old' varieties (a) with nil N applied and (b) with optimum N applied. Both relationships were statistically significant. The dotted line shows equivalence between old and new varieties.

5.2.7 Timing of N for alcohol production (2007 only)

5.2.7.1 Effect on Grain Yield

Unfortunately 2007 was a low yielding year, and the N optima were generally low so the N rates at which the N timings were tested were generally all larger than the N optimum (Table 5.7). In addition, 2007 had a very dry period during and following the main fertiliser application period, so conditions were not appropriate for expression of N timing effects. In the event, there were no significant effects of N timing on grain yield at any site (Table 5.7).

5.2.7.2 Effect on alcohol processing yield and alcohol yield per ha

The N timing treatments had no significant effect on grain N%, hence on estimated alcohol processing yield at any of the five sites for which data are available (Table 5.8). The estimated alcohol processing yields were remarkably consistent across treatments and sites.

Table 5.7. N application rates, N optimums and effects of N timing on grain yield at 6 sites in 2007.

	N rates (kg/ha)		**Grain yields according to N timing (t/ha)**				
Site	*Tested*	*Optimum*	*Nil N*	*50% Early*	*33% Early*	*Normal*	*SED*
Boxworth	220-370	171	5.88	9.05	8.79	8.96	0.26
High Mowthorpe	220-370	220	4.71	8.57	8.48	8.38	0.30
Terrington	180-300	64	6.04	8.09	7.84	8.16	0.29
Rosemaund	150-250	100	5.03	9.93	9.88	9.88	0.43
Kent	150-250	129	7.38	8.90	8.97	9.10	0.52
Laurencekirk	180-300	172	ND	8.01	7.94	8.06	0.31
Mean		**143**	**5.81**	**8.76**	**8.65**	**8.76**	

Table 5.8. Effects of N timing on alcohol processing yield (estimated from grain N concentration), hence alcohol yield at five sites in 2007.

	Alcohol processing yield (litres / dry tonne)				**Alcohol yield (litres / hectare)**			
Site	*N timing treatment*				*N timing treatment*			
	50% Early	*33% Early*	*Normal*	*SED*	*50% Early*	*33% Early*	*Normal*	*SED*
Boxworth	438	438	435	*3.5*	3,959	3,851	3,897	*70*
High Mowthorpe	429	429	427	*2.3*	3,676	3,639	3,578	*79*
Terrington	432	431	431	*2.4*	3,495	3,375	3,520	*109*
Rosemaund	440	441	442	*3.8*	4,372	4,358	4,367	*118*
Kent	431	431	432	*2.9*	3,835	3,870	3,929	*191*
Mean	**434**	**434**	**433**		**3,867**	**3,819**	**3,858**	*113*

Due to the lack of effects on grain yield and alcohol processing yield, calculated alcohol yields per hectare also showed no significant effects of the N timings. As was explained in the proposal for this extension to the main project, N timings are best tested at N rates less than and approaching amounts that prove optimal for grain yield, and in seasons when adequate rainfall provides for rapid availability of N applications. Due to structural problems with the trial design and the low optima for the season it was only possible to test these N timings at N rates well above the N optimum. Therefore, these trials did not provide a good test of the hypothesis that advanced N timing can help to maximise alcohol yields from winter wheat. Further experimentation is required to evaluate whether timing of N application is an important factor in growing wheat for bioethanol.

5.3 Spring Barley Experiments

5.3.1 Soil N Supplies (SNS)

Soil N supply (SNS) assessed by soil analysis in the spring barley trials varied from 23 kg/ha at York 2006 after winter wheat with 0.10% total N in the topsoil to 224 kg/ha at Laurencekirk in 2005 after setaside, and with 0.34% total N in the topsoil. As with the wheat sites, the Field Assessment Method (FAM) defined in RB209 (combining previous cropping, soil type and over-winter rainfall) was not a satisfactory predictor of SNS as assessed by soil and crop analysis in these trials. Also as for wheat sites, SNS by analysis related better to total topsoil N than to previous cropping (Fig. 5.14).

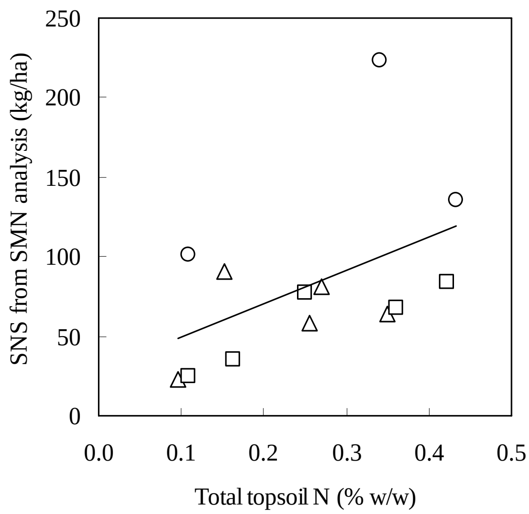


Fig. 5.14 Relationship between SNS and total topsoil N for barley trials harvested in 2005 (circles), 2006 (triangles) and 2007 (squares). R^2 was 0.23.

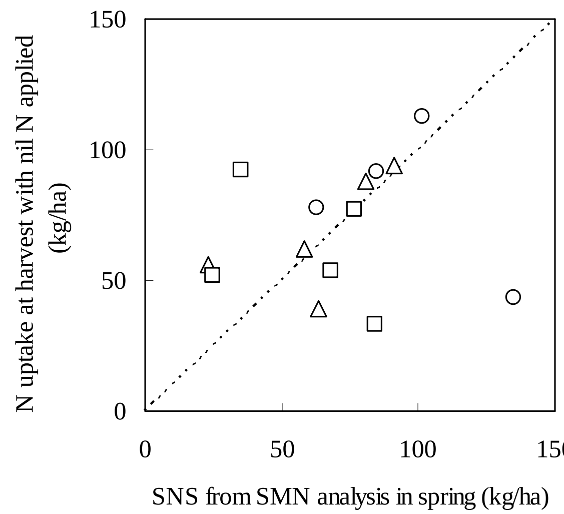


Fig. 5.15 SNS derived by soil analysis in spring and crop N uptake by spring barley with nil N applied: 2005 (circles), 2006 (triangles) & 2007 (squares). R^2 = 0.01.

As with the wheat trials, and assuming an N harvest index of 0.7, there was no significant relationship between SNS determined by the FAM of RB209 and nil N uptake. On average across sites SNS by soil analysis gave similar quantities to nil-N uptake at harvest, but despite the wide range of SNS by soil analysis it showed no relationship with nil-N uptake (Fig. 5.15). Clearly the processes governing soil N recovery work in a different way with spring barley than with winter wheat.

5.3.2 Grain yield & Grain N

5.3.2.1 Site & Season

The sites chosen for these trials were all on the east of the UK, 6 in Scotland and 9 in England. Soil types were sandy (3), shallow over chalk (5), deep silty (3) and other mineral (4). Previous crops were spring peas or beans (2), setaside (2), sugar beet (1) and cereals (10), and previous crop residues were baled (11) or incorporated (4). Thus sites provided a good representation of how spring barley is grown in the UK. Optimum grain yields in the trials were generally modest for spring barley at about 6 t/ha (Table 5.9). Spring barley yields in Scotland were greater than in England, and yields on the deep silty soil (with the lowest organic matter) at York were consistently poor compared to other sites (Table 5.9).

Table 5.9 Mean grain yields (t/ha @ 85%DM) of modern varieties at each spring barley site in the three seasons of N response experiments described here.

Barley sites	**2005**	**2006**	**2007**	**Mean**
	Mean grain yield at optimum N, t/ha			
SAC, Aberdeen	7.06	5.29	6.17	**6.17**
SAC, Laurencekirk	7.31	6.34	7.38	**7.01**
ADAS, Rosemaund	5.44			**5.44**
ADAS, High Mowthorpe		6.75	5.48	**6.11**
NDSM, York	4.19	4.01	4.41	**4.20**
Masstock, Fowlmere	6.83	5.19	6.71	**6.24**
Mean	**6.17**	**5.52**	**6.03**	**5.86**

5.3.2.2 Variety

The performance of varieties in the trials, and particularly the lower yields of older varieties, were much as expected. Overall it was expected from RL data that the old varieties of barley grown here would yield 77% of the newer varieties. In the event they yielded better than this, at 85% of the newer varieties (Table 5.10). This appeared to be because the newest and highest yielding varieties from the RL (Waggon and Publican) were only tested in 2007, when yields were compromised by this being the lowest yielding season.

Average Nopts were similar for old and new varieties, despite the higher yields of the new varieties. This clearly contrasts with the findings on winter wheat. Interestingly, along with their higher yields, new varieties had smaller grain N% at Nopt than old varieties. Thus the estimated N Use Efficiency (NUE, kg grain DM formed per kg soil & fertiliser N supplied at Nopt) of new varieties was greater, at 39 kg DM / kg N, than for the old varieties at 31 kg DM / kg N (NHI was assumed to be 0.7 at Nopt). In Section 3.2.1.5 (Fig. 3.9) it was noted that the long term trend has been for a decrease in average national on-farm grain N%.

Malting varieties yielded similarly to feed types and had a 9 kg/ha lower average N optimum. The lower optimum of the malting varieties resulted from a slightly better recovery of soil N (at nil N applied) rather than a lower grain N%. However, the overall NUE of malting varieties was no better than that of feed varieties – slightly better N Utilisation Efficiency (kg grain DM per kg N uptake) was offset by slightly worse N Uptake Efficiency (kg N uptake per kg N supplied from soil & fertiliser).

Table 5.10 N optima (LEXP parameters varying for variety, except R which was fixed by site), grain yields and grain N contents of each spring barley type averaged over the 15 site-seasons of N response experiments described here. (Grain not analysed for N at York 2005.)

Variety	**N opt**	**Grain yield**		**Grain N%**		**Grain N offtake**	
Type		nil N	opt N	nil N	opt N	nil N	opt N
	kg/ha	*t/ha*	*t/ha*	*% dmb*	*% dmb*	*kg/ha*	*kg/ha*
Old	138	3.36	4.99	1.61	2.11	45	89
New	134	3.90	5.90	1.48	1.96	48	98
Malt	130	3.68	5.36	1.55	2.02	48	91
Feed	139	3.45	5.36	1.48	1.97	44	92

5.3.3 N responses

In 2005, 2006 and 2007 the responses to N were 22%, 37% and 38% of optimum yield respectively, and the average Nopts were 105, 159 and 144 kg/ha N. Average yield response at a site was up to 60% of optimum yield, and was 32% on average. Thus most sites provided a reasonable opportunity to discriminate between responsiveness to N of different varieties. In each of the three seasons there was one site where the response in grain yield to applied N was small or nil, hence Nopt was difficult to determine, and it was not possible to discriminate between the responsiveness of varieties to applied N at these sites. Unresponsive sites were at York in 2005 and 2007 and Fowlmere in 2006. Whilst York 2005 was low yielding and had a relatively large SNS (101 kg/ha), there is no obvious explanation for the lack of response at the other two sites.

5.3.3.1 Grain yield responses

Except for the 3 sites where there was little response to N, the LEXP function accounted for 77% of variation in yields on average (range 43% to 92%). Even at the site accounting for only 43% (SAC Kirkton 2005) of the variation, the SE of Nopts were only about 20 kg/ha, so the Nopts were determined with reasonable precision. In general, a curve only differing in the '*a*' parameter (giving a vertical shift, hence not affecting Nopt) accounted for as much variation as when parameters '*b*' and '*c*', or '*b*', '*c*' & '*r*' were also allowed to vary between varieties. Thus there was seldom statistical evidence that Nopt differed between varieties.

However, as for wheat, the Nopts presented here are those fitted with just the '*r*' parameter held constant within each site (*a*, *b* & *c* varying between varieties), so that any non-significant differences in Nopts between varieties can be examined.

Whilst the variation between sites in Nopt (average of the two modern varieties) was clearly related to the soil N supply as estimated from nil N uptake at each site (Fig. 5.16a), Nopt was not related to any estimate of soil N supply that could have been made in spring, either using the FAM or soil analysis (SMN or topsoil N%). Site-season Nopt was related significantly to site-season yield (Fig. 5.16a) but there were not sufficient points to distinguish whether the relationship for sites, as opposed to seasons, was sufficiently consistent for this to be considered as a useful component of Nopt prediction.

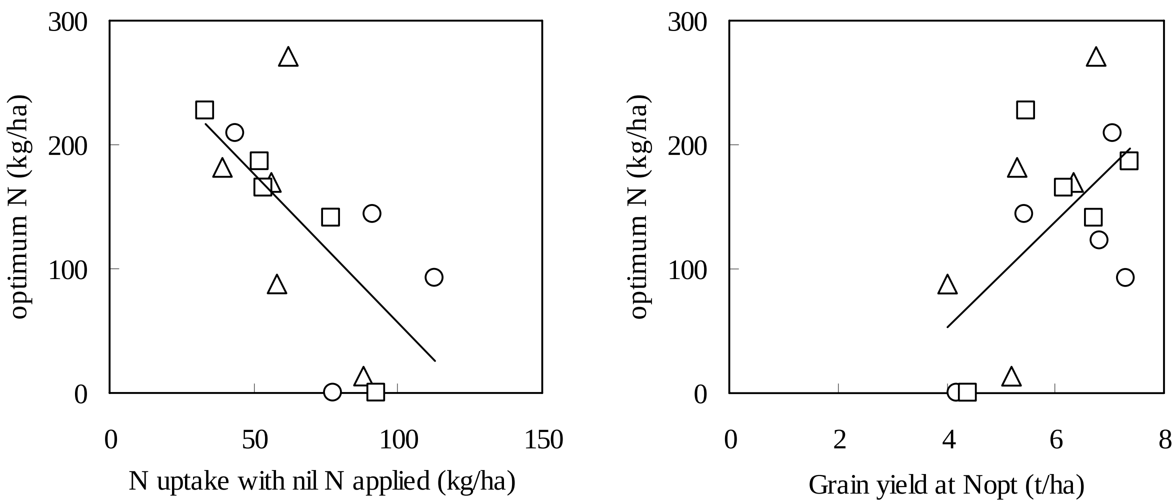


Fig. 5.16 Relationship between the mean N optimum at BER 3:1 of two modern varieties spring barley in 2005 (circles), 2006 (triangles) and 2007 (squares) and (left) SNS as estimated from nil N uptake (assuming NHI=0.7; R^2 = 0.43) or (right) grain yield with optimum N (R^2 = 0.35).

Nopts for individual varieties ranged from nil to greater than the maximum level tested (300 kg/ha N) and their grain yields with optimum fertiliser N (sometimes nil) varied from 2.6 to 7.5 t/ha. However, in contrast to the data on wheat, there was no evidence for a relationship between the yield differences between varieties (within a site) and differences in Nopt between varieties, despite yield differences within a site being up to 2 t/ha (Fig. 5.17). It appears that this arises because, whilst breeders have achieved significant yield improvements in modern spring barley varieties, they have also increased their NUE sufficiently to negate the need for more fertiliser N to achieve those yields (see Section 5.3.2.2).

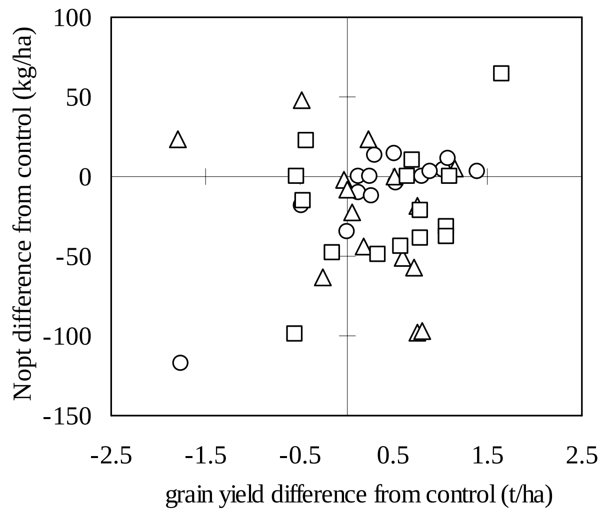


Fig. 5.17. Differences from a control variety in N optimum (BER 3:1) in relation to differences in grain yield at Nopt for spring barley varieties tested in 15 site-seasons: 2005 (circles), 2006 (triangles) and 2007 (squares). $R^2 = 0.04$.

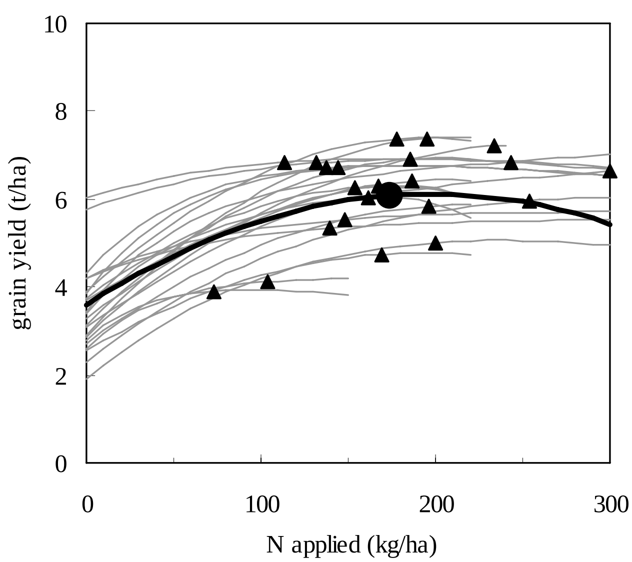


Fig. 5.18 Twenty two response curves from barley trials in 2005-7, all for individual varieties where R^2 for LEXP was >0.5 and Nopt<Nmax (grey lines), each marked (triangles) with their Nopt at BER 3:1, and an 'average' curve (bold line) fitted to their average fitted yields, giving an 'average Nopt' of 174 kg/ha N at BER 3:1 (black circle).

The 'average' response curve (Fig. 5.18) determined for barley, in the same way that it was for wheat (see Section 5.2.3.3), 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.

5.3.3.2 Grain N

In barley grain N% (dry basis) at Nopt averaged at 2.11 and 1.96% for old and new varieties respectively (Table 5.10), with a tendency for a slight but significant positive relationship with Nopt (Fig. 5.19). This trend applied to both old and modern varieties of spring barley. If use of grain N% is to be broadened to spring barley (and other crops) it will clearly be important, in the further review of this relationship (under HGCA Project 3436) to explore whether it applies to the larger dataset being collated there. The lower grain N% at Nopt for modern varieties than for the old varieties implies that the guideline grain N% to be used to indicate optimal N use of spring barley would have to be checked and (if necessary) changed as breeding progressed, in addition to making adjustments for BER (Table 5.11).

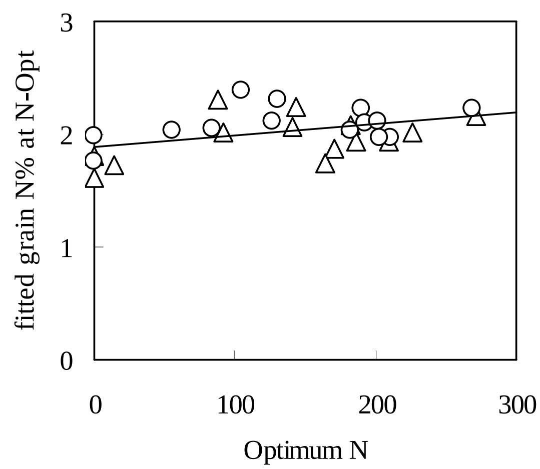


Fig. 5.19 Mean grain N (% DM) in relation to Nopt for old (circles) and new (triangles) varieties of spring barley tested in N response trials from 2005 to 2007. The regression line has a slope of 0.11% N per 100 kg/ha N applied ($R^2 = 0.19$).

The majority of spring barley crops will be intended for the malting market. Malting varieties had similar grain N% to feed varieties at Nopt. Even at Nopt BER 6:1 the average was 1.89% (Table 5.11)so would have been too high to meet most malting specifications (Fig. 5.20; HGCA 2001). For grain N in 80% of these crops to have been less than 1.75%, very little applied N (<20 kg/ha) should have been used; even for average grain N to be less than 1.75% only 70 kg/ha applied N would have been required. However the profit foregone from only applying 70 kg/ha would have been equivalent to the value of 28 kg/ha N – or a premium would have been required of at least the value of 6 kg N per tonne grain to make this N adjustment worthwhile. Clearly, as BER increases, there is a decrease in the premium required to justify under-fertilising for the malting market; at BER 3:1 the premium required would have been the value of 28 kg fertiliser N per tonne.

Table 5.11. Mean, maximum and minimum grain N (% DM) at Nopt in each of 15 N response trials on spring barley from 2005-2007 according to different Break-Even Ratios.

	BER 3:1		**BER 6:1**		**BER 9:1**	
Variety type	*Old*	*New*	*Old*	*New*	*Old*	*New*
Mean grain N%	2.09	1.96	2.00	1.89	1.93	1.82
Max grain N%	2.49	2.37	2.24	2.26	2.20	2.19
Min grain N%	1.68	1.55	1.68	1.55	1.68	1.55

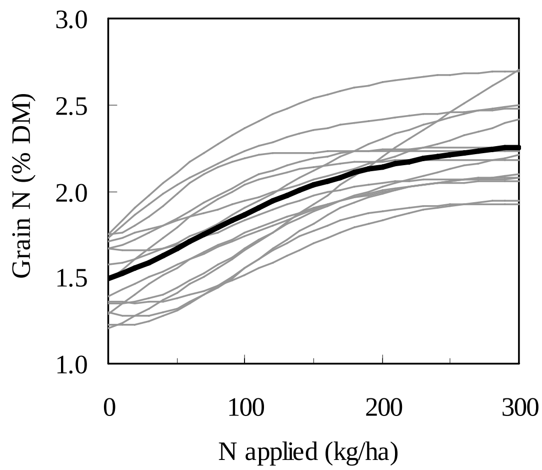


Fig. 5.20 Fitted responses in grain N (% DM) to applied N for all new varieties of malting barley tested in trials from 2005 to 2007.

5.3.4 Economic performance of N recommendations

Comparing N recommendations based either on the FAM of RB209 or on SMN analysis it is clear that both approaches advocated significantly too little fertiliser N to optimise production of modern feed varieties. The 'blanket' increases needed to minimise unrealised profit of the two approaches in these trials were 40 and 66 kg/ha N respectively. However, it is not clear that either of these approaches was worthwhile given the poor performance of recommendations based either on FAM or SMN in predicting SNS (as determined by nil N uptake – see Section 5.3.1).

It is therefore important to explore the economic implications of imprecise prediction of Nopt for spring barley. The shapes of the changes in unrealised profit as N rates change (Fig. 5.21) appeared to be more symmetrical with spring barley than with winter wheat, probably because yield losses were more common at N rates greater than optimum.

As with wheat the FAM and SMN approaches were compared with a fixed N rate at all sites (162 kg/ha, which maximised average profit) to test whether the recommendation systems would have achieved a useful economic benefit, and the results are shown in Table 5.12. It is important to note that this analysis necessarily under-estimated unrealised profit from using the N recommendations because three sites had to be excluded where effects of N on yield were not described satisfactorily by fitted functions; Nopts at these sites were at or near zero, yet N amounts recommended by both approaches were relatively large.

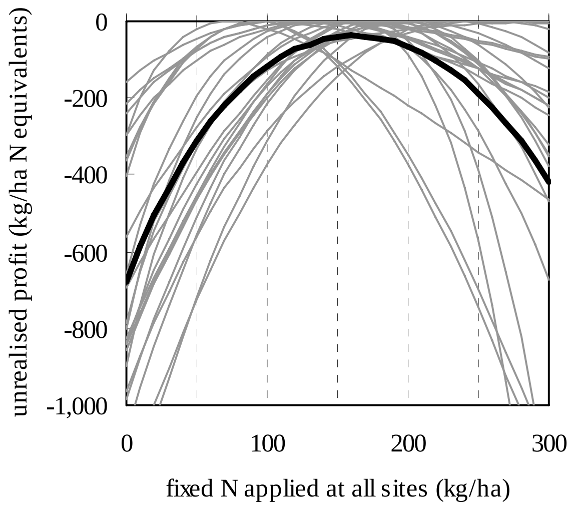


Fig. 5.21 Unrealised profit for the two modern varieties of spring barley tested in each of 12 response trials from 2005 to 2007 according to a fixed N rate applied at all sites. The average unrealised profit for all varieties at all sites is shown by the bold. The minimum unrealised profit was with 160 kg/ha N applied over all 24 responses.

Whilst Nopt varied between 88 and 271 kg/ha, recommended N varied between 80 and 190 kg/ha. The maximum amounts by which N was over-recommended were larger than if a fixed N rate had been used because large N recommendations sometimes coincided with small Nopts e.g. NDSM York 2006. Significant under-recommendation also occurred at some sites, e.g. ADAS High Mowthorpe in 2006 and 2007, resulting in 0.2-0.4 t/ha of unrealised grain yield. However, there was less difference for barley than for wheat between the average performance of the fixed N rate and the two approaches to N recommendation. FAM-based recommendations performed slightly better than a fixed N rate and SMN-based recommendations performed slightly better than FAM, but it is unlikely that these differences should be regarded as significant.

Table 5.12. Summary data from comparing economic performance of recommendation systems for the 12 site-seasons where optima could be determined on modern spring barley varieties (omitting York 2005 & 2007, and Fowlmere 2006).

	Units	Maximum	Minimum	Median	Mean
Nopt at BER 3:1	*kg/ha*	271	88	167	167
Grain yield at Nopt	*t/ha*	7.38	4.01	6.52	6.23
N recommended by FAM[1]	*kg/ha*	190	80	178	160
N recommended by SMN[1]	*kg/ha*	186	96	176	160
N difference at 162 kg/ha N[2]	*kg/ha*	74	-109	-5	-5
N difference at Nrec by FAM	*kg/ha*	102	-81	-9	-7
N difference at Nrec by SMN	*kg/ha*	98	-85	-9	-6
Yield change at 162-N	*t/ha*	0.07	-0.42	-0.08	-0.13
Yield change at FAM-N	*t/ha*	0.05	-0.30	-0.08	-0.11
Yield change at SMN-N	*t/ha*	0.05	-0.31	-0.07	-0.10
Unrealised profit at 162-N	*kg/ha N equiv.*	159	1	19	38
Unrealised profit at FAM-N	*kg/ha N equiv.*	126	0	21	30
Unrealised profit at SMN-N	*kg/ha N equiv.*	120	1	19	26

[1] Recommendations were increased by 40 and 66 kg/ha N for FAM and SMN respectively, to minimise mean unrealised profit.
[2] 162 kg/ha N was set to minimise mean unrealised profit.

Again, it is disappointing that N recommendations do not provide a significant economic advantage for the grower over using a fixed N rate. The results here call into question the value of adopting a relatively complex approach to assessing soil N supply, requiring assessment not only of previous crops, but also of soil types and over-winter rainfall, if it does not provide a reasonable economic advantage. One fixed N rate would undoubtedly be much simpler and easier to communicate and apply if this was advocated for all spring barley crops. It is possible, however, that the fixed N rate would lead to greater risk of N pollution; although the average amount of N needed to minimise unrealised profit was no different than the average N recommendations based on FAM or SMN, the frequency of over-recommendation with fixed N rate was greater.

6. Key Conclusions and Recommendations

6.1 Nitrogen requirements of modern versus old cereal varieties

This project has provided a crude comparison between species as well as comparing varieties. N requirements of wheat were generally greater than those of barley, but in both cases Nopt varied between zero and >300 kg/ha. Average yield of modern winter wheat varieties grown here were 9.9 t/ha compared to 6.1 t/ha for modern spring barley varieties, yet on average winter wheat required only about 20 kg/ha more fertiliser N than spring barley. This appears to indicate that overall N Use Efficiency (NUE) of wheat was much better than that of barley, but in fact average NUE (BER 3:1) for wheat was 34 kg DM per kg N supplied compared to barley at 36 kg DM per kg N supplied; the similarity was due to greater mean SMN and Nopt levels for wheat than barley which fully compensated for wheat's better yield.

Comparing old and new varieties, breeders have successfully improved yields of both wheat and barley since the 1980s. Wheat breeding has developed better fertiliser N recovery but not enough to compensate for better yields, whilst barley breeding has developed both better N utilisation efficiency and better N uptake efficiency, mainly through the better yields but also through reducing grain N%. Hence N requirements of wheat have increased whilst those of barley have not. It is likely that both effects on NUE are inadvertent, although it is possible that one objective of barley breeders has been reduction in grain N%, and that this has affected performance of all modern barley varieties, whether for feeding or malting. Given the different mechanisms of the improvements in NUE of wheat and barley, it will be worth exploring the genetic and physiological basis for the efficiency changes in both species.

6.2 Adjusting N recommendations for expected yield

In addition to adjusting fertiliser N applications according to soil N supplies, it is generally assumed that (if we could satisfactorily predict it) N applications would also depend closely on achievable grain yield. However, variety effects on grain yield are only one of a list of yield-effecting factors which the farmer may take into account when setting N applications. As with the variety effects studied here, it is clear from previous work that efficiency effects are often associated with yield effects, and that these may modify or (as in the case of barley varieties here) completely negate the expected yield effect on N requirements.

The following points summarise previous findings on effects of yield-affecting factors on N requirements of winter wheat:

- Concurrent differences between varieties on the RL (this report; Dampney *et al.* 2006; Foulkes *et al.* 1998) – the main differences are between Group 1 varieties and the rest. Group 1 varieties generally require high grain N%, counteracting the yield effect. Other variety differences are generally too small to justify a significant adjustment in fertiliser N.

- Progress in variety yields through breeding – there is a general trend for greater fertiliser N requirements. Foulkes *et al.* (1998) concluded the effect was ~30 kg per tonne. However they had to rely on a FITCON statistical approach to analyse a very incomplete data matrix. The work of Dampney *et al.* (2006) and data in this report provides a more robust assessment, suggesting the effect is ~20 kg N per tonne grain yield. This is explained by the associated improvement in fertiliser N recovery in the new varieties.

- Soil types confer different yield potentials, and they also are recognised to have different capacities for retention of N and water. As a consequence there are not necessarily inherent associations between yield differences and differences in N requirements:

    - Comparisons between different clay types e.g Oxford clay vs. Hanslope clay have generally shown that the lower yielding, heavier soils also have counteracting differences in apparent recovery of fertiliser N (Vaidyanathan *et al.* 1987; Vaidyanathan & Wilson, 1992)

    - Work on sands showed that yields were constrained by drought in dry years and that apparent recovery of fertiliser N was greater than on other soils, hence Nopts were generally lower than other soil types (Webb *et al.* 1998b, 2000).

    - Experiments on shallow soils over chalk showed lower yields compared to those on clays, but they also showed lower N recoveries, and these were the more significant in terms of N nutrition, resulting in larger Nopts (Grylls *et al.* 1997).

- First wheats generally yield more than second or subsequent wheats in the rotation. Paired experiments in the 1980s showed that second wheats had lower yields and similar apparent N recovery to first wheats, but they had higher grain N% at Nopt than first wheats (Vaidyanathan *et al.* 1987). Hence their total N uptake was very similar in both situations, so first wheats had markedly smaller Nopts than second wheats, in line with their significantly greater SNS (Sylvester-Bradley *et al.* 1987).

- Delays in sowing generally reduce yields of wheat. When N responses were compared through a series of sowings from autumn to spring it was found that apparent N recovery also decreased as sowing was delayed, so that Nopt was not significantly affected – late sowings required similar N amounts to earlier sowings (Webb *et al.* 1995).

- There are yield differences between region and farm which are difficult to assess and test objectively. Regional differences may be climatic in part, but farm differences are mainly due to differences in crop management and soil fertility. No good comparisons have been published of overall management differences on Nopt, except to say that recent work looking at the interaction between foliar disease control (with fungicides) and Nopt shows a clear association between yield and Nopt (Paveley *et al.* 2008). Whilst further work on farm-to-farm variation in yield and Nopt seems worthwhile, for the time being it is probably best to assume that grain N% is likely to indicate this yield effect on Nopt.

Seasonal variation in grain yield is not predictable. In retrospect it is fairly clear that seasonal variation in Nopt relates positively to seasonal variation in grain yield (Sylvester-Bradley *et al.* 1987; Webb *et al.* 1998a). For example 2007 was a low yielding year with low Nopts (Fig. 5.5).

- It is of concern that trial yields generally exceed field yields. Unfortunately this effect is untestable, since Nopts always have to be determined by trial. Again grain N% is probably the best indicator of whether field or farm N use relates to Nopt, since one key difficulty in comparing trial and field yields is the measurement of crop area, and grain N% does not depend on an area measurement.

In conclusion it seems that there are four predictable yield-affecting factors that also affect Nopt:

1. **Progress due to plant breeding**. For wheat this effect works out to be only about 2 kg N per ha per year so it is probably best taken into account in each revision of N recommendations, rather than by an on-farm adjustment. This effect has not been significant for barley.

2. **Soil type**. In RB209, this effect has been taken into account by having different rows in the recommendation tables which take into account both yield and N recovery effects.

3. **Farm management**. There is a question of whether grain yield or grain N% is the better indicator of this effect on N requirements. From experience in trying to compare on-farm data it would appear that grain N% is simpler to obtain, requiring no calculations, and can be provided by a third party hence can be accredited. The comparability of on-farm observations of grain yield is often more questionable.

4. **Region**. Regional yield data (e.g. from Defra statistics) do not show sufficient differences to indicate there might be significant effects on Nopt. However, mean grain N concentrations are available for different regions and seasons based on large numbers of samples (Table 6.1). Given that grain N% appears relatively consistent at Nopt (Figs. 5.11 & 5.19), it may be possible to infer how regional N use relates to optimal N use. For example, the low grain N concentrations in Scotland may indicate the degree to which N use is sub-optimal for yield in Scotland. Note that grain N% at Nopt for the Scottish trials reported here was 1.97% for wheat and 1.96% for barley, little less than those of English sites (means 2.06% and 1.99%). However this approach requires further work before firm conclusions can be drawn for instance to correct for effects of growing for bread making or malting markets.

Table 6.1. Regional grain N data from HGCA Cereal Quality Survey 2003-5 harvests. These are unadjusted for variety types (feed, bread making and malting).

	Barley	*Wheat*
Scotland	1.62%	1.99%
North	1.78%	2.09%
Midlands	1.81%	2.23%
East	1.79%	2.24%
South East	1.78%	2.25%
South West	1.77%	2.22%

6.3 Determination of SNS for N decision-making

Whilst this Project was not primarily intended to assess the accuracy and precision of different approaches to N recommendation and on-farm decision-making, it has clearly been useful in highlighting the difficulties in designing a useful Field Assessment Method and the value of soil analysis in on-farm assessment of SNS. It is reassuring that the relationship between SNS estimated from soil analysis and N offtake with nil applied N (Fig. 5.4) was very similar to that found in previous published work (Sylvester-Bradley *et al.,* 2001) at least for wheat. Similarly it is reassuring that the relationship between Nopt and SNS estimated from soil analysis was highly significant and compatible with that reported in previous published work (Harrison, 1995). It The slope of the relationship found here (Fig. 6.1) was 1.39 kg fertiliser N per kg SNS, steeper than that reported by Harrison (0.62 kg/kg), probably because there were fewer cases with very high SNS and nil Nopt in this dataset.

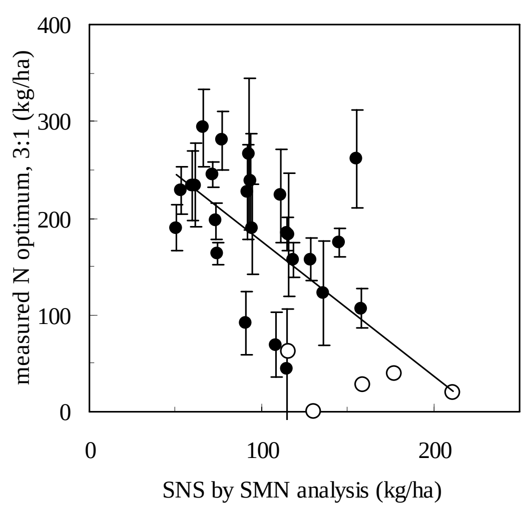


Fig. 6.1. Relationship between mean optimum N applied at BER 3:1 for two modern varieties and SNS determined by soil analysis for SMN over-winter (uncorrected for leaching) for all 30 wheat site-seasons tested in this Project. Open circles indicate sites where the LEXP function did not fit and Nopt was estimated by inspection. The fitted line is y = 314 – 1.39x; R^2 = 0.40***.

There are apparent discrepancies between the conclusions drawn here and those drawn in HGCA Project 3287 (Knight *et al.*, 2008) which studied soil N recovery and how fertiliser N affects soil N recovery, based on studies with N^{15}-labelled fertiliser. The conclusion in HGCA Project 3287 was that the recovery of SNS by the crop decreases as SNS increases; this may appear inconsistent with the direct relationship illustrated for this Project in Fig. 5.4 and from previous work by Sylvester-Bradley *et al.* (2001). However, the decrease in recovery is consistent with the present results; it arises because of the significant positive intercept in these relationships. The interpretation of SMN data advocated by RB209 discounts any intercept (i.e. underestimates true SNS at all SNS levels) and assumes direct equivalence between SNS by SMN analysis and true SNS, an approach which errs towards ensuring ample N supply.

Although it is perturbing to conclude that the FAM was not worthwhile in terms of profit for either wheat or barley, this conclusion is important in highlighting how future N recommendations might be devised, improved and tested. Assuming appropriate site and crop descriptions have been collated during the preparation of the 8th edition of RB209 it should prove possible to examine unrealised profit for a range of different approaches to recommendation. Key indications from the analysis presented here are listed below. These need testing on the wider dataset.

- Wider use of soil analysis would be worthwhile.
- The average level of N recommended (i.e. accuracy as opposed to the precision) has a large effect on unrealised profit, and careful attention needs to be paid to getting this right.
- Lost profit can be much more seriously affected by not recognising a few sites with unusual Nopts, than by not recognising small imprecisions at the majority of sites that have close-to-average Nopts. This points to a need to develop a risk analysis approach to underlie N decision-making.

6.3.1 Recognition of different conditions in Scotland

As explained by Sinclair *et al.* (2002), recommendations for fertiliser N in RB209 are not entirely appropriate for Scottish conditions. Differences relate to differences in the classification and behaviour of organic matter in soils, generally wetter weather over-winter, generally cooler and moister summers, and consequently slower winter growth with prolonged and less droughted summer growth.

Organic soils as defined in RB209 are predominantly mineral, with between 6 and 20% organic matter, and peaty soils are defined as soils that contain more than 20% organic matter (derived from sedge or similar material). N recommendations for the “organic soils” category in RB209 would seriously underestimate the N responsiveness of the major crops in Scotland. For example, in RB209 the highest N recommendation for winter barley grown in a soil with between 6 and 20% organic matter is 120kg/ha. Winter barley grown in trials in Scotland on soils with between 6 and 15% organic matter have given economic responses up to 180kg/ha. These differences may be explained by greater mineralisation of organic N during the growing season in English conditions, compared with soils of similar total organic matter content in Scotland.

Alternatively they could result from higher rates of leaching and/or denitrification in wet soils with high organic matter concentrations.

Greater immobilisation of fertiliser N may also contribute to greater N requirements in Scotland. It is possible that this is linked to differences in soil properties, but there is also some indication that plant growth, and particularly variations in rates of turnover of root tissues, are also responsible. Research in Scotland is investigating the effects of root carbon deposition on N immobilisation in soils planted with wheat. This should eventually lead to clarification of the reasons for the Scottish-English difference.

Differences in fertiliser N recovery between Scotland and England my also arise. Crops are often grown on light sand soils e.g. sands and loamy sand textured soils, in Scotland, and these tend to respond to higher rates of N than are recommended in RB209, probably because drought conditions are less common, giving greater yields on these soil types than are generally found in England.

Thus the fertiliser recommendation system for N under Scottish conditions (Sinclair, 2002: SAC Technical Note T516) differs from RB209. It is based on previous crop and grass/clover management, modified by N mineralised from soil organic matter, previous organic manuring and recent crop debris, and N lost by overwinter leaching. Average over-winter rainfall for all agro-climatic areas in Scotland is over 700mm, with the exception of the Lothian coastal plain. Each SNS Index is defined in terms of a range of estimated SNS amounts in a 0-90 cm soil depth (or maximum rooting depth where rock restricts rooting). Rooting depth is less than 90 cm in many soils in Scotland.

6.4 Effects of prices on N optima

The recent volatility in prices of fertiliser and grain have accentuated the need for guidelines on adjusting for BER. In scientific terms these adjustments depend on the rate of change of slope of the grain yield response curves. (This leaves aside the commercial issues concerning the time-lag between the farmer paying for the fertiliser and receiving payment for the grain, and judgement of which N rate should form the basis for adjustment.) However, it has been unclear whether the rate of change of slope differs depending on whether the curve considered is derived from one site (or curves co-located at their Nopts and Yopts before averaging; Fig. 5.8) or is an average of curves from many sites, often having differing optima (Fig. 5.9). It was reassuring to find that these were little different, and also to find that the adjustment per point change in BER was relatively stable over the range of BER that has been experienced, averaging 11 and 8 kg/ha N per point increase for wheat and barley respectively.

Taking the best estimates of standard curves for wheat and barley from these data, a price adjustment table was devised (Table 6.2) for both cereal species. A similar table has been proposed for inclusion in RB209:

Table 6.2. Appropriate adjustments to fertiliser N rates, depending on prices of fertiliser and grain.

	Fertiliser N content (%)	*Fertiliser Cost (£/tonne PRODUCT)*				
Ammonium Nitrate	34.5%	£104	£207	£311	£414	£518
Urea	46.0%	£138	£276	£414	£552	£690
Urea-Ammonium Nitrate liquid	28.0%	£84	£168	£252	£336	£420
Cost of fertiliser nitrogen	*£/kg N*	£0.30	£0.60	£0.90	£1.20	£1.50
Change to recommended N for WHEAT (kg/ha)						
Wheat sale price (£/tonne)	50	-30	-75	-105	-130	-150
	100	0	-30	-55	-75	-90
	150	15	-10	-30	-50	-65
	200	20	0	-15	-30	-45
decrease	250	25	10	-5	-20	-30
increase	300	30	15	0	-10	-20
	350	30	15	5	-5	-15
	400	30	20	10	0	-10
	450	35	25	15	5	-5
	500	35	25	15	10	0
Change to recommended N for BARLEY (kg/ha)						
Barley sale price (£/tonne)	50	-25	-70	-115	-160	-205
	100	0	-25	-45	-70	-90
	150	10	-10	-25	-40	-55
	200	10	0	-10	-25	-35
decrease	250	15	5	-5	-15	-25
increase	300	15	10	0	-10	-15
	350	15	10	5	-5	-10
	400	15	10	5	0	-5
	450	20	15	10	5	-5
	500	20	15	10	5	0

6.5 Recommendations for further research

Whilst some clear conclusions have been drawn, many concerns and uncertainties have arisen in the interpretation of these data which may be addressed usefully by further research.

- Improvements in N Use Efficiency have occurred through breeding that have clearly been important in minimising increases in N requirements of UK cereals. Given the hugely increased prices of fertiliser N in recent years it will be very important for these to continue – there is still much scope to improve NUE of both wheat and barley – hence it will be important to understand the genetical and physiological basis of recent improvements, and to explain why some components of NUE have not improved.

- A comparison of NUE of different cereal species could provide a key to informing breeding strategies for NUE. The effects of breeding on NUE in wheat and barley differed here so it may be possible to identify particular genetical means or particular plant breeding strategies that will encourage improvements in both N capture and N utilisation in breeding programmes of both species. It should be noted that oats and triticale have reputations for high NUE, particularly through high N capture.
- Given the increasing concerns about fertiliser costs in growing cereals it will be important to consider how RL testing can be modified to encourage further improvements in NUE of cereals whilst not inhibiting improvements in productivity. 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.
- 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 but there is clearly an urgent need to devise alternative ways of specifying N requirements. These are likely to be less sophisticated than the FAM in RB209, but must prove more robust in identifying sites with aberrant responses. Wider use of analysis for total topsoil N could be useful here.
- There has been controversy in the interpretation of SMN data from this and other HGCA projects conducted by Rothamsted Research, The Arable Group and ADAS. It will be important that this is resolved, probably under HGCA project RD-2007-3425, so that confusion is not 'sown' in the industry.
- The SMN results from this project showed a better relationship with nil N offtake *with* rather than without correction for over-winter leaching, whereas they showed a better relationship with Nopt *without* rather than with correction for over-winter leaching. Since SMN is being determined under HGCA project RD-2007-3425 both in autumn and spring it will be important that the need for leaching correction is resolved and the best methodology developed. It should be noted that the method used here was crude; there was no capacity to optimise this.
- Given the imprecision of N recommendations, and consequent occurrence of lodging in some cases, it will be important for yield enhancement to know whether lodging due to over-fertilisation can be prevented, and what are the best avoidance strategies. Given the later uptake of fertiliser N, it is likely that lodging due to over-fertilisation happens in a different way to lodging due to high soil N supplies.
- 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 current uncertainty in the industry about optimum N timing for modern cereal varieties. The last comprehensive work on N timing for wheat was completed in 1981 and on barley was completed in 1984, so it is highly likely that the recommendations

that remain in RB209 require revision; in the last 25 years there have been significant changes in many aspects of soil management, climate, varieties and markets that are likely to affect optimum N timings.

- Data from this project were used in HGCA reports on optimising N for alcohol production (Kindred *et al.* 2007) and data from one site was used to illustrate how N might be optimised to mitigate greenhouse gas emissions from cereal production (Kindred *et al.* 2007; Sylvester-Bradley & Kindred 2008). Now that the complete dataset has been collated there is an opportunity to deduce general rules on these issues from these data.
- The fertiliser used here was exclusively ammonium nitrate. Given the high prices of this and other conventional N fertilisers, the industry is now being offered various alternative sources of N, including urea, calcium cyanamide, TwinN, calcium ammonium nitrate, and various inhibitors of urease and nitrification. Product choice would be assisted by comparisons of these products.
- Defra, under Project IS0223, has funded additional experimental work on a sub-set of the sites used here to follow and quantify the effects of applied N on N residues and the potential for N pollution through leaching and nitrous oxide emissions. It will be important that these data are combined with data on the economic performance of the sub-set of crops to reach appropriate conclusions on any compromise between environmental and economic repercussions of N fertiliser use.
- 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 Nopt, and the effect of breeding on grain N% in barley.

7. Knowledge transfer

The primary knowledge transfer vehicle for this project has been provision of data to Rothamsted Research, along with involvement of Peter Dampney on the SNS Working Group and Roger Sylvester-Bradley on the N Responses Working Group for the revision of RB209. However the project has also been widely promoted in the industry through the following channels:

Cereals 2005, 2007 & 2008

ADAS Open Days 2005: Rosemaund, High Mowthorpe, Boxworth

Farmacy & SAC Open Days: Barr Farm (Lincs.), Laurencekirk and Aberdeenshire

Articles in Crops 16 July 2005, Farmers Guardian 8 July, Hereford times May 19

Article in Crops, January 2006

Kemira / GrowHow events 2006

ADAS Open Days 2006: Rosemaund, High Mowthorpe, Boxworth

ADAS Spring N advice 2007.

Articles in the farming press 2007

HGCA 'Topic Breakfast' meetings: 2007 & 2008 campaigns

ADAS Open Days 2008: Rosemaund, High Mowthorpe, Boxworth.

SAC Open Days: Aberdeen, Kincardine, Pitlochry

HGCA R&D conference 2008

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9. References

Anon (2000). *Fertiliser Recommendations for Agricultural and Horticultural Crops (RB209), 7th edition.* MAFF, London (Available from The Stationery Office, Norwich).

Bloom, T.M., Sylvester-Bradley, R., Vaidyanathan, L.V. & Murray, A.W.A. (1988). *Apparent recovery of applied N by winter wheat,* in Efficiency of Nitrogen Use, eds. D.S. Jenkinson & K.A. Smith. Elsevier, London, pp. 27-37.

Dampney, P.M.R. (2000). *Development and revision of national recommendations for the use of fertilisers and organic manures in England and Wales.* Proceedings of the International Fertiliser Society No. 457, PO Box 4, York.

Dampney, P.M.R., Edwards, A. & Dyer, C.J. (2006). *Managing nitrogen applications to new Group 1 and 2 wheat varieties.* HGCA Project Report 400. 121 pp.

Defra (2008). *Guidelines for Farmers in NVZs – England.* Defra publications www.defra.gov.uk

Foulkes, M.J., Sylvester-Bradley, R. & Scott, R.K. (1998) Evidence for differences between winter wheat cultivars in aquisition of soil mineral nitrogen and uptake and utilization of applied fertilizer nitrogen. *Journal of Agricultural Science, Cambridge* **130**, 29-44.

George, B.J. (1984). *Design and interpretation of nitrogen response experiments.* In 'The nitrogen requirement of cereals', Reference Book 385, 133-149, MAFF.

Goodlass, G., Sylvester-Bradley, R. & Dyer, C.J. (2002). Estimation of the nitrogen requirement of winter wheat in the UK: a multiple regression approach. *Journal of the Science of Food and Agriculture* **82**, 720-727.

Grylls J.P., Webb, J. & Dyer, C.J. (1997). Seasonal variation in response of winter cereals to nitrogen fertilizer and apparent recovery of fertilizer nitrogen on chalk soils in southern England. *Journal of Agricultural Science* **128**, 251-262.

Harrison, R. (1995). An investigation of the relationship between soil mineral nitrogen in the autumn or spring and optimum nitrogen rate for winter cereals. *Soil Use & Management* **11**, 186-192.

HGCA (annual). *Cereal Quality Surveys.* www.hgca.com

HGCA (2001). *Introductory Guide to Malting Barley*. HGCA, London, 24 pp.

Kindred, D.R., Smith, T.C., Sylvester-Bradley, R., Ginsberg, D. & Dyer, C.J. (2007). *Optimising nitrogen applications for wheat grown for the biofuels market.* HGCA Project Report No. 417. 44 pp.

Knight, S., Macdonald, A., Glendining, M., Whitmore, A., Dailey, G., Goulding, K., Sinclair, A., & Rees, B. (2008). *Better estimation of soil nitrogen use efficiency by cereals and oilseed rape*. Research Review No. 68 London: HGCA.

Overthrow, R. (2005). *Nitrogen management in spring malting barley for optimum yield and quality.* HGCA Project Report No. 367. 58 pp.

Paveley, N., Kindred, D., Berry, P. & SPINK, J. (2008). Can disease management reduce greenhouse gas emissions? In 'Arable cropping in a changing climate' HGCA conference 23-24 January 2008, pp. 38-46.

SEERAD (2003). Guidelines for farmers in nitrate vulnerable zones. Edinburgh.

Sinclair, A.H. (2002). Nitrogen recommendations for Cereals, Oilseed Rape and Potatoes. SAC Technical Note T516, Edinburgh.

Sinclair, A.H., Bingham, I.J., Rees, R.M., Ball, B.C., Still, E.B., Watt, D. & Booth, E. (2002). Review of fertiliser guidance available to farmers in Nitrate Vulnerable Zones, relevance to Scottish conditions and gaps in information. *Report prepared for Scottish Executive Environment and Rural Affairs Department Agricultural and Biological Research Group.* Project No. SAC/315/01.

Smith, T.C., Kindred, D.R., Brosnan, J.M., Weightman, R.M., Shepherd, M. & Sylvester-Bradley, R. (2006). *Wheat as a feedstock for alcohol production.* HGCA Research Review No. 61, 88 pp.

Sylvester-Bradley, R., Bloom, T.M., Vaidyanathan, L.V. & Murray, A.W.A. (1987). *The quest for the optimum: a comparison of N recommendation systems for winter wheat*, in Proceedings of Third Meeting of NW Europe Study Group for the Assessment of N Fertiliser Requirements, Copenhagen, pp 113-133.

Sylvester-Bradley, R., Addiscott, T.M., Vaidyanathan, L.V., Murray, A.W.A., & Whitmore, A.P. (1987). *Nitrogen advice for cereals: present realities and future possibilities.* Proceedings of the Fertiliser Society No. 263, 36 pp.

Sylvester-Bradley, R., Stokes, D.T. & Scott, R.K. (2001). Dynamics of nitrogen capture without fertiliser: the baseline for fertilising winter wheat in the UK. *Journal of Agricultural Science* **136**, 15-33.

Sylvester-Bradley, R. & Kindred, D.R. (2008). Developing and growing wheat for the biofuels market. In *'Arable cropping in a changing climate'* HGCA conference 23-24 January 2008, pp. 110-125.

Vaidyanathan, L.V., Sylvester-Bradley, R., Bloom, T.M. & Murray, A.W.A. (1987). Effects of previous cropping and applied N on grain nitrogen content of winter wheat. *Aspects of Applied Biology* **15**, *Cereal Quality*, 227-237.

Vaidyanathan, L.V. & Wilson, W.S. (1992). Influence of organic-carbon and nitrogen associated with cropping history and soil textural class on nitrogen use by winter-wheat (*Triticum aestivum*) pp. 57-68 in *Developments in agricultural and managed-forest ecology, 25: Humus, its structure and role in agriculture and environment*.

Webb, J.D., Sylvester-Bradley, R. & Wafford, J.D. (1995). Influence of sowing date on the uptake of and responses to soil and fertilizer nitrogen by a spring wheat cultivar Tonic. *Journal of Agricultural Science* **125**, 25-37.

Webb, J., Sylvester-Bradley, R., Shepherd, M.A. & Goodlass, G. (1998a). A review of recent UK studies to improve fertilizer-N recommendations for cereals. In *Fertilization for sustainable plant production and soil fertility, 11th International World Fertiliser Congress, Gent, Belgium, Vol. III* Eds. O. Van Cleemput, S. Haneklaus, G. Hofman, E. Schnug & A. Vermoesen, pp. 419-435.

Webb, J.D., Seeney, F.M. & Sylvester-Bradley, R. (1998b). The response to fertiliser nitrogen of cereals grown on sandy soils. *Journal of Agricultural Science* **130**, 271-286.

Webb, J.D., Sylvester-Bradley, R. & Seeney, F.M. (2000). The fertiliser nitrogen requirement of cereals grown on sandy soils. *Journal of the Science of Food and Agriculture* **80**, 263-274.

Webb, J. Ellis, S. Harrison, R. & Thorman, R. (2004). Measurement of N fluxes and soil N in two arable soils in the UK. *Plant and Soil* 260, 253-270.

Withers, P.J.A. & Dyer, C. (1990). The effect of applied nitrogen on the acceptability of spring barley for malting. *Aspects of Applied Biology* **25**, 329–337.

2005 Univ. Nott., Sutton Bonington, Winter Wheat

Grid Ref. SK505267

Soil Group	*Topsoil*		*Subsoil*		*Depth (cm)*	*Total N (%)*
Medium soils	Sandy loam		Clay at 50cm		>90	0.23
Previous crops	*-1 year*	*-1 residues*	*-2 years*	*-3 years*		
	Winter Oats	Baled	Winter wheat	Sugar Beet		

Varieties	Riband	Avalon	Deben	Gladiator
1st year on RL	1987	1980	1999	2002

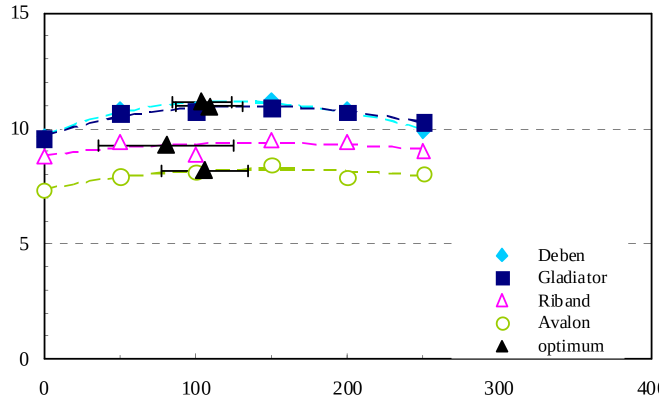
Sowing date	*Over-winter rain*	*N application dates*			*Harvest*
	mm	*1st*	*2nd*	*3rd*	
7 October 2004	75	23 Mar	6 Apr	26 Apr	12 Aug

Comments: NA

Soil N analysis and Nitrogen recommendations

Soil analysis date	*Crop N*	*Soil mineral N by depth (kg/ha)*			*Soil N Supply*	
	eye-estimate	*0-30 cm*	*30-60 cm*	*60-90 cm*	*Total*	
21 Feb	5	66	46	41	158	*kg/ha*
		RB209 recommendation (by SNS Index)			220	*kg/ha*
		RB209 recommendation (by SMN analysis)			60	*kg/ha*

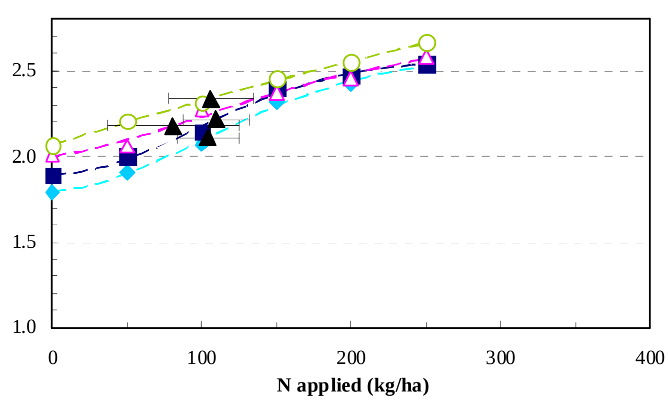
Grain yield (t/ha at 85% DM)



Statistics

	F probability
Nitrogen (N)	<0.001
Variety (V)	0.12
N x V	0.37
CV%	4.10
Variance accounted for by curve fit:	78%

Grain N (%, dry basis)



Statistics

	F probability
Nitrogen (N)	<0.001
Variety (V)	<0.001
N x V	0.098
CV%	2.6

Variety effects	*Grain N at nil N*	*Optimum N (3:1)*	*SE Nopt*	*Change for BER=6:1*	*Grain yield at opt N*	*Grain N at opt N*
	kg/ha	*kg/ha*	*kg/ha*	*kg/ha*	*t/ha*	*% DM*
Avalon	129	106	28	-35	8.18	2.34
Riband	150	81	44	-47	9.27	2.18
Deben	147	104	20	-16	11.14	2.11
Gladiator	154	109	22	-22	10.93	2.22
SED (N x V)					0.470	0.062
d.f.					22	29

2005 ADAS Boxworth, Winter Wheat

Grid Ref. TL337637

Soil Group	***Topsoil***		***Subsoil***		***Depth (cm)***	***Total N (%)***
Deep clay soils	Clay loam		Hanslope, CBC		>90	0.27
Previous crops	***-1 year***	***-1 residues***	***-2 years***	***-3 years***		
	Spring beans	Incorp	Winter wheat	Winter wheat		

Varieties	Riband	Slejpner	Deben	Robigus
1st year on RL	1987	1984	1999	2001

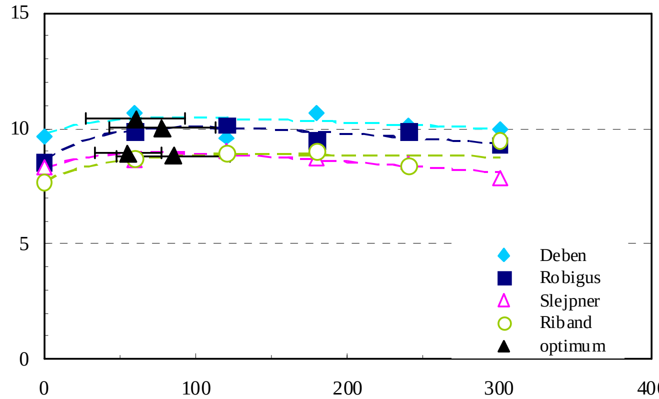
Sowing date	***Over-winter rain***	***N application dates***			***Harvest***
	mm	*1st*	*2nd*	*3rd*	
22 October 2004	70	3 Mar	20 Apr	9 May	8 Aug

Comments: Trial design randomisation problems

Soil N analysis and Nitrogen recommendations

Soil analysis date	***Crop N***	***Soil mineral N by depth (kg/ha)***			***Soil N Supply***	
	eye-estimate	*0-30 cm*	*30-60 cm*	*60-90 cm*	*Total*	
3 Dec	10	44	27	27	108	*kg/ha*
		RB209 recommendation (by SNS Index)			150	*kg/ha*
		RB209 recommendation (by SMN analysis)			150	*kg/ha*

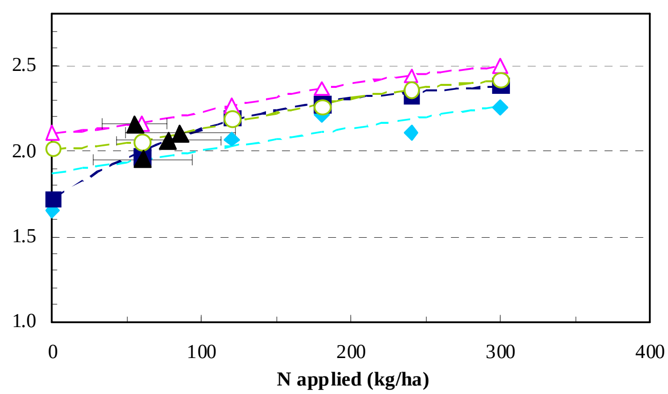
Grain yield (t/ha at 85% DM)



Statistics

	F probability
Nitrogen (N)	<0.001
Variety (V)	0.00
N x V	0.03
CV%	5.40
Variance accounted for by curve fit:	59%

Grain N (%, dry basis)



Statistics

	F probability
Nitrogen (N)	<0.001
Variety (V)	<0.001
N x V	<0.001
CV%	3

Variety effects	***Grain N at nil N***	***Optimum N (3:1)***	*SE Nopt*	*Change for BER=6:1*	***Grain yield at opt N***	***Grain N at opt N***
	kg/ha	*kg/ha*	*kg/ha*	*kg/ha*	*t/ha*	*% DM*
Riband	132	85	37	-22	8.81	2.10
Slejpner	148	55	22	-13	8.93	2.16
Deben	135	61	33	-16	10.42	1.95
Robigus	125	78	35	-13	10.02	2.06
SED (N x V)					0.405	0.052
d.f.					28	28

2005 ADAS High Mowthorpe, Winter Wheat

Grid Ref. SE882692

Soil Group	***Topsoil***		***Subsoil***		***Depth (cm)***	***Total N (%)***
Shallow over chalk	Silty clay loam		Wolds chalk		45	0.27
Previous crops	***-1 year***	***-1 residues***	***-2 years***	***-3 years***		
	Spring beans	Incorp	Spring barley	Winter wheat		

Varieties	Riband	Slejpner	Istabraq	Dickson
1st year on RL	1987	1984	2002	2002

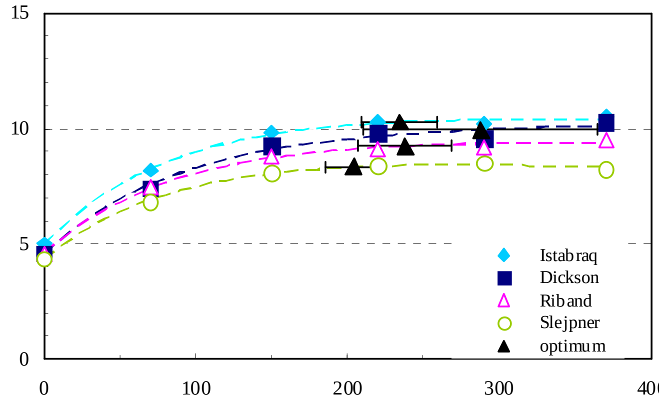
Sowing date	***Over-winter rain***	***N application dates***			***Harvest***
	mm	*1st*	*2nd*	*3rd*	
7 October 2004	178	21 Mar	6 May	19 May	30 Aug

Comments: Very little pest or disease damage

Soil N analysis and Nitrogen recommendations

Soil analysis date	***Crop N***	***Soil mineral N by depth (kg/ha)***			***Soil N Supply***	
	eye-estimate	*0-30 cm*	*30-60 cm*	*60-90 cm*	*Total*	
24 Nov	5	101	39	10	155	*kg/ha*
		RB209 recommendation (by SNS Index)			200	*kg/ha*
		RB209 recommendation (by SMN analysis)			110	*kg/ha*

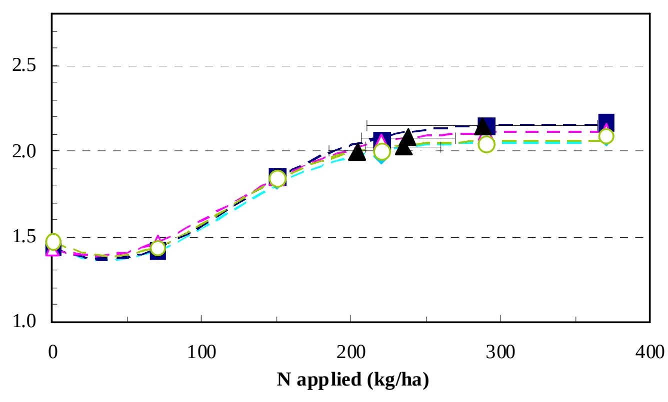
Grain yield (t/ha at 85% DM)



Statistics

	F probability
Nitrogen (N)	<0.001
Variety (V)	<0.001
N x V	<0.001
CV%	3.20
Variance accounted for by curve fit:	95%

Grain N (%, dry basis)



Statistics

	F probability
Nitrogen (N)	<0.001
Variety (V)	<0.001
N x V	0.084
CV%	2.2

Variety effects	***Grain N at nil N***	***Optimum N (3:1)***	*SE Nopt*	*Change for BER=6:1*	***Grain yield at opt N***	***Grain N at opt N***
	kg/ha	*kg/ha*	*kg/ha*	*kg/ha*	*t/ha*	*% DM*
Riband	55	238	31	-50	9.24	2.08
Slejpner	55	204	19	-38	8.33	2.00
Istabraq	61	234	25	-43	10.27	2.02
Dickson	56	288	77	-74	9.94	2.15
SED (N x V)					0.337	0.041
d.f.					20	32

2005 ADAS Terrington, Winter Wheat

Grid Ref. TF548180

Soil Group	*Topsoil*		*Subsoil*		*Depth (cm)*	*Total N (%)*
Deep fertile silty soils	Silty clay loam		ZC		>90	0.16
Previous crops	*-1 year*	*-1 residues*	*-2 years*	*-3 years*		
	Sugar Beet	Incorp	Winter wheat	WOSR		

Varieties	Riband	Slejpner	Istabraq	Robigus
1st year on RL	1987	1984	2002	2001

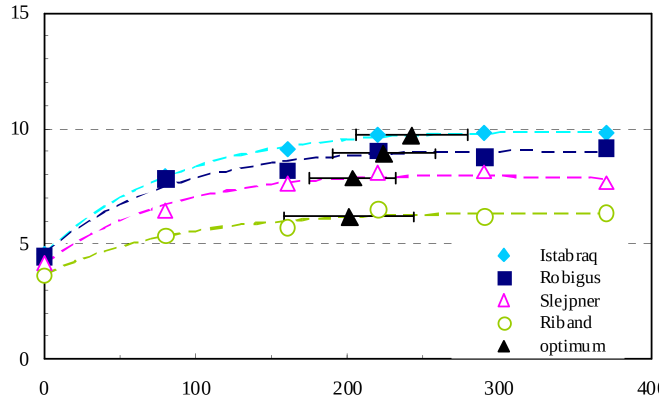
Sowing date	*Over-winter rain*	*N application dates*			*Harvest*
	mm	*1st*	*2nd*	*3rd*	
17 November 2004	60	16 Mar	27 Apr	6 May	18 Aug

Comments: Poor establishment, especially of Robigus, but general control levels were good

Soil N analysis and Nitrogen recommendations

Soil analysis date	*Crop N*	*Soil mineral N by depth (kg/ha)*			*Soil N Supply*	
	eye-estimate	*0-30 cm*	*30-60 cm*	*60-90 cm*	*Total*	
14 Dec	0	32	15	13	60	*kg/ha*
		RB209 recommendation (by SNS Index)			180	*kg/ha*
		RB209 recommendation (by SMN analysis)			200	*kg/ha*

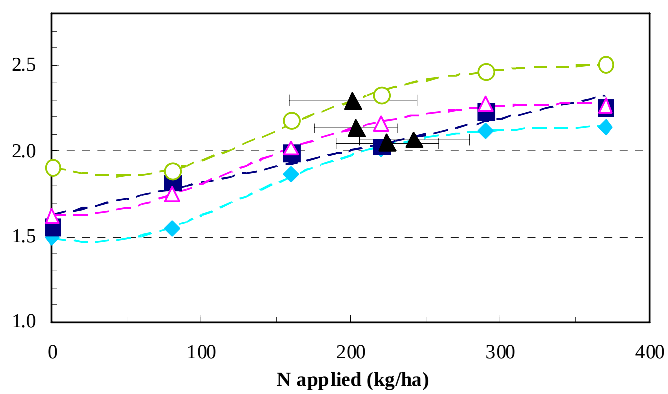
Grain yield (t/ha at 85% DM)



Statistics

	F probability
Nitrogen (N)	<0.001
Variety (V)	<0.001
N x V	0.09
CV%	8.50
Variance accounted for by curve fit:	90%

Grain N (%, dry basis)



Statistics

	F probability
Nitrogen (N)	<0.001
Variety (V)	<0.001
N x V	0.792
CV%	4.9

Variety effects	*Grain N at nil N*	*Optimum N (3:1)*	*SE Nopt*	*Change for BER=6:1*	*Grain yield at opt N*	*Grain N at opt N*
	kg/ha	*kg/ha*	*kg/ha*	*kg/ha*	*t/ha*	*% DM*
Riband	59	201	43	-56	6.16	2.30
Slejpner	58	203	28	-39	7.85	2.14
Istabraq	58	242	37	-46	9.70	2.07
Robigus	59	224	34	-44	8.91	2.05
SED (N x V)					0.524	0.077
d.f.					44	45

2005 ADAS Rosemaund, Winter Wheat

Grid Ref. SO488568

Soil Group	*Topsoil*		*Subsoil*		*Depth (cm)*	*Total N (%)*
Medium soils	Sandy clay loam		Bromyard, ZCL		>90	0.14
Previous crops	*-1 year*	*-1 residues*	*-2 years*	*-3 years*		
	Winter oats	Baled	Winter wheat	WOSR		

Varieties	Riband	Slejpner	Gladiator	Dickson
1st year on RL	1987	1984	2002	2002

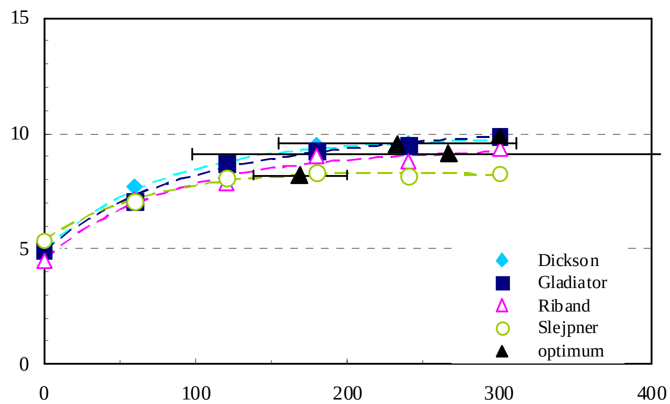
Sowing date	*Over-winter rain*	*N application dates*			*Harvest*
	mm	*1st*	*2nd*	*3rd*	
6 October 2004	200	11 Mar	15 Apr	19 May	15 Aug

Comments: Minimal slug damage, good weed control, minimal disease

Soil N analysis and Nitrogen recommendations

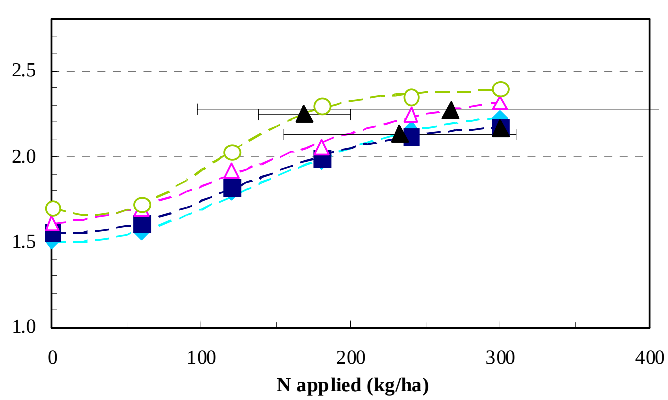
Soil analysis date	*Crop N*	*Soil mineral N by depth (kg/ha)*			*Soil N Supply*	
	eye-estimate	*0-30 cm*	*30-60 cm*	*60-90 cm*	*Total*	
23 Nov	5	41	30	17	93	*kg/ha*
		RB209 recommendation (by SNS Index)			220	*kg/ha*
		RB209 recommendation (by SMN analysis)			180	*kg/ha*

Grain yield (t/ha at 85% DM)



Statistics	
	F probability
Nitrogen (N)	<0.001
Variety (V)	<0.001
N x V	0.18
CV%	7.40
Variance accounted for by curve fit:	85%

Grain N (%, dry basis)



Statistics	
	F probability
Nitrogen (N)	<0.001
Variety (V)	<0.001
N x V	0.413
CV%	3.3

Variety effects	***Grain N at nil N***	***Optimum N (3:1)***	*SE Nopt*	*Change for BER=6:1*	***Grain yield at opt N***	***Grain N at opt N***
	kg/ha	*kg/ha*	*kg/ha*	*kg/ha*	*t/ha*	*% DM*
Riband	62	266	169	-74	9.12	2.27
Slejpner	78	169	31	-34	8.20	2.25
Dickson	62	233	78	-50	9.57	2.13
Gladiator	66	300	0	-73	9.88	2.17
SED (N x V)					0.482	0.053
d.f.					46	46

2005 Farmacy, Edlington, Winter Wheat

Grid Ref. TF235716

Soil Group	***Topsoil***	***Subsoil***	***Depth (cm)***	***Total N (%)***
Shallow over limestone	Sandy clay loam	Wolds limestone	20	0.16

Previous crops	***-1 year***	***-1 residues***	***-2 years***	***-3 years***
	Peas	Incorp	Winter wheat	Winter wheat

Varieties	Riband	Avalon	Gladiator	Robigus
1st year on RL	1987	1980	2002	2001

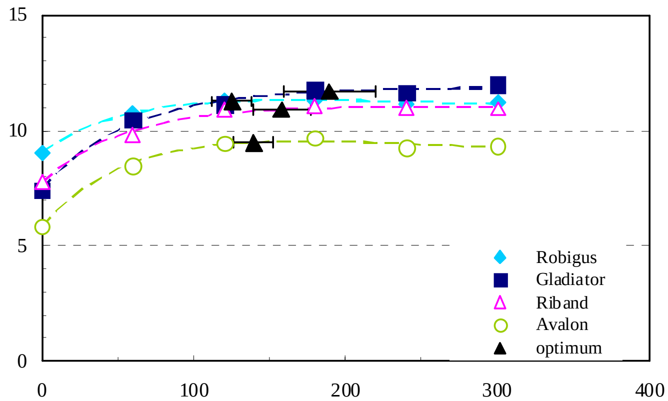
Sowing date	***Over-winter rain***	***N application dates***			***Harvest***
	mm	*1st*	*2nd*	*3rd*	
12 October 2004	50	1 Apr	15 Apr	5 May	1 Aug

Comments: Good control of weeds, diseases, pests & lodging

Soil N analysis and Nitrogen recommendations

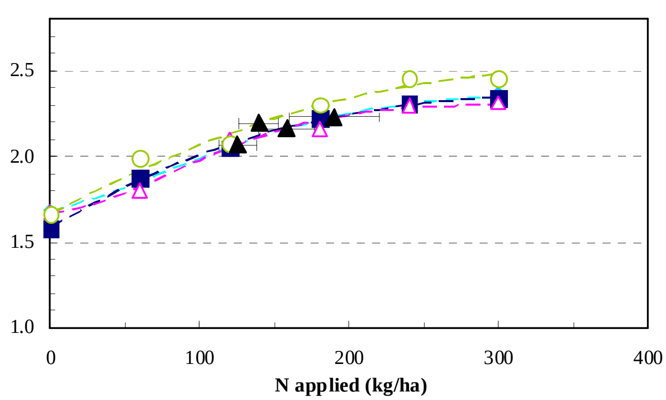
Soil analysis date	***Crop N***	***Soil mineral N by depth (kg/ha)***			***Soil N Supply***	
	eye-estimate	*0-30 cm*	*30-60 cm*	*60-90 cm*	*Total*	
25 Nov	5	31	45	47	129	*kg/ha*
		RB209 recommendation (by SNS Index)			180	*kg/ha*
		RB209 recommendation (by SMN analysis)			100	*kg/ha*

Grain yield (t/ha at 85% DM)



Statistics	
	F probability
Nitrogen (N)	<0.001
Variety (V)	<0.001
N x V	0.00
CV%	3.60
Variance accounted for by curve fit:	94%

Grain N (%, dry basis)



Statistics	
	F probability
Nitrogen (N)	<0.001
Variety (V)	<0.001
N x V	0.134
CV%	4.1

Variety effects	***Grain N at nil N***	***Optimum N (3:1)***	*SE Nopt*	*Change for BER=6:1*	***Grain yield at opt N***	***Grain N at opt N***
	kg/ha	*kg/ha*	*kg/ha*	*kg/ha*	*t/ha*	*% DM*
Avalon	82	140	13	-21	9.48	2.19
Riband	111	158	19	-33	10.90	2.16
Gladiator	99	190	30	-43	11.68	2.23
Robigus	129	125	13	-25	11.26	2.07
SED (N x V)					0.299	0.070
d.f.					46	46

2005 SAC Forgandenny, Winter Wheat

Grid Ref. NO082179

Soil Group	***Topsoil***		***Subsoil***		***Depth (cm)***	***Total N (%)***
Deep clay soils	Clay loam		Balrownie		60	0.22
Previous crops	***-1 year***	***-1 residues***	***-2 years***	***-3 years***		
	Spring barley	Baled	Winter wheat	Swedes		

Varieties	Riband	Avalon	Deben	Istabraq
1st year on RL	1987	1980	1999	2002

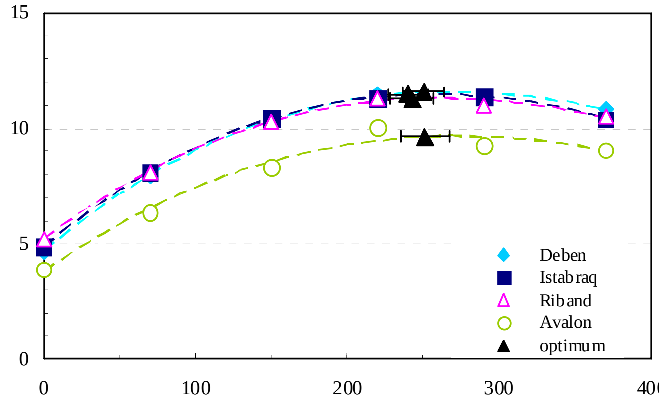
Sowing date	***Over-winter rain***	***N application dates***			***Harvest***
	mm	*1st*	*2nd*	*3rd*	
11 October 2004	300	12 Mar	12 Apr	5 Jun	30 Aug

Comments: Moderate mildew control, good otherwise.

Soil N analysis and Nitrogen recommendations

Soil analysis date	***Crop N***	***Soil mineral N by depth (kg/ha)***			***Soil N Supply***	
	eye-estimate	*0-30 cm*	*30-60 cm*	*60-90 cm*	*Total*	
16 Nov	5	41	26	-	72	*kg/ha*
		RB209 recommendation (by SNS Index)			220	*kg/ha*
		RB209 recommendation (by SMN analysis)			220	*kg/ha*

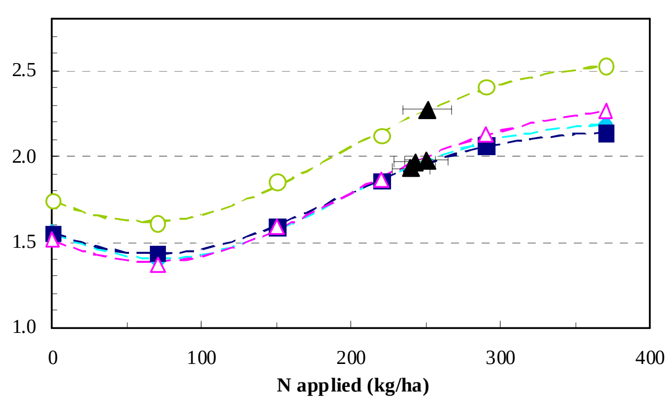
Grain yield (t/ha at 85% DM)



Statistics

	F probability
Nitrogen (N)	<0.001
Variety (V)	<0.001
N x V	0.86
CV%	6.30
Variance accounted for by curve fit:	92%

Grain N (%, dry basis)



Statistics

	F probability
Nitrogen (N)	<0.001
Variety (V)	<0.001
N x V	0.029
CV%	2.6

Variety effects	***Grain N at nil N***	***Optimum N (3:1)***	*SE Nopt*	*Change for BER=6:1*	***Grain yield at opt N***	***Grain N at opt N***
	kg/ha	*kg/ha*	*kg/ha*	*kg/ha*	*t/ha*	*% DM*
Avalon	57	251	16	-21	9.62	2.27
Riband	67	243	14	-19	11.27	1.97
Deben	62	250	14	-17	11.56	1.98
Istabraq	64	240	13	-17	11.45	1.93
SED (N x V)					0.466	0.039
d.f.					46	46

2005 Agrovista, Stoughton, Winter Wheat

Grid Ref. SK671021

Soil Group	*Topsoil*		*Subsoil*		*Depth (cm)*	*Total N (%)*
Deep clay soils	Sandy clay loam		Ragdale		>70	0.34
Previous crops	*-1 year*	*-1 residues*	*-2 years*	*-3 years*		
	SOSR	Incorp	Winter wheat	Not known		

Varieties	Avalon	Riband	Dickson	Robigus
1st year on RL	1980	1987	2002	2001

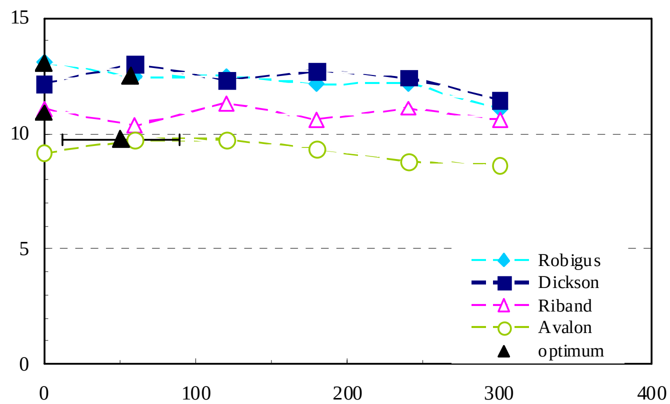
Sowing date	*Over-winter rain*	*N application dates*			*Harvest*
	mm	*1st*	*2nd*	*3rd*	
13 October 2004	75	21 Mar	12 Apr	6 May	16 Aug

Comments: Moderate slug control, good weed & disease control.

Soil N analysis and Nitrogen recommendations

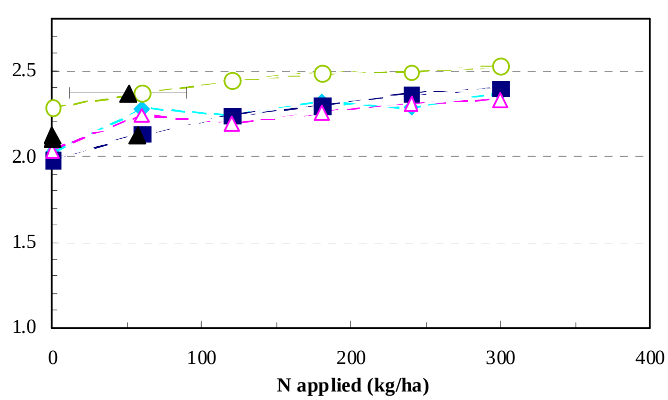
Soil analysis date	*Crop N*	*Soil mineral N by depth (kg/ha)*			*Soil N Supply*	
	eye-estimate	*0-30 cm*	*30-60 cm*	*60-90 cm*	*Total*	
22 Dec	5	72	58	23	159	*kg/ha*
		RB209 recommendation (by SNS Index)			150	*kg/ha*
		RB209 recommendation (by SMN analysis)			100	*kg/ha*

Grain yield (t/ha at 85% DM)



Statistics	*F probability*
Nitrogen (N)	<0.001
Variety (V)	0.07
N x V	0.71
CV%	7.20
Variance accounted for by curve fit:	51%

Grain N (%, dry basis)



Statistics	*F probability*
Nitrogen (N)	<0.001
Variety (V)	<0.001
N x V	0.708
CV%	3.7

Variety effects	***Grain N at nil N***	***Optimum N (3:1)***	*SE Nopt*	*Change for BER=6:1*	***Grain yield at opt N***	***Grain N at opt N***
	kg/ha	*kg/ha*	*kg/ha*	*kg/ha*	*t/ha*	*% DM*
Avalon	178	51	39	-12	9.74	2.37
Riband	192	0	>opt	0	10.90	2.10
Dickson	205	57	>opt	-57	12.53	2.12
Robigus	225	0	>opt	0	13.03	2.12
SED (N x V)					0.656	0.070
d.f.					43	46

2005 ADAS Kent, Winter Wheat

Grid Ref. TR065388

Soil Group	*Topsoil*		*Subsoil*		*Depth (cm)*	*Total N (%)*
Medium soils	Sandy loam		Greensand		>90	0.21
Previous crops	*-1 year*	*-1 residues*	*-2 years*	*-3 years*		
	WOSR	Incorp	Winter wheat	WOSR		

Varieties	Avalon	Riband	Gladiator	Istabraq
1st year on RL	1980	1987	2002	2002

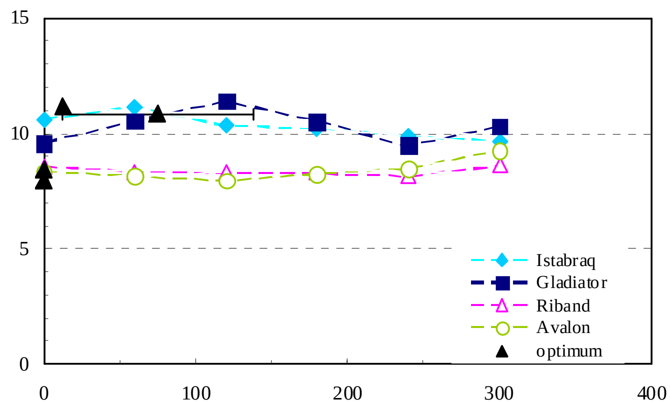
Sowing date	*Over-winter rain*	*N application dates*			*Harvest*
	mm	*1st*	*2nd*	*3rd*	
18 October 2004	75	24 Mar	21 Apr	5 May	26 Aug

Comments: Good weed control, some slug damage, some lodging and some disease.

Soil N analysis and Nitrogen recommendations

Soil analysis date	*Crop N*	*Soil mineral N by depth (kg/ha)*			*Soil N Supply*	
	eye-estimate	*0-30 cm*	*30-60 cm*	*60-90 cm*	*Total*	
24 Mar	30	36	29	19	115	*kg/ha*
		RB209 recommendation (by SNS Index)			150	*kg/ha*
		RB209 recommendation (by SMN analysis)			150	*kg/ha*

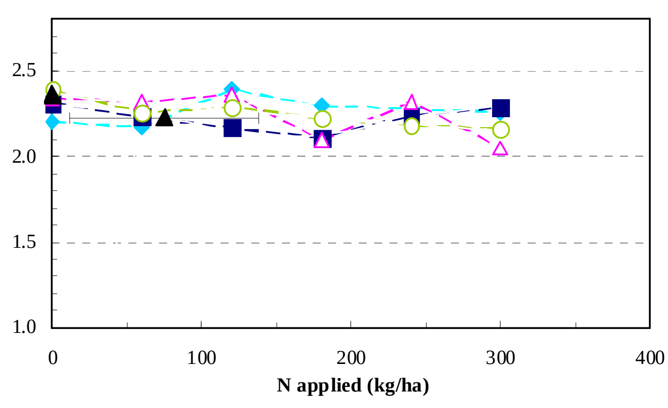
Grain yield (t/ha at 85% DM)



Statistics

	F probability
Nitrogen (N)	<0.001
Variety (V)	0.37
N x V	0.04
CV%	7.10
Variance accounted for by curve fit:	0%

Grain N (%, dry basis)



Statistics

	F probability
Nitrogen (N)	0.837
Variety (V)	0.131
N x V	0.251
CV%	6.3

Variety effects	*Grain N at nil N*	*Optimum N (3:1)*	*SE Nopt*	*Change for BER=6:1*	*Grain yield at opt N*	*Grain N at opt N*
	kg/ha	*kg/ha*	*kg/ha*	*kg/ha*	*t/ha*	*% DM*
Avalon	170	0	*	0	7.99	2.35
Riband	170	0	*	0	8.40	2.37
Gladiator	188	75	63	-13	10.85	2.23
Istabraq	199	13	>opt	-1	11.16	0.00
SED (N x V)					0.544	0.115
d.f.					46	46

2005 Masstock Stebbing, Winter Wheat

Grid Ref. TL654195

Soil Group	***Topsoil***		***Subsoil***		***Depth (cm)***	***Total N (%)***
Deep clay soils	Silty clay		Hanslope, CBC		>90	0.15
Previous crops	***-1 year***	***-1 residues***	***-2 years***	***-3 years***		
	Winter wheat	Incorp	WOSR	Winter wheat		

Varieties	Avalon	Riband	Deben	Dickson
1st year on RL	1980	1987	1999	2002

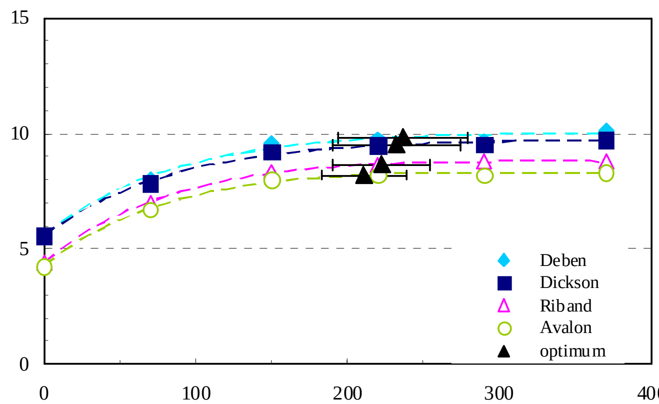
Sowing date	***Over-winter rain***	***N application dates***			***Harvest***
	mm	*1st*	*2nd*	*3rd*	
22 October 2004	75	14 Mar	14 Apr	27 Apr	30 Aug

Comments: NA

Soil N analysis and Nitrogen recommendations

Soil analysis date	***Crop N***	***Soil mineral N by depth (kg/ha)***			***Soil N Supply***	
	eye-estimate	*0-30 cm*	*30-60 cm*	*60-90 cm*	*Total*	
6 Jan	5	25	18	14	62	*kg/ha*
RB209 recommendation (by SNS Index)					180	*kg/ha*
RB209 recommendation (by SMN analysis)					220	*kg/ha*

Grain yield (t/ha at 85% DM)



Statistics

	F probability
Nitrogen (N)	<0.001
Variety (V)	<0.001
N x V	0.98
CV%	3.80
Variance accounted for by curve fit:	91%

Grain N (%, dry basis)

Not determined

Statistics

	F probability
Nitrogen (N)	ND
Variety (V)	ND
N x V	ND
CV%	ND

Variety effects	***Grain N at nil N***	***Optimum N (3:1)***	*SE Nopt*	*Change for BER=6:1*	***Grain yield at opt N***	***Grain N at opt N***
	kg/ha	*kg/ha*	*kg/ha*	*kg/ha*	*t/ha*	*% DM*
Avalon	ND	211	28	-43	8.20	ND
Riband	ND	223	32	-46	8.67	ND
Deben	ND	237	43	-54	9.84	ND
Dickson	ND	232	42	-54	9.51	ND
SED (N x V)					0.454	
d.f.					17	

2006 Univ. Nott., Sutton Bonington, Winter Wheat

Grid Ref. SK505267

Soil Group	*Topsoil*		*Subsoil*		*Depth (cm)*	*Total N (%)*
Medium soils	Sandy loam		Clay at 50cm		>90	0.23
Previous crops	*-1 year*	*-1 residues*	*-2 years*	*-3 years*		
	Winter Oats	Baled	Winter wheat	Sugar Beet		

Varieties	Norman	Hobbit	Istabraq	Gladiator
1st year on RL	1980	1978	2002	2002

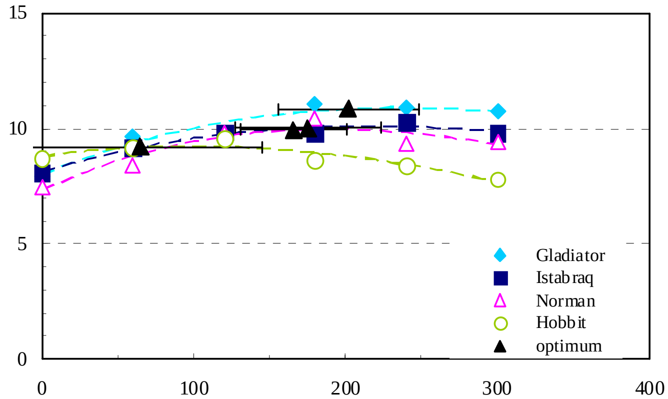
Sowing date	*Over-winter rain*	*N application dates*			*Harvest*
	mm	*1st*	*2nd*	*3rd*	
5 October 2005	75	6 Apr	19 Apr	5 May	8 Aug

Comments: NA

Soil N analysis and Nitrogen recommendations

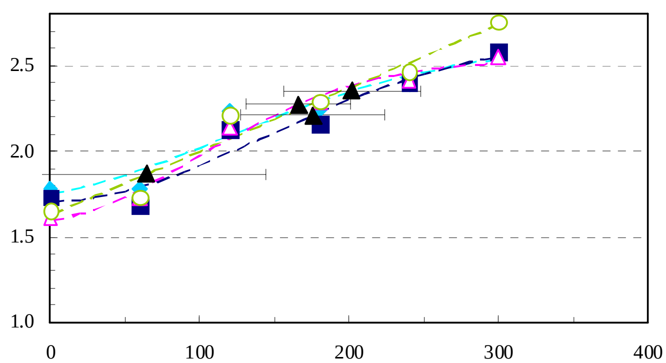
Soil analysis date	*Crop N*	*Soil mineral N by depth (kg/ha)*			*Soil N Supply*	
	eye-estimate	*0-30 cm*	*30-60 cm*	*60-90 cm*	*Total*	
10 Jan	5	26	27	37	95	*kg/ha*
				RB209 recommendation (by SNS Index)	220	*kg/ha*
				RB209 recommendation (by SMN analysis)	180	*kg/ha*

Grain yield (t/ha at 85% DM)



Statistics	*F probability*
Nitrogen (N)	<0.001
Variety (V)	0.20
N x V	0.05
CV%	9.30
Variance accounted for by curve fit:	37%

Grain N (%, dry basis)



Statistics	*F probability*
Nitrogen (N)	0.019
Variety (V)	<0.001
N x V	0.058
CV%	3.4

Variety effects	*Grain N at nil N*	*Optimum N (3:1)*	*SE Nopt*	*Change for BER=6:1*	*Grain yield at opt N*	*Grain N at opt N*
	kg/ha	*kg/ha*	*kg/ha*	*kg/ha*	*t/ha*	*% DM*
Hobbit	122	65	80	-30	9.19	1.87
Norman	102	166	35	-22	9.94	2.27
Gladiator	120	202	46	-31	10.84	2.35
Istabraq	119	175	48	-37	10.03	2.21
SED (N x V)					0.970	0.072
d.f.					25	33

2006 ADAS Boxworth, Winter Wheat

Grid Ref. TL337637

Soil Group	***Topsoil***		***Subsoil***		***Depth (cm)***	***Total N (%)***
Deep clay soils	Clay		Hanslope, CBC		>90	0.26
Previous crops	***-1 year***	***-1 residues***	***-2 years***	***-3 years***		
	WOSR	Incorp	Winter wheat	Winter wheat		

Varieties	Norman	Longbow	Gladiator	Alchemy
1st year on RL	1980	1981	2002	2004

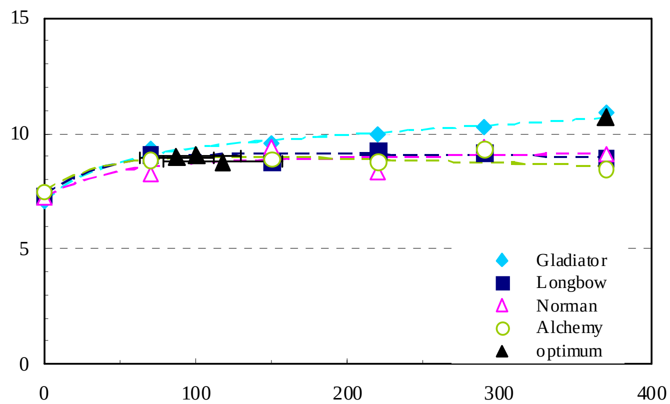
Sowing date	***Over-winter rain***	***N application dates***			***Harvest***
	mm	*1st*	*2nd*	*3rd*	
6 October 2005	25	6 Mar	11 Apr	5 May	10 Aug

Comments: NA

Soil N analysis and Nitrogen recommendations

Soil analysis date	***Crop N***	***Soil mineral N by depth (kg/ha)***			***Soil N Supply***	
	eye-estimate	*0-30 cm*	*30-60 cm*	*60-90 cm*	*Total*	
21 Nov	5	23	13	13	54	*kg/ha*
		RB209 recommendation (by SNS Index)			100	*kg/ha*
		RB209 recommendation (by SMN analysis)			240	*kg/ha*

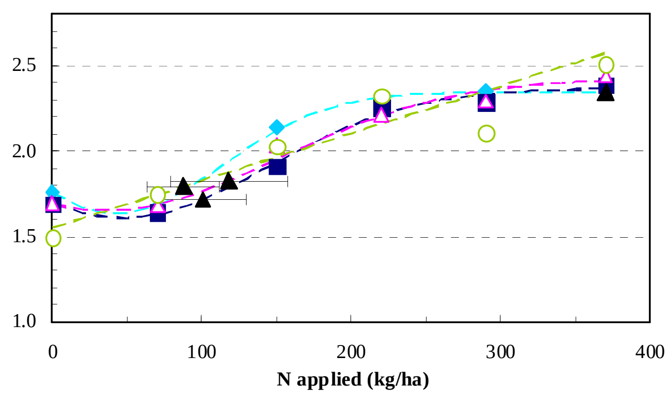
Grain yield (t/ha at 85% DM)



Statistics

	F probability
Nitrogen (N)	<0.001
Variety (V)	<0.001
N x V	0.04
CV%	6.40
Variance accounted for by curve fit:	68%

Grain N (%, dry basis)



Statistics

	F probability
Nitrogen (N)	0.722
Variety (V)	<0.001
N x V	0.944
CV%	8.9

Variety effects	***Grain N at nil N***	***Optimum N (3:1)***	*SE Nopt*	*Change for BER=6:1*	***Grain yield at opt N***	***Grain N at opt N***
	kg/ha	*kg/ha*	*kg/ha*	*kg/ha*	*t/ha*	*% DM*
Longbow	105	101	29	-23	9.05	1.72
Norman	104	118	39	-37	8.78	1.82
Alchemy	95	87	24	-18	8.95	1.79
Gladiator	105	370 *		-238	10.67	2.35
SED (N x V)					0.464	0.149
d.f.					46	46

2006 ADAS High Mowthorpe, Winter Wheat

Grid Ref. SE882692

Soil Group	***Topsoil***	***Subsoil***	***Depth (cm)***	***Total N (%)***
Shallow over chalk	Sandy clay loam	Wold series	45-60	0.34

Previous crops	***-1 year***	***-1 residues***	***-2 years***	***-3 years***
	WOSR	Incorp	Set aside	Winter wheat

Varieties	Norman	Hobbit	Istabraq	Ambrosia
1st year on RL	1980	1978	2002	2003

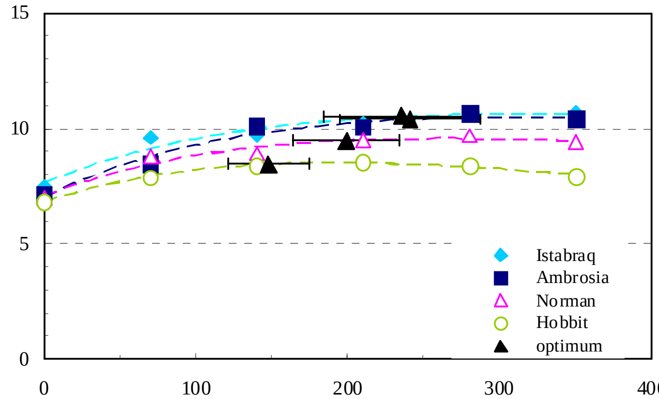
Sowing date	***Over-winter rain***	***N application dates***			***Harvest***
	mm	*1st*	*2nd*	*3rd*	
15 October 2005	113	7 Apr	3 May	18 May	25 Aug

Comments: NA

Soil N analysis and Nitrogen recommendations

Soil analysis date	***Crop N***	***Soil mineral N by depth (kg/ha)***			***Soil N Supply***	
	eye-estimate	*0-30 cm*	*30-60 cm*	*60-90 cm*	*Total*	
17 Nov	5	46	44	-	94	*kg/ha*
		RB209 recommendation (by SNS Index)			160	*kg/ha*
		RB209 recommendation (by SMN analysis)			200	*kg/ha*

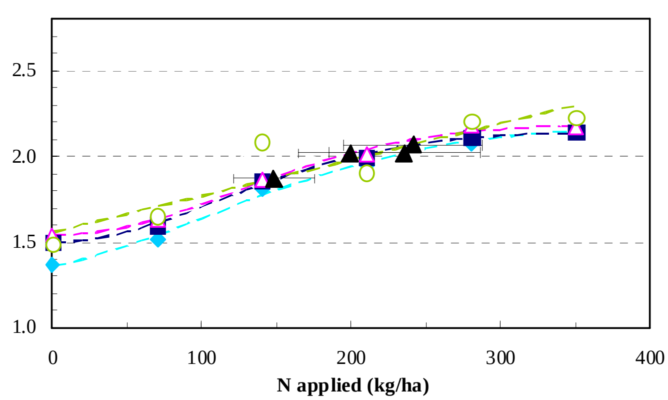
Grain yield (t/ha at 85% DM)



Statistics

	F probability
Nitrogen (N)	<0.001
Variety (V)	<0.001
N x V	0.28
CV%	7.50
Variance accounted for by curve fit:	74%

Grain N (%, dry basis)



Statistics

	F probability
Nitrogen (N)	0.065
Variety (V)	<0.001
N x V	0.861
CV%	6.9

Variety effects	***Grain N at nil N***	***Optimum N (3:1)***	*SE Nopt*	*Change for BER=6:1*	***Grain yield at opt N***	***Grain N at opt N***
	kg/ha	*kg/ha*	*kg/ha*	*kg/ha*	*t/ha*	*% DM*
Hobbit	87	148	27	-35	8.45	1.87
Norman	91	199	35	-46	9.48	2.02
Ambrosia	91	241	46	-50	10.39	2.07
Istabraq	87	235	51	-56	10.51	2.02
SED (N x V)					0.550	0.106
d.f.					46	46

2006 ADAS Terrington, Winter Wheat

Grid Ref. TF548180

Soil Group	***Topsoil***	***Subsoil***	***Depth (cm)***	***Total N (%)***
Deep fertile silty soils	Silty clay loam	ZCL	>90	0.20

Previous crops	***-1 year***	***-1 residues***	***-2 years***	***-3 years***
	WOSR	Incorp	Winter wheat	WOSR

Varieties	Longbow	Virtue	Gladiator	Ambrosia
1st year on RL	1981	1980	2002	2003

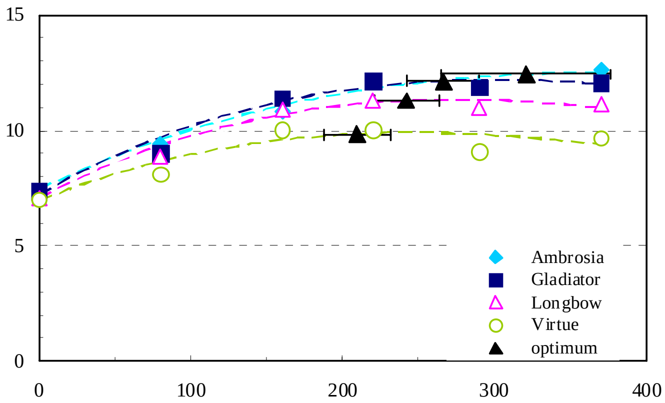
Sowing date	***Over-winter rain***	***N application dates***			***Harvest***
	mm	*1st*	*2nd*	*3rd*	
11 October 2005	75	6 Mar	25 Apr	11 May	8 Aug

Comments: NA

Soil N analysis and Nitrogen recommendations

Soil analysis date	***Crop N***	***Soil mineral N by depth (kg/ha)***			***Soil N Supply***	
	eye-estimate	*0-30 cm*	*30-60 cm*	*60-90 cm*	*Total*	
11 Nov	5	31	17	13	66	*kg/ha*
		RB209 recommendation (by SNS Index)			80	*kg/ha*
		RB209 recommendation (by SMN analysis)			180	*kg/ha*

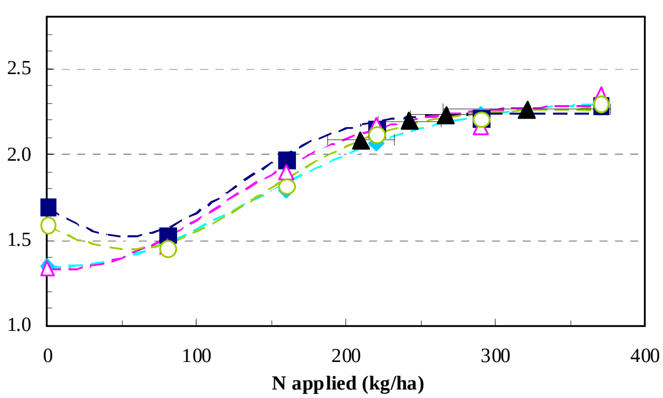
Grain yield (t/ha at 85% DM)



Statistics

	F probability
Nitrogen (N)	<0.001
Variety (V)	<0.001
N x V	<0.001
CV%	2.60
Variance accounted for by curve fit:	88%

Grain N (%, dry basis)



Statistics

	F probability
Nitrogen (N)	0.048
Variety (V)	<0.001
N x V	0.228
CV%	6.1

Variety effects	***Grain N at nil N***	***Optimum N (3:1)***	*SE Nopt*	*Change for BER=6:1*	***Grain yield at opt N***	***Grain N at opt N***
	kg/ha	*kg/ha*	*kg/ha*	*kg/ha*	*t/ha*	*% DM*
Longbow	81	242	21	-30	11.29	2.20
Virtue	95	210	22	-34	9.84	2.09
Ambrosia	85	321	56	-49	12.43	2.26
Gladiator	106	266	24	-32	12.15	2.23
SED (N x V)					0.458	0.107
d.f.					14	38

2006 ADAS Rosemaund, Winter Wheat

Grid Ref. SO488568

Soil Group	***Topsoil***		***Subsoil***		***Depth (cm)***	***Total N (%)***
Medium soils	Sandy clay loam		Bromyard, ZCL		>90	0.23
Previous crops	***-1 year***	***-1 residues***	***-2 years***	***-3 years***		
	SOSR	Incorp	Potatoes	Winter barley		

Varieties	Longbow	Hustler	Robigus	Ambrosia
1st year on RL	1981	1979	2001	2003

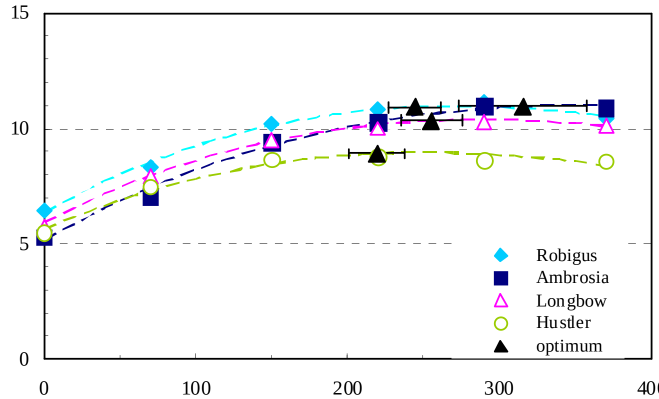
Sowing date	***Over-winter rain***	***N application dates***			***Harvest***
	mm	*1st*	*2nd*	*3rd*	
14 October 2005	200	21 Mar	30 Apr	11 May	10 Aug

Comments: Low levels of leaning and some brackling on Hustler at high N levels

Soil N analysis and Nitrogen recommendations

Soil analysis date	***Crop N***	***Soil mineral N by depth (kg/ha)***			***Soil N Supply***	
	eye-estimate	*0-30 cm*	*30-60 cm*	*60-90 cm*	*Total*	
19 Dec	5	37	19	17	78	*kg/ha*
		RB209 recommendation (by SNS Index)			180	*kg/ha*
		RB209 recommendation (by SMN analysis)			220	*kg/ha*

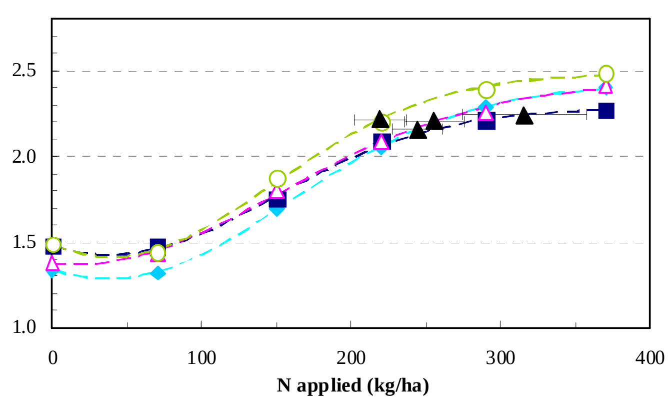
Grain yield (t/ha at 85% DM)



Statistics

	F probability
Nitrogen (N)	<0.001
Variety (V)	<0.001
N x V	<0.001
CV%	4.20
Variance accounted for by curve fit:	91%

Grain N (%, dry basis)



Statistics

	F probability
Nitrogen (N)	<0.001
Variety (V)	<0.001
N x V	0.004
CV%	3.1

Variety effects	***Grain N at nil N***	***Optimum N (3:1)***	*SE Nopt*	*Change for BER=6:1*	***Grain yield at opt N***	***Grain N at opt N***
	kg/ha	*kg/ha*	*kg/ha*	*kg/ha*	*t/ha*	*% DM*
Hustler	69	219	18	-31	8.91	2.22
Longbow	68	255	20	-31	10.33	2.20
Ambrosia	67	316	42	-37	10.96	2.24
Robigus	73	244	17	-27	10.92	2.16
SED (N x V)					0.498	0.067
d.f.					19	24

2006 Farmacy, Metheringham , Winter Wheat

Grid Ref. TF069615

Soil Group	*Topsoil*		*Subsoil*		*Depth (cm)*	*Total N (%)*
Deep clay soils	Silty clay loam		ZCL		>90	0.70
Previous crops	*-1 year*	*-1 residues*	*-2 years*	*-3 years*		
	WOSR	Incorp	Winter wheat	Linseed		

Varieties	Longbow	Hobbit	Alchemy	Ambrosia
1st year on RL	1981	1978	2004	2003

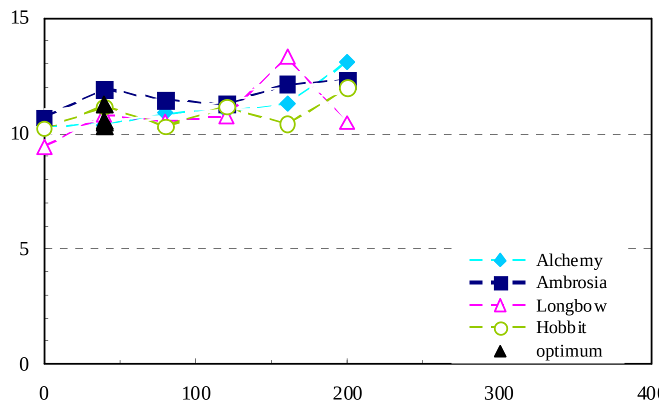
Sowing date	*Over-winter rain*	*N application dates*			*Harvest*
	mm	*1st*	*2nd*	*3rd*	
29 September 2005	99	NA	10 Apr	8 May	6 Aug

Comments: High residual N, no lodging recorded

Soil N analysis and Nitrogen recommendations

Soil analysis date	*Crop N*	*Soil mineral N by depth (kg/ha)*			*Soil N Supply*	
	eye-estimate	*0-30 cm*	*30-60 cm*	*60-90 cm*	*Total*	
29 Nov	5	55	74	43	178	*kg/ha*
		RB209 recommendation (by SNS Index)			100	*kg/ha*
		RB209 recommendation (by SMN analysis)			60	*kg/ha*

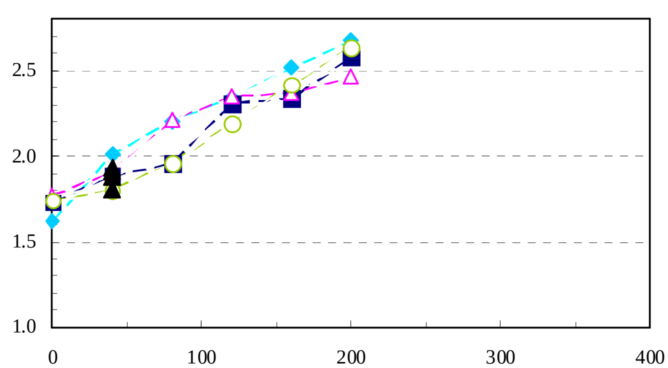
Grain yield (t/ha at 85% DM)



Statistics

	F probability
Nitrogen (N)	0.04
Variety (V)	<0.001
N x V	0.02
CV%	7.90
Variance accounted for by curve fit:	0%

Grain N (%, dry basis)



Statistics

	F probability
Nitrogen (N)	0.072
Variety (V)	0.001
N x V	0.168
CV%	5.9

Variety effects	*Grain N at nil N*	*Optimum N (3:1)*	*SE Nopt*	*Change for BER=6:1*	*Grain yield at opt N*	*Grain N at opt N*
	kg/ha	*kg/ha*	*kg/ha*	*kg/ha*	*t/ha*	*% DM*
Hobbit	151	40	*	0	10.56	1.80
Longbow	142	40	*	0	10.33	1.91
Alchemy	142	40	*	0	10.44	1.93
Ambrosia	158	40	*	0	11.27	1.88
SED (N x V)					0.720	0.104
d.f.					46	46

2006 SAC Laurencekirk, Winter Wheat

Grid Ref. NO686714

Soil Group	***Topsoil***		***Subsoil***		***Depth (cm)***	***Total N (%)***
Medium soils	Sandy clay loam		Luther, SCL		65-75	0.29
Previous crops	***-1 year***	***-1 residues***	***-2 years***	***-3 years***		
	WOSR	Baled	Set aside	Spring barley		

Varieties	Longbow	Virtue	Istabraq	Robigus
1st year on RL	1981	1980	2002	2001

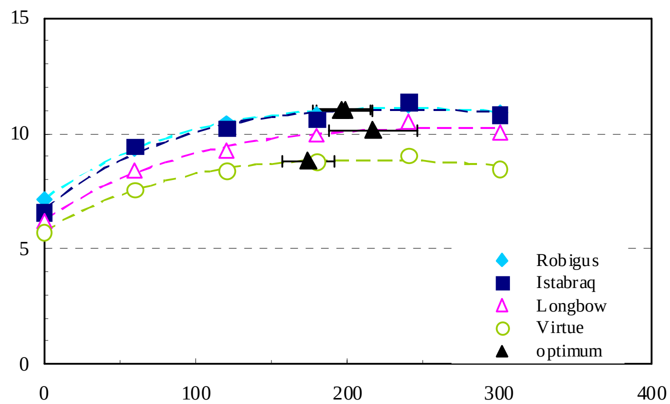
Sowing date	***Over-winter rain***	***N application dates***			***Harvest***
	mm	*1st*	*2nd*	*3rd*	
4 October 2005	200	4 Apr	2 May	12 May	4 Sep

Comments: Lodging scored at harvest

Soil N analysis and Nitrogen recommendations

Soil analysis date	***Crop N***	***Soil mineral N by depth (kg/ha)***			***Soil N Supply***	
	eye-estimate	*0-30 cm*	*30-60 cm*	*60-90 cm*	*Total*	
28 Nov	5	31	38	-	74	*kg/ha*
		RB209 recommendation (by SNS Index)			180	*kg/ha*
		RB209 recommendation (by SMN analysis)			220	*kg/ha*

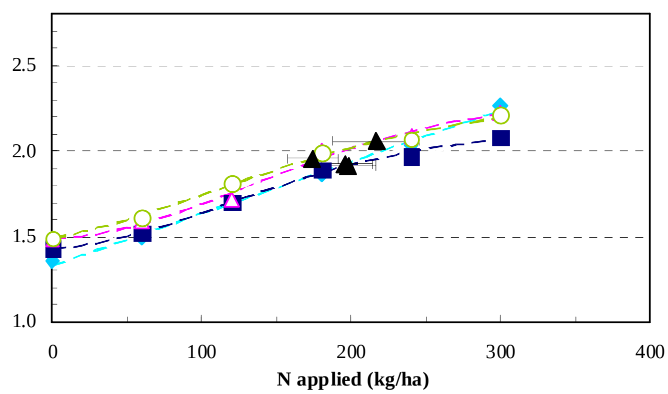
Grain yield (t/ha at 85% DM)



Statistics

	F probability
Nitrogen (N)	<0.001
Variety (V)	<0.001
N x V	0.38
CV%	4.50
Variance accounted for by curve fit:	92%

Grain N (%, dry basis)



Statistics

	F probability
Nitrogen (N)	<0.001
Variety (V)	<0.001
N x V	0.069
CV%	3.2

Variety effects	***Grain N at nil N***	***Optimum N (3:1)***	*SE Nopt*	*Change for BER=6:1*	***Grain yield at opt N***	***Grain N at opt N***
	kg/ha	*kg/ha*	*kg/ha*	*kg/ha*	*t/ha*	*% DM*
Longbow	78	216	29	-37	10.15	2.06
Virtue	73	174	17	-27	8.80	1.96
Istabraq	80	198	18	-27	10.99	1.92
Robigus	82	196	19	-28	11.03	1.92
SED (N x V)					0.339	0.048
d.f.					46	46

2006 Masstock, Fowlmere, Winter Wheat

Grid Ref. TL403740

Soil Group	***Topsoil***		***Subsoil***		***Depth (cm)***	***Total N (%)***
Shallow over chalk	Sandy loam		Over chalk		40-60	0.15
Previous crops	***-1 year***	***-1 residues***	***-2 years***	***-3 years***		
	Peas	Incorp	Winter wheat	Peas		

Varieties	Norman	Hobbit	Istabraq	Alchemy
1st year on RL	1980	1978	2002	2004

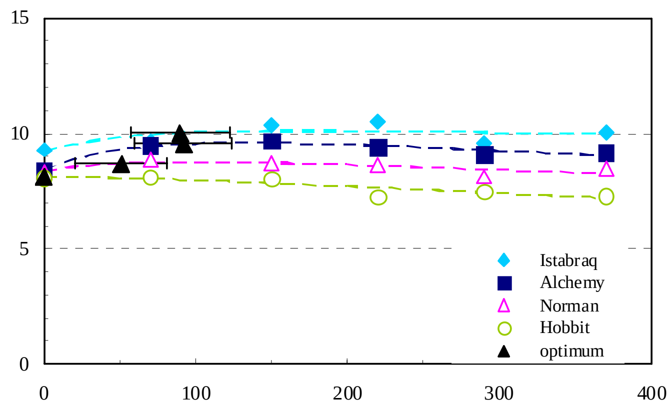
Sowing date	***Over-winter rain***	***N application dates***			***Harvest***
	mm	*1st*	*2nd*	*3rd*	
27 October 2005	75	16 Mar	25 Apr	18 May	30 Aug

Comments: Some lodging

Soil N analysis and Nitrogen recommendations

Soil analysis date	***Crop N***	***Soil mineral N by depth (kg/ha)***			***Soil N Supply***	
	eye-estimate	*0-30 cm*	*30-60 cm*	*60-90 cm*	*Total*	
7 Feb	50	13	20	-	91	*kg/ha*
		RB209 recommendation (by SNS Index)			200	*kg/ha*
		RB209 recommendation (by SMN analysis)			200	*kg/ha*

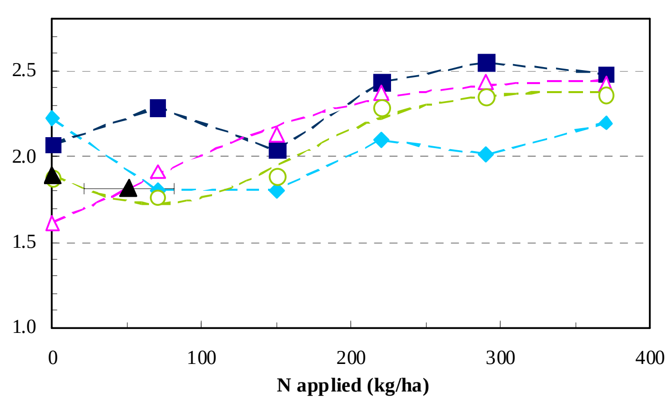
Grain yield (t/ha at 85% DM)



Statistics

	F probability
Nitrogen (N)	<0.001
Variety (V)	<0.001
N x V	0.01
CV%	4.30
Variance accounted for by curve fit:	76%

Grain N (%, dry basis)



Statistics

	F probability
Nitrogen (N)	0.032
Variety (V)	<0.001
N x V	0.446
CV%	13.7

Variety effects	***Grain N at nil N***	***Optimum N (3:1)***	*SE Nopt*	*Change for BER=6:1*	***Grain yield at opt N***	***Grain N at opt N***
	kg/ha	*kg/ha*	*kg/ha*	*kg/ha*	*t/ha*	*% DM*
Hobbit	129	0	*	0	8.09	1.90
Norman	114	51	30	-25	8.70	1.81
Alchemy	148	92	32	-22	9.55	
Istabraq	175	90	33	-31	10.02	
SED (N x V)					0.312	0.239
d.f.					46	46

2006 ADAS Kent, Winter Wheat

Grid Ref. TR057331

Soil Group	***Topsoil***		***Subsoil***		***Depth (cm)***	***Total N (%)***
Deep clay soils	Clay		Clay at 1m		>90	0.30
Previous crops	***-1 year***	***-1 residues***	***-2 years***	***-3 years***		
	WOSR	Incorp	Winter wheat	Winter wheat		

Varieties	Norman	Hobbit	Alchemy	Robigus
1st year on RL	1980	1978	2004	2001

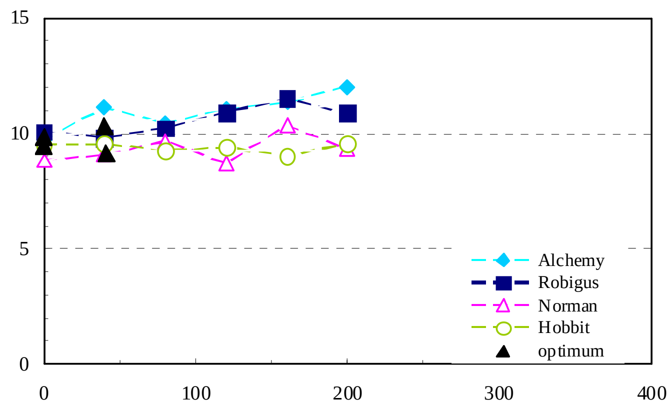
Sowing date	***Over-winter rain***	***N application dates***			***Harvest***
	mm	*1st*	*2nd*	*3rd*	
4 October 2005	113	N/A	13 Apr	27 Apr	22 Aug

Comments: 20/06/2006 only 5-10% Sep GS 71/73. No lodging at harvest

Soil N analysis and Nitrogen recommendations

Soil analysis date	***Crop N***	***Soil mineral N by depth (kg/ha)***			***Soil N Supply***	
	eye-estimate	*0-30 cm*	*30-60 cm*	*60-90 cm*	*Total*	
16 Jan	15	84	72	41	211	*kg/ha*
		RB209 recommendation (by SNS Index)			100	*kg/ha*
		RB209 recommendation (by SMN analysis)			60	*kg/ha*

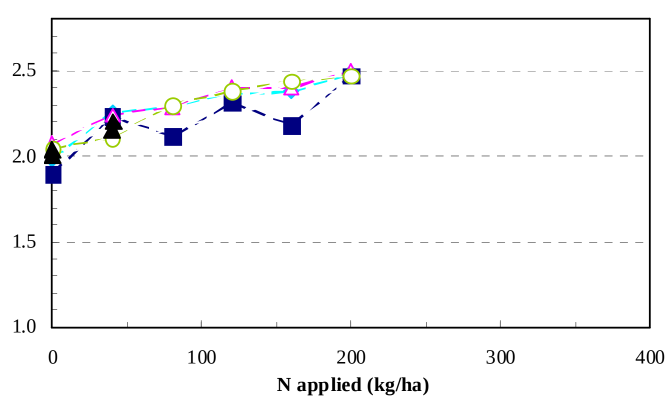
Grain yield (t/ha at 85% DM)



Statistics

	F probability
Nitrogen (N)	<0.001
Variety (V)	0.00
N x V	0.02
CV%	5.90
Variance accounted for by curve fit:	0%

Grain N (%, dry basis)



Statistics

	F probability
Nitrogen (N)	0.021
Variety (V)	<0.001
N x V	0.618
CV%	5

Variety effects	***Grain N at nil N***	***Optimum N (3:1)***	***SE Nopt***	***Change for BER=6:1***	***Grain yield at opt N***	***Grain N at opt N***
	kg/ha	*kg/ha*	*kg/ha*	*kg/ha*	*t/ha*	*% DM*
Hobbit	165	0	*	0	9.45	2.04
Norman	155	41	>opt	-15	9.17	2.20
Alchemy	164	40	*	0	10.33	2.15
Robigus	163	0	*	0	9.86	2.00
SED (N x V)					0.486	0.092
d.f.					37	37

2006 Masstock, Stebbing, Winter Wheat

Grid Ref. TL654195

Soil Group	***Topsoil***		***Subsoil***		***Depth (cm)***	***Total N (%)***
Deep clay soils	Clay loam		Chalky boulder clay		>90	0.20
Previous crops	***-1 year***	***-1 residues***	***-2 years***	***-3 years***		
	Winter wheat	Incorp	Beans	Winter wheat		

Varieties	Longbow	Virtue	Gladiator	Robigus
1st year on RL	1981	1980	2002	2001

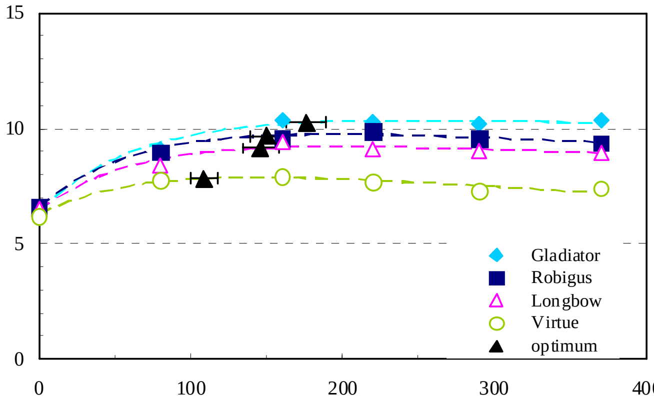
Sowing date	***Over-winter rain***	***N application dates***			***Harvest***
	mm	*1st*	*2nd*	*3rd*	
7 October 2005	75	21 Mar	2 May	19 May	12 Aug

Comments: Some lodging

Soil N analysis and Nitrogen recommendations

Soil analysis date	***Crop N***	***Soil mineral N by depth (kg/ha)***			***Soil N Supply***	
	eye-estimate	*0-30 cm*	*30-60 cm*	*60-90 cm*	*Total*	
7 Feb	60	17	19	14	74	*kg/ha*
		RB209 recommendation (by SNS Index)			180	*kg/ha*
		RB209 recommendation (by SMN analysis)			220	*kg/ha*

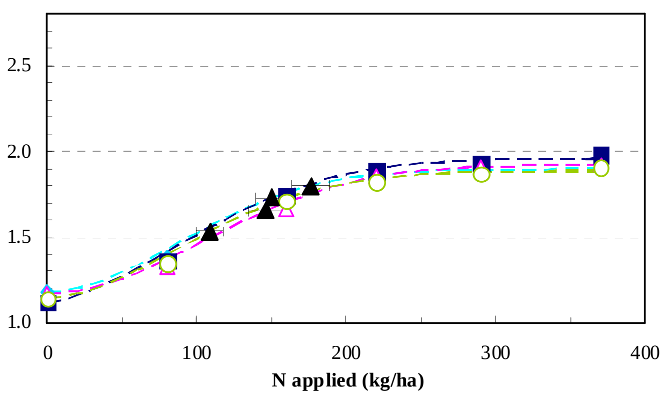
Grain yield (t/ha at 85% DM)



Statistics

	F probability
Nitrogen (N)	<0.001
Variety (V)	<0.001
N x V	<0.001
CV%	3.50
Variance accounted for by curve fit:	95%

Grain N (%, dry basis)



Statistics

	F probability
Nitrogen (N)	0.015
Variety (V)	<0.001
N x V	0.087
CV%	2.1

Variety effects	***Grain N at nil N***	***Optimum N (3:1)***	*SE Nopt*	*Change for BER=6:1*	***Grain yield at opt N***	***Grain N at opt N***
	kg/ha	*kg/ha*	*kg/ha*	*kg/ha*	*t/ha*	*% DM*
Longbow	65	146	12	-28	9.14	1.65
Virtue	60	109	9	-23	7.84	1.53
Gladiator	64	176	13	-33	10.25	1.80
Robigus	63	150	11	-26	9.68	1.73
SED (N x V)					0.249	0.029
d.f.					45	46

2007 Univ. Nott., Sutton Bonington, Winter Wheat

Grid Ref. SK508264

Soil Group	*Topsoil*		*Subsoil*		*Depth (cm)*	*Total N (%)*
Light sands or shallow c	Sandy loam		Dunnington Heath		>90	0.21
Previous crops	*-1 year*	*-1 residues*	*-2 years*	*-3 years*		
	Winter Oats	Baled	Winter Wheat	Sugar Beet		

Varieties	Virtue	Hobbit	Robigus	Oakley
1st year on RL	1980	1978	2001	2005

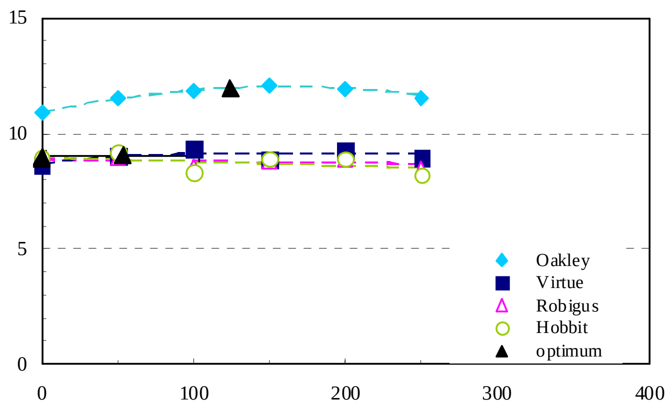
Sowing date	*Over-winter rain*	*N application dates*			*Harvest*
	mm	*1st*	*2nd*	*3rd*	
3 October 2006	200	27 Mar	4 Apr	8 May	7 Aug

Comments: 00/01/1900

Soil N analysis and Nitrogen recommendations

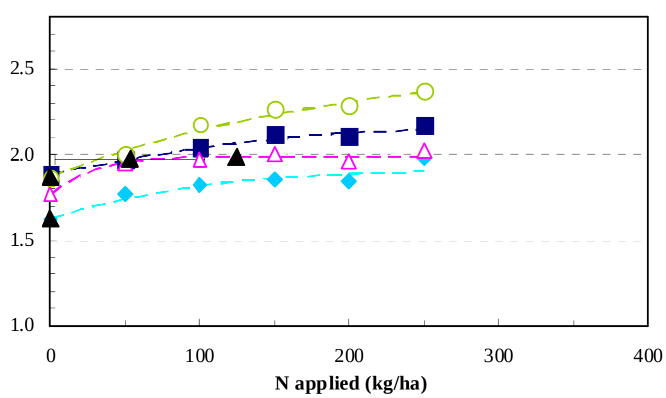
Soil analysis date	*Crop N*	*Soil mineral N by depth (kg/ha)*			*Soil N Supply*	
	eye-estimate	*0-30 cm*	*30-60 cm*	*60-90 cm*	*Total*	
20 Feb	5	39	31	41	116	*kg/ha*
				RB209 recommendation (by SNS Index)	160	*kg/ha*
				RB209 recommendation (by SMN analysis)	160	*kg/ha*

Grain yield (t/ha at 85% DM)



Statistics	
	F probability
Nitrogen (N)	<0.001
Variety (V)	0.32
N x V	0.56
CV%	6.70
Variance accounted for by curve fit:	0%

Grain N (%, dry basis)



Statistics	
	F probability
Nitrogen (N)	<0.001
Variety (V)	<0.001
N x V	0.045
CV%	3.5

Variety effects	*Grain N at nil N*	*Optimum N (3:1)*	*SE Nopt*	*Change for BER=6:1*	*Grain yield at opt N*	*Grain N at opt N*
	kg/ha	*kg/ha*	*kg/ha*	*kg/ha*	*t/ha*	*% DM*
Hobbit	142	0	*	0	8.97	1.87
Virtue	139	53	50	-24	9.03	1.97
Oakley	150	0	*	0	8.88	1.63
Robigus	136	124	>opt	-34	11.97	1.98
SED (N x V)					0.500	0.055
d.f.					46	46

2007 ADAS Boxworth, Winter Wheat

Grid Ref. TL344647

Soil Group	***Topsoil***		***Subsoil***		***Depth (cm)***	***Total N (%)***
Deep clay soils	Clay		Hanslope, CBC		>90	0.24
Previous crops	***-1 year***	***-1 residues***	***-2 years***	***-3 years***		
	WOSR	Incorp	Winter wheat	Winter wheat		

Varieties	Hustler	Hobbit	Robigus	Glasgow
1st year on RL	1979	1978	2001	2003

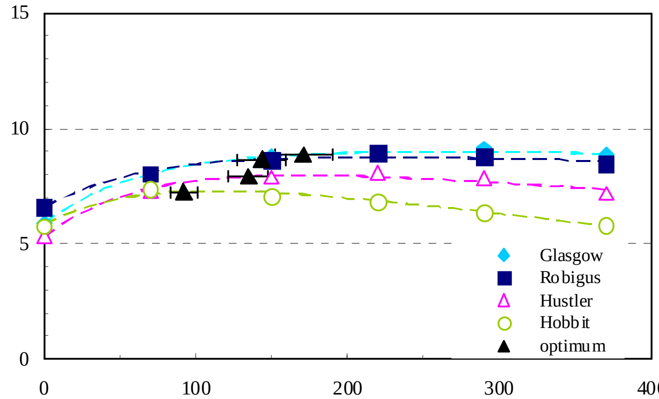
Sowing date	***Over-winter rain***	***N application dates***			***Harvest***
	mm	*1st*	*2nd*	*3rd*	
28 September 2006	113	6 Mar	4 Apr	20 Apr	10 Aug

Comments: 4th N applied on 04/05/07

Soil N analysis and Nitrogen recommendations

Soil analysis date	***Crop N***	***Soil mineral N by depth (kg/ha)***			***Soil N Supply***	
	eye-estimate	*0-30 cm*	*30-60 cm*	*60-90 cm*	*Total*	
22 Nov	15	69	20	15	119	*kg/ha*
		RB209 recommendation (by SNS Index)			100	*kg/ha*
		RB209 recommendation (by SMN analysis)			150	*kg/ha*

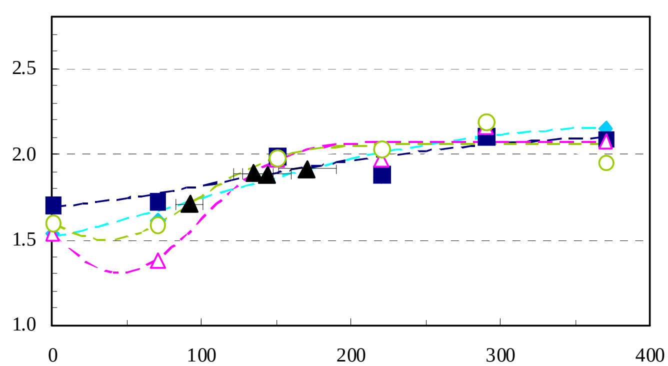
Grain yield (t/ha at 85% DM)



Statistics

	F probability
Nitrogen (N)	<0.001
Variety (V)	<0.001
N x V	<0.001
CV%	4.50
Variance accounted for by curve fit:	90%

Grain N (%, dry basis)



Statistics

	F probability
Nitrogen (N)	0.783
Variety (V)	<0.001
N x V	0.872
CV%	10.2

Variety effects	***Grain N at nil N***	***Optimum N (3:1)***	*SE Nopt*	*Change for BER=6:1*	***Grain yield at opt N***	***Grain N at opt N***
	kg/ha	*kg/ha*	*kg/ha*	*kg/ha*	*t/ha*	*% DM*
Hobbit	78	92	9	-16	7.26	1.71
Hustler	70	135	13	-23	7.92	1.89
Glasgow	77	171	19	-37	8.87	1.91
Robigus	95	144	16	-33	8.66	1.88
SED (N x V)					0.280	0.157
d.f.					46	46

2007 ADAS High Mowthorpe, Winter Wheat

Grid Ref. SE893689

Soil Group	***Topsoil***		***Subsoil***		***Depth (cm)***	***Total N (%)***
Shallow over chalk	Silty clay loam		Panholes		45-60	0.42
Previous crops	***-1 year***	***-1 residues***	***-2 years***	***-3 years***		
	WOSR	Incorp	W barley	W wheat		

Varieties	Hustler	Longbow	Ambrosia	Glasgow
1st year on RL	1979	1981	2003	2003

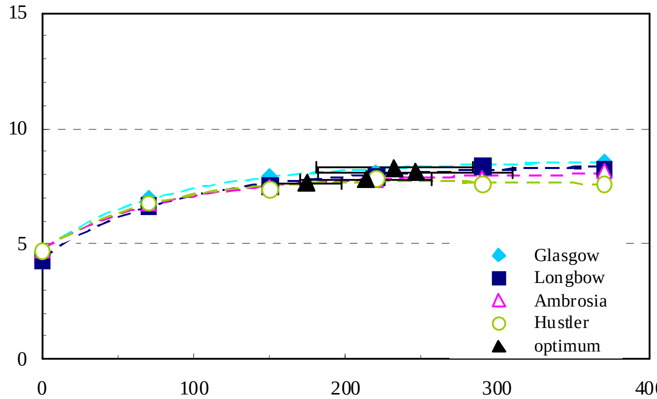
Sowing date	***Over-winter rain***	***N application dates***			***Harvest***
	mm	*1st*	*2nd*	*3rd*	
12 October 2006	200	4 Apr	23 Apr	11 May	31 Aug

Comments: Higher N rates up to 10% lodged

Soil N analysis and Nitrogen recommendations

Soil analysis date	***Crop N***	***Soil mineral N by depth (kg/ha)***			***Soil N Supply***	
	eye-estimate	*0-30 cm*	*30-60 cm*	*60-90 cm*	*Total*	
27 Nov	5	42	39	26	111	*kg/ha*
		RB209 recommendation (by SNS Index)			200	*kg/ha*
		RB209 recommendation (by SMN analysis)			160	*kg/ha*

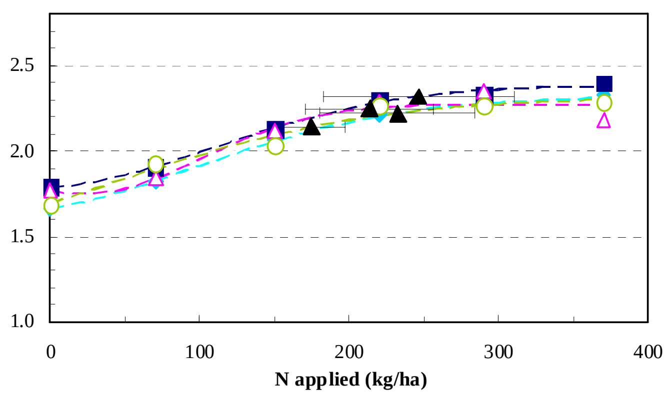
Grain yield (t/ha at 85% DM)



Statistics

	F probability
Nitrogen (N)	<0.001
Variety (V)	<0.001
N x V	0.01
CV%	3.20
Variance accounted for by curve fit:	87%

Grain N (%, dry basis)



Statistics

	F probability
Nitrogen (N)	0.043
Variety (V)	<0.001
N x V	0.53
CV%	4.3

Variety effects	***Grain N at nil N***	***Optimum N (3:1)***	*SE Nopt*	*Change for BER=6:1*	***Grain yield at opt N***	***Grain N at opt N***
	kg/ha	*kg/ha*	*kg/ha*	*kg/ha*	*t/ha*	*% DM*
Hustler	67	175	23	-37	7.61	2.14
Longbow	66	246	64	-72	8.09	2.32
Ambrosia	71	214	43	-59	7.79	2.25
Glasgow	67	232	52	-64	8.29	2.22
SED (N x V)					0.373	0.074
d.f.					15	45

2007 ADAS Terrington, Winter Wheat

Grid Ref. TF544184

Soil Group	***Topsoil***		***Subsoil***		***Depth (cm)***	***Total N (%)***
Deep fertile silty soils	Silty clay loam		Agney, ZCL		>90	0.20
Previous crops	***-1 year***	***-1 residues***	***-2 years***	***-3 years***		
	WOSR	Incorp	Winter wheat	WOSR		

Varieties	Hustler	Virtue	Alchemy	Ambrosia
1st year on RL	1979	1980	2004	2003

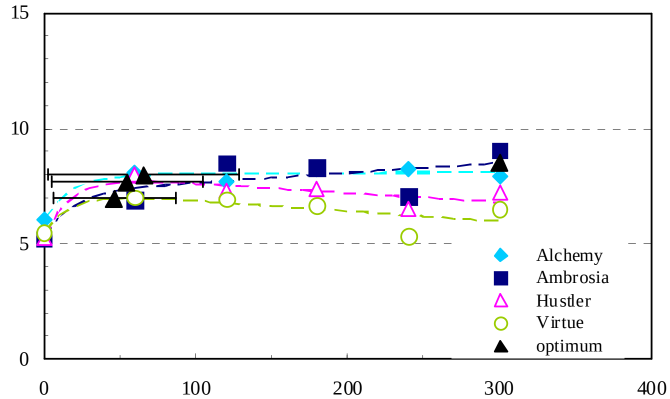
Sowing date	***Over-winter rain***	***N application dates***			***Harvest***
	mm	*1st*	*2nd*	*3rd*	
16 October 2006	113	16 Mar	19 Apr	11 May	13 Aug

Comments: Very low levels Septoria. Severe lodging scored at gs75

Soil N analysis and Nitrogen recommendations

Soil analysis date	***Crop N***	***Soil mineral N by depth (kg/ha)***			***Soil N Supply***	
	eye-estimate	*0-30 cm*	*30-60 cm*	*60-90 cm*	*Total*	
16 Nov	5	66	29	17	116	*kg/ha*
		RB209 recommendation (by SNS Index)			80	*kg/ha*
		RB209 recommendation (by SMN analysis)			120	*kg/ha*

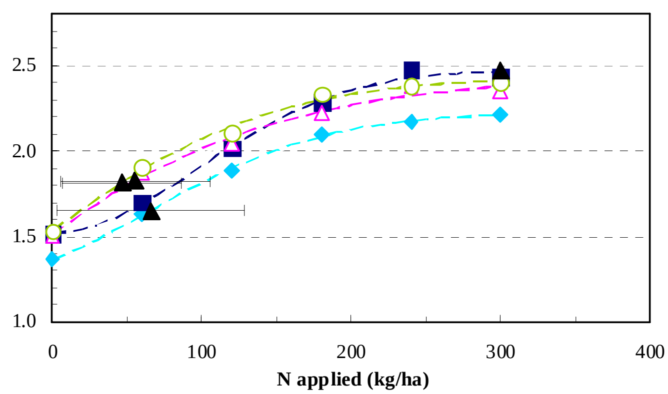
Grain yield (t/ha at 85% DM)



Statistics

	F probability
Nitrogen (N)	<0.001
Variety (V)	<0.001
N x V	0.01
CV%	9.00
Variance accounted for by curve fit:	53%

Grain N (%, dry basis)



Statistics

	F probability
Nitrogen (N)	<0.001
Variety (V)	<0.001
N x V	0.573
CV%	4.8

Variety effects	***Grain N at nil N***	***Optimum N (3:1)***	*SE Nopt*	*Change for BER=6:1*	***Grain yield at opt N***	***Grain N at opt N***
	kg/ha	*kg/ha*	*kg/ha*	*kg/ha*	*t/ha*	*% DM*
Hustler	67	55	50	-6	7.68	1.83
Virtue	71	47	40	-6	6.98	1.82
Alchemy	70	66	63	-13	7.98	1.65
Ambrosia	67	300 *		-225	8.51	2.47
SED (N x V)					0.586	0.078
d.f.					38	46

2007 ADAS Rosemaund, Winter Wheat

Grid Ref. SO485559

Soil Group	***Topsoil***		***Subsoil***		***Depth (cm)***	***Total N (%)***
Medium soils	Silty clay loam		Bromyard, ZCL		>90	0.23
Previous crops	***-1 year***	***-1 residues***	***-2 years***	***-3 years***		
	Spring wheat	Baled	Potatoes	Winter wheat		

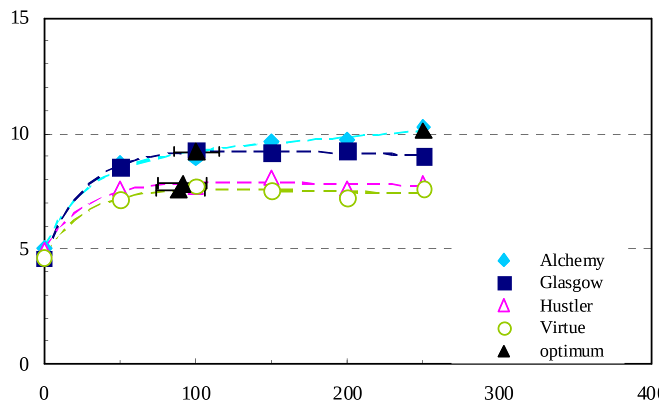
Varieties	Hustler	Virtue	Glasgow	Alchemy
1st year on RL	1979	1980	2003	2004

Sowing date	***Over-winter rain***	***N application dates***			***Harvest***
	mm	*1st*	*2nd*	*3rd*	
27 September 2006	400	1 Apr	15 Apr	10 May	22 Aug
Comments:	00/01/1900				

Soil N analysis and Nitrogen recommendations

Soil analysis date	***Crop N***	***Soil mineral N by depth (kg/ha)***			***Soil N Supply***	
	eye-estimate	*0-30 cm*	*30-60 cm*	*60-90 cm*	*Total*	
18 Dec	40	45	34	27	145	*kg/ha*
		RB209 recommendation (by SNS Index)			220	*kg/ha*
		RB209 recommendation (by SMN analysis)			100	*kg/ha*

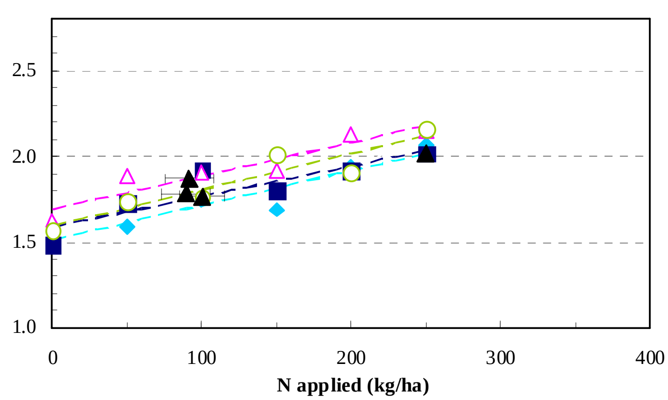
Grain yield (t/ha at 85% DM)



Statistics

	F probability
Nitrogen (N)	<0.001
Variety (V)	<0.001
N x V	<0.001
CV%	3.70
Variance accounted for by curve fit:	88%

Grain N (%, dry basis)



Statistics

	F probability
Nitrogen (N)	0.002
Variety (V)	0.002
N x V	0.36
CV%	6.9

Variety effects	***Grain N at nil N***	***Optimum N (3:1)***	*SE Nopt*	*Change for BER=6:1*	***Grain yield at opt N***	***Grain N at opt N***
	kg/ha	*kg/ha*	*kg/ha*	*kg/ha*	*t/ha*	*% DM*
Hustler	69	91	16	-15	7.83	1.87
Virtue	62	89	16	-14	7.53	1.78
Alchemy	67	250 *		-106	10.11	2.02
Glasgow	58	100	15	-13	9.22	1.77
SED (N x V)					0.425	0.127
d.f.					17	36

2007 Farmacy, Metheringham, Winter Wheat

Grid Ref. TF069615

Soil Group	*Topsoil*		*Subsoil*		*Depth (cm)*	*Total N (%)*
Deep clay soils	Silty clay loam		ZCL		>90	0.51
Previous crops	*-1 year*	*-1 residues*	*-2 years*	*-3 years*		
	Linseed	Incorp	Winter wheat	WOSR		

Varieties	Hustler	Virtue	Ambrosia	Robigus
1st year on RL	1979	1980	2003	2001

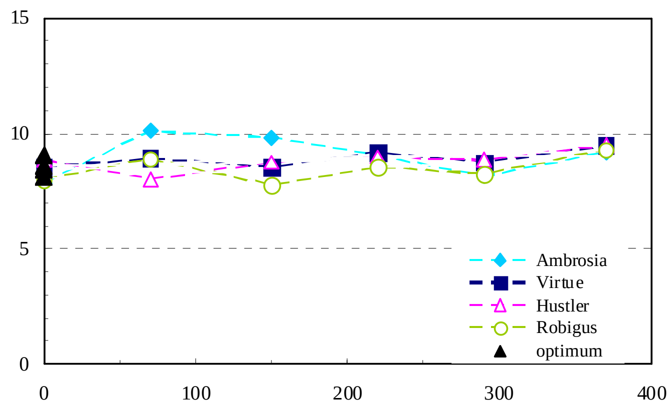
Sowing date	*Over-winter rain*	*N application dates*			*Harvest*
	mm	*1st*	*2nd*	*3rd*	
28 September 2006	113	5 Apr	26 Apr	16 May	3 Aug

Comments: Some random grazing of hares in the autumn, but crop grew away. Small focci of yellow

Soil N analysis and Nitrogen recommendations

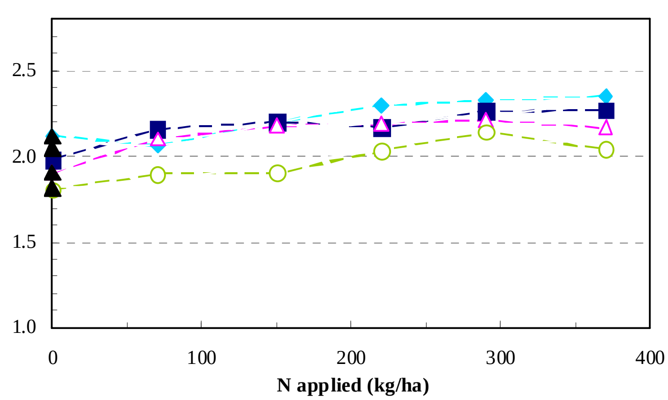
Soil analysis date	*Crop N*	*Soil mineral N by depth (kg/ha)*			*Soil N Supply*	
	eye-estimate	*0-30 cm*	*30-60 cm*	*60-90 cm*	*Total*	
30 Nov	30	23	45	33	130	*kg/ha*
		RB209 recommendation (by SNS Index)			180	*kg/ha*
		RB209 recommendation (by SMN analysis)			100	*kg/ha*

Grain yield (t/ha at 85% DM)



Statistics	*F probability*
Nitrogen (N)	0.20
Variety (V)	0.05
N x V	0.20
CV%	9.20
Variance accounted for by curve fit:	0%

Grain N (%, dry basis)



Statistics	*F probability*
Nitrogen (N)	<0.001
Variety (V)	<0.001
N x V	0.509
CV%	4.4

Variety effects	*Grain N at nil N*	*Optimum N (3:1)*	*SE Nopt*	*Change for BER=6:1*	*Grain yield at opt N*	*Grain N at opt N*
	kg/ha	*kg/ha*	*kg/ha*	*kg/ha*	*t/ha*	*% DM*
Hustler	144	0	*	0	8.41	1.91
Virtue	144	0	*	0	8.57	2.05
Ambrosia	142	0	*	0	9.03	2.12
Robigus	123	0	*	0	8.10	1.82
SED (N x V)					0.661	0.077
d.f.					46	46

2007 SAC Laurencekirk, Winter Wheat

Grid Ref. NO675719

Soil Group	*Topsoil*		*Subsoil*		*Depth (cm)*	*Total N (%)*
Medium soils	Sandy silt loam		Luther, SL		70-75	0.35
Previous crops	*-1 year*	*-1 residues*	*-2 years*	*-3 years*		
	WOSR	Baled	Winter barley	Winter wheat		

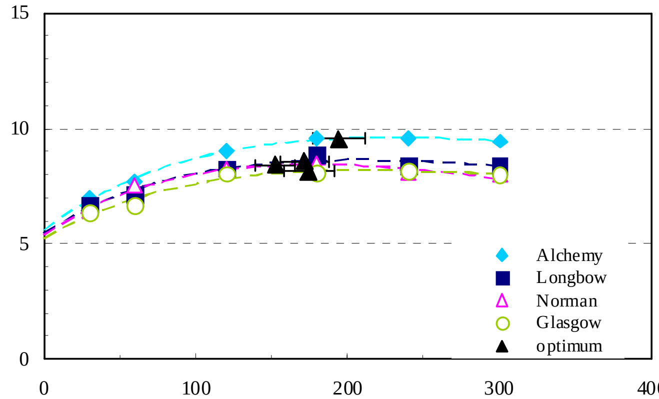
Varieties	Norman	Longbow	Alchemy	Glasgow
1st year on RL	1980	1981	2004	2003

Sowing date	*Over-winter rain*	*N application dates*			*Harvest*
	mm	*1st*	*2nd*	*3rd*	
4 October 2006	325	28 Mar	13 Apr	24 Apr	1 Sep
Comments:	00/01/1900				

Soil N analysis and Nitrogen recommendations

Soil analysis date	*Crop N*	*Soil mineral N by depth (kg/ha)*			*Soil N Supply*	
	eye-estimate	*0-30 cm*	*30-60 cm*	*60-90 cm*	*Total*	
27 Feb 07*	5	77	33	-	115	*kg/ha*
		RB209 recommendation (by SNS Index)			220	*kg/ha*
		RB209 recommendation (by SMN analysis)			150	*kg/ha*

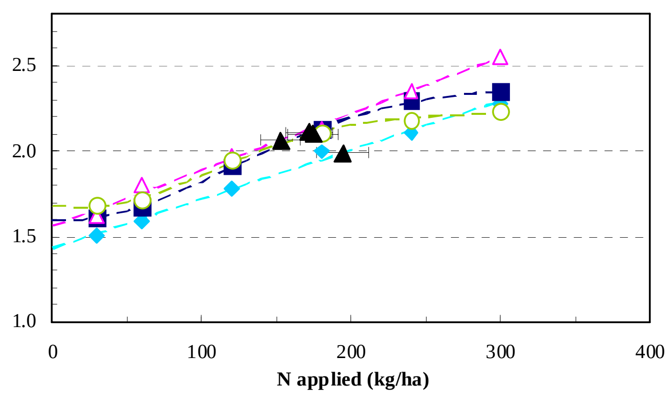
Grain yield (t/ha at 85% DM)



Statistics

	F probability
Nitrogen (N)	<0.001
Variety (V)	<0.001
N x V	0.06
CV%	4.20
Variance accounted for by curve fit:	84%

Grain N (%, dry basis)



Statistics

	F probability
Nitrogen (N)	<0.001
Variety (V)	<0.001
N x V	0.121
CV%	4.2

Variety effects	*Grain N at nil N*	*Optimum N (3:1)*	*SE Nopt*	*Change for BER=6:1*	*Grain yield at opt N*	*Grain N at opt N*
	kg/ha	*kg/ha*	*kg/ha*	*kg/ha*	*t/ha*	*% DM*
Longbow	92	172	16	-26	8.58	2.11
Norman	88	153	13	-20	8.40	2.06
Alchemy	90	194	17	-28	9.56	1.99
Glasgow	91	175	17	-29	8.14	2.10
SED (N x V)					0.276	0.068
d.f.					44	46

2007 Masstock, Stebbing, Winter Wheat

Grid Ref. TL657197

Soil Group	***Topsoil***		***Subsoil***		***Depth (cm)***	***Total N (%)***
Deep clay soils	Chalky boulder clay		Clay		>90	0.22
Previous crops	***-1 year***	***-1 residues***	***-2 years***	***-3 years***		
	Winter wheat	Incorp	Winter wheat	Beans		

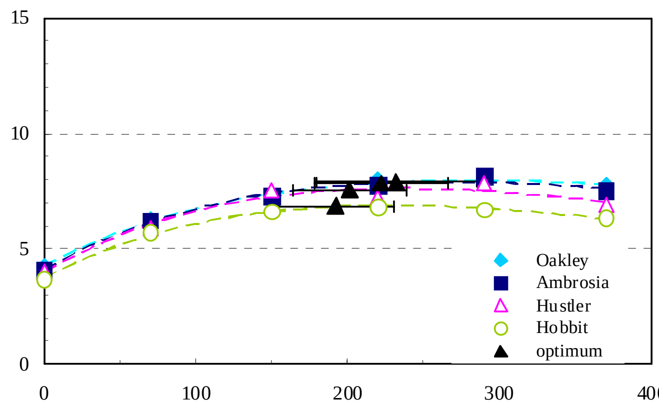
Varieties	Hustler	Hobbit	Ambrosia	Oakley
1st year on RL	1979	1978	2003	2005

Sowing date	***Over-winter rain***	***N application dates***			***Harvest***
	mm	*1st*	*2nd*	*3rd*	
16 October 2006	200	16 Mar	16 Apr	3 May	28 Aug
Comments:	00/01/1900				

Soil N analysis and Nitrogen recommendations

Soil analysis date	***Crop N***	***Soil mineral N by depth (kg/ha)***			***Soil N Supply***	
	eye-estimate	*0-30 cm*	*30-60 cm*	*60-90 cm*	*Total*	
6 Feb	15	20	26	30	92	*kg/ha*
				RB209 recommendation (by SNS Index)	220	*kg/ha*
				RB209 recommendation (by SMN analysis)	180	*kg/ha*

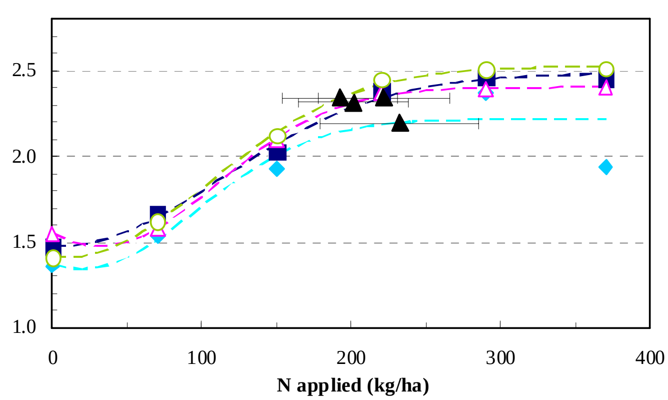
Grain yield (t/ha at 85% DM)



Statistics

	F probability
Nitrogen (N)	<0.001
Variety (V)	<0.001
N x V	0.76
CV%	8.00
Variance accounted for by curve fit:	52%

Grain N (%, dry basis)



Statistics

	F probability
Nitrogen (N)	0.02
Variety (V)	<0.001
N x V	0.613
CV%	9.169596348

Variety effects	***Grain N at nil N***	***Optimum N (3:1)***	*SE Nopt*	*Change for BER=6:1*	***Grain yield at opt N***	***Grain N at opt N***
	kg/ha	*kg/ha*	*kg/ha*	*kg/ha*	*t/ha*	*% DM*
Hobbit	44	192	38	-30	6.83	2.34
Hustler	53	201	37	-28	7.57	2.31
Ambrosia	51	222	44	-34	7.85	2.34
Oakley	49	232	53	-40	7.89	2.20
SED (N x V)					0.574	0.153
d.f.					26	46

2007 ADAS Kent, Winter Wheat

Grid Ref. TR057330

Soil Group	***Topsoil***		***Subsoil***		***Depth (cm)***	***Total N (%)***
Deep clay soils	Clay loam		New Romney, lias clay		>90	0.30
Previous crops	***-1 year***	***-1 residues***	***-2 years***	***-3 years***		
	Winter wheat	Incorp	WOSR	Winter wheat		

Varieties	Hustler	Norman	Alchemy	Oakley
1st year on RL	1979	1980	2004	2005

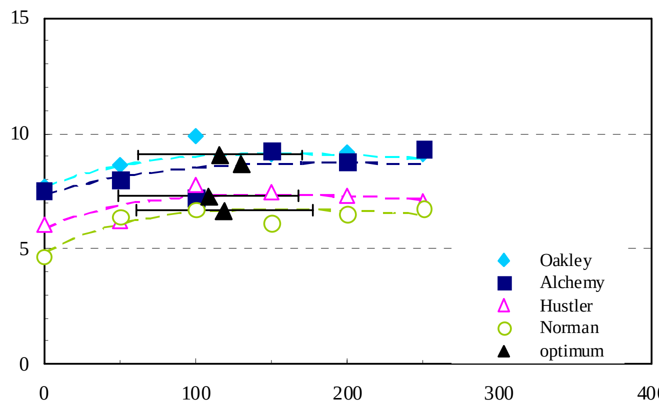
Sowing date	***Over-winter rain***	***N application dates***			***Harvest***
	mm	*1st*	*2nd*	*3rd*	
9 October 2006	325	21 Mar	5 Apr	18 Apr	17 Aug

Comments: Brown rust 40% flag Alchemy, other cvs a trace, moderate S.tritici Norman/Hustler

Soil N analysis and Nitrogen recommendations

Soil analysis date	***Crop N***	***Soil mineral N by depth (kg/ha)***			***Soil N Supply***	
	eye-estimate	*0-30 cm*	*30-60 cm*	*60-90 cm*	*Total*	
5 Feb	15	42	39	39	136	*kg/ha*
		RB209 recommendation (by SNS Index)			220	*kg/ha*
		RB209 recommendation (by SMN analysis)			100	*kg/ha*

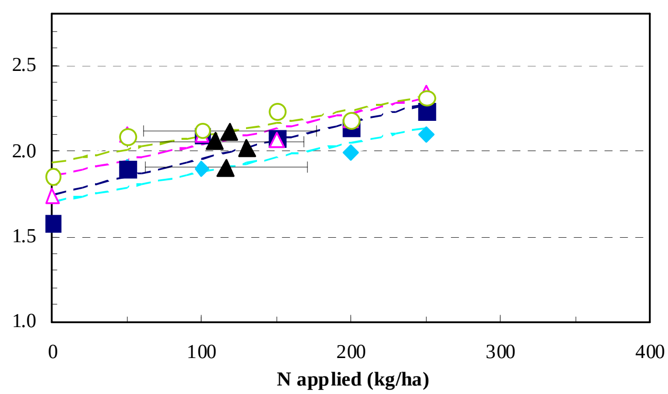
Grain yield (t/ha at 85% DM)



Statistics

	F probability
Nitrogen (N)	<0.001
Variety (V)	0.06
N x V	0.94
CV%	18.10
Variance accounted for by curve fit:	37%

Grain N (%, dry basis)



Statistics

	F probability
Nitrogen (N)	<0.001
Variety (V)	<0.001
N x V	0.794
CV%	6

Variety effects	***Grain N at nil N***	***Optimum N (3:1)***	*SE Nopt*	*Change for BER=6:1*	***Grain yield at opt N***	***Grain N at opt N***
	kg/ha	*kg/ha*	*kg/ha*	*kg/ha*	*t/ha*	*% DM*
Hustler	90	109	59	-24	7.29	2.06
Norman	74	119	58	-23	6.66	2.12
Alchemy	101	130	*	-38	8.63	2.02
Oakley	103	116	54	-27	9.07	1.90
SED (N x V)					1.121	0.099
d.f.					43	43

2007 Masstock, Fowlmere, Winter Wheat

Grid Ref. TL403474

Soil Group	***Topsoil***		***Subsoil***		***Depth (cm)***	***Total N (%)***
Shallow over chalk	Sandy loam		Chalk		40-60	0.16
Previous crops	***-1 year***	***-1 residues***	***-2 years***	***-3 years***		
	Winter oats	Baled	Peas	Winter wheat		

Varieties	Hustler	Hobbit	Robigus	Oakley
1st year on RL	1979	1978	2001	2005

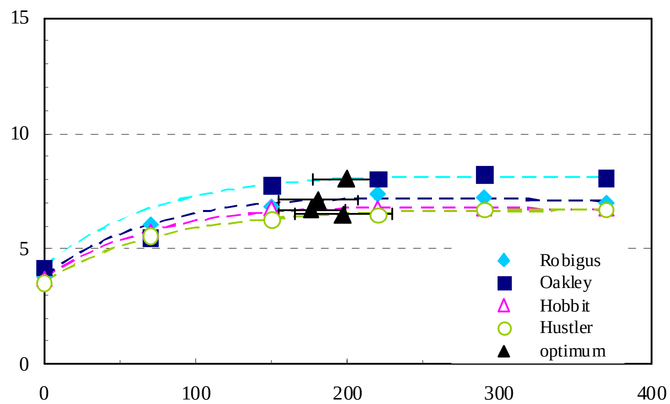
Sowing date	***Over-winter rain***	***N application dates***			***Harvest***
	mm	*1st*	*2nd*	*3rd*	
13 October 2006	200	28 Mar	17 Apr	4 May	8 Aug

Comments: Low disease levels

Soil N analysis and Nitrogen recommendations

Soil analysis date	***Crop N***	***Soil mineral N by depth (kg/ha)***			***Soil N Supply***	
	eye-estimate	*0-30 cm*	*30-60 cm*	*60-90 cm*	*Total*	
6 Feb	15	19	16	-	50	*kg/ha*
		RB209 recommendation (by SNS Index)			240	*kg/ha*
		RB209 recommendation (by SMN analysis)			260	*kg/ha*

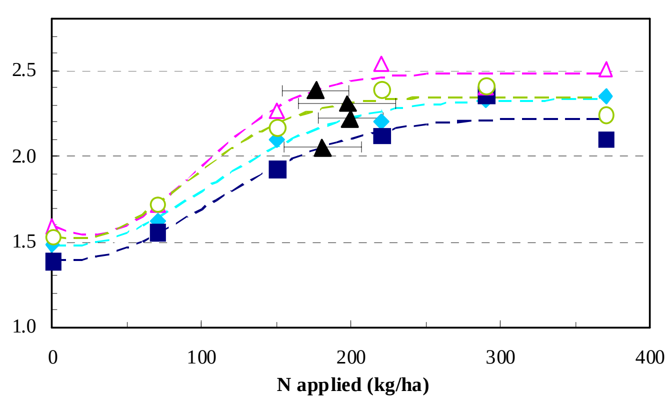
Grain yield (t/ha at 85% DM)



Statistics

	F probability
Nitrogen (N)	<0.001
Variety (V)	<0.001
N x V	0.43
CV%	9.00
Variance accounted for by curve fit:	88%

Grain N (%, dry basis)



Statistics

	F probability
Nitrogen (N)	<0.001
Variety (V)	<0.001
N x V	0.797
CV%	7.8

Variety effects	***Grain N at nil N***	***Optimum N (3:1)***	*SE Nopt*	*Change for BER=6:1*	***Grain yield at opt N***	***Grain N at opt N***
	kg/ha	*kg/ha*	*kg/ha*	*kg/ha*	*t/ha*	*% DM*
Hobbit	50	176	22	-37	6.70	2.39
Hustler	46	197	32	-50	6.51	2.31
Oakley	50	180	26	-36	7.11	2.05
Robigus	48	199	22	-40	8.04	2.22
SED (N x V)					0.532	0.131
d.f.					36	45

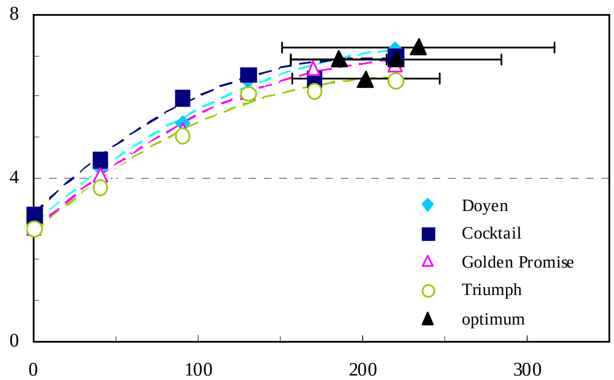
2005 SAC Aberdeen, Spring Barley

2005 SAC Aberdeen, Spring Barley					***Grid Ref.***	NJ722307
Soil Group	***Topsoil***		***Subsoil***		***Depth (cm)***	***Total N (%)***
Sandy	Sandy loam		Insch series		55	0.43
Previous crops	***-1 year***	***-1 residues***	***-2 years***	***-3 years***		
	Spring barley	baled	Spring barley	Spring barley		
Varieties	Triumph	Golden Promise	Cocktail	Doyen		
1st year on RL	1980	<1980	2003	2004		
Sowing date	***Over-winter rain***	***N application dates***			***Harvest***	
	mm	*1st*	*2nd*			
6 April 2005	200	12 May	3 Jun		20 Sep	
Comments:	NA					

Soil N analysis and Nitrogen recommendations

Soil analysis date	***Crop N***	***Soil mineral N by depth (kg/ha)***			***Soil N Supply***	
	eye-estimate	*0-30 cm*	*30-60 cm*	*60-90 cm*	*Total*	
18 May	5	99	31	-	135	*kg/ha*
				Feed	***Malting***	
	RB209 recommendation (by SNS Index)			125	100	*kg/ha*
	RB209 recommendation (by SMN analysis)			30	0	*kg/ha*

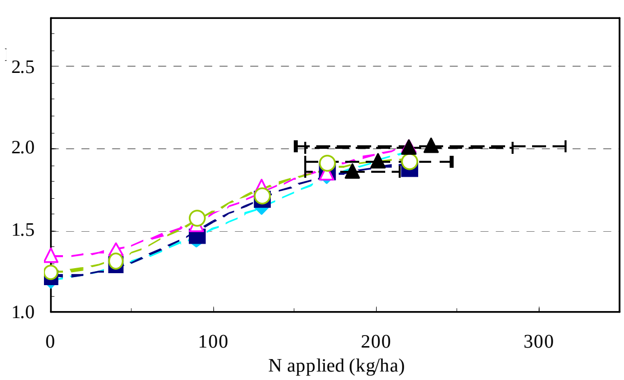
Grain yield (t/ha at 85% DM)



Statistics

	F probability
Nitrogen (N)	<.001
Variety (V)	0.00
N x V	0.91
CV%	7.90
Variance accounted for by curve fit:	86%

Grain N (%, dry basis)



Statistics

	F probability
Nitrogen (N)	<.001
Variety (V)	<.001
N x V	0.524
CV%	4.3

Variety effects	***Grain N at nil N***	***Optimum N (3:1)***	*SE Nopt*	*Change for BER=6:1*	***Grain yield at opt N***	***Grain N at opt N***
	kg/ha	*kg/ha*	*kg/ha*	*kg/ha*	*t/ha*	*% DM*
Golden Promise	31	220	64	-23	6.90	2.01
Triumph	29	202	45	-21	6.43	1.92
Cocktail	32	186	29	-18	6.91	1.86
Doyen	29	234	83	-25	7.21	2.02
SED (N x V)					0.345	0.056
d.f.					46	46

2005 SAC Laurencekirk, Spring Barley

Grid Ref. NO732739

Soil Group	***Topsoil***		***Subsoil***		***Depth (cm)***	***Total N (%)***
Other mineral	Sandy silt loam		Oldcake series		60	0.34
Previous crops	***-1 year***	***-1 residues***	***-2 years***	***-3 years***		
	Set aside	incorp	Set aside	Winter wheat		

Varieties	Atem	Golden Promise	Cocktail	Troon
1st year on RL	1980	<1980	2003	2003

Sowing date	***Over-winter rain***	***N application dates***		***Harvest***
	mm	*1st*	*2nd*	
9 April 2005	200	11 May	10 Jun	12 Sep

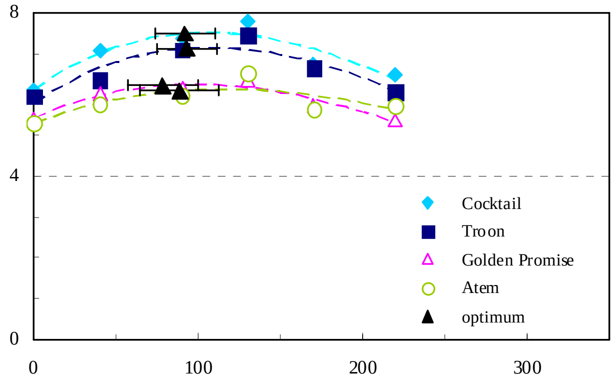
Comments: Disease, pest & weed control good, but mod. couch grass in some plots

Soil N analysis and Nitrogen recommendations

Soil analysis date	***Crop N***	***Soil mineral N by depth (kg/ha)***			***Soil N Supply***	
	eye-estimate	*0-30 cm*	*30-60 cm*	*60-90 cm*	*Total*	
13 May	5	116	103	-	224	*kg/ha*

	Feed	***Malting***	
RB209 recommendation (by SNS Index)	80	50	*kg/ha*
RB209 recommendation (by SMN analysis)	30	0	*kg/ha*

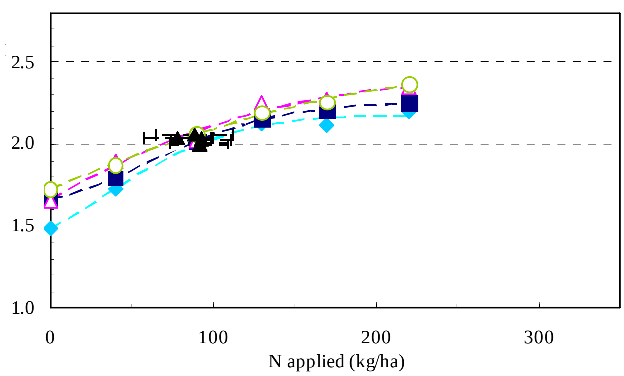
Grain yield (t/ha at 85% DM)



Statistics

	F probability
Nitrogen (N)	<.001
Variety (V)	<.001
N x V	1.00
CV%	10.10
Variance accounted for by curve fit:	43%

Grain N (%, dry basis)



Statistics

	F probability
Nitrogen (N)	<.001
Variety (V)	0.001
N x V	0.986
CV%	5.5

Variety effects	***Grain N at nil N***	***Optimum N (3:1)***	*SE Nopt*	*Change for BER=6:1*	***Grain yield at opt N***	***Grain N at opt N***
	kg/ha	*kg/ha*	*kg/ha*	*kg/ha*	*t/ha*	*% DM*
Atem	78	89	24	-23	6.10	2.06
Golden Promise	76	78	21	-18	6.22	2.04
Cocktail	77	92	18	-13	7.49	2.00
Troon	84	93	18	-14	7.13	2.03
SED (N x V)					0.520	0.091
d.f.					46	46

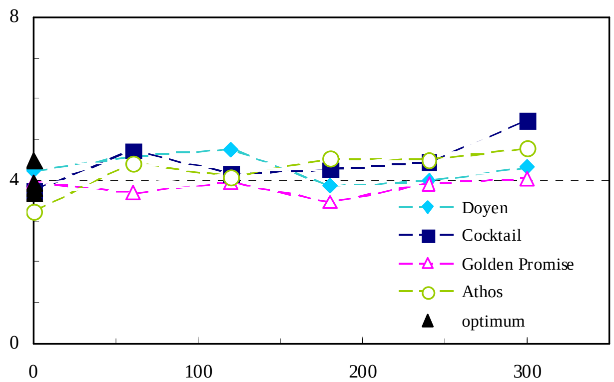
2005 NSDM York, Spring Barley

					Grid Ref.	SE715615
Soil Group	***Topsoil***		***Subsoil***		***Depth (cm)***	***Total N (%)***
Other mineral	Silty clay loam		Deep silty		>90	0.11
Previous crops	***-1 year***	***-1 residues***	***-2 years***	***-3 years***		
	Sugar beet	incorp	Winter barley	Winter barley		
Varieties	Athos	Golden Promise	Cocktail	Doyen		
1st year on RL	1980	<1980	2003	2004		
Sowing date	***Over-winter rain***	***N application dates***			***Harvest***	
	mm	*1st*	*2nd*			
13 March 2005	75	13 Apr	10 May		17 Aug	
Comments:	NA					

Soil N analysis and Nitrogen recommendations

Soil analysis date	***Crop N***	***Soil mineral N by depth (kg/ha)***			***Soil N Supply***	
	eye-estimate	*0-30 cm*	*30-60 cm*	*60-90 cm*	*Total*	
15 Feb	0	51	34	16	101	*kg/ha*
				Feed	***Malting***	
RB209 recommendation (by SNS Index)				150	120	*kg/ha*
RB209 recommendation (by SMN analysis)				80	50	*kg/ha*

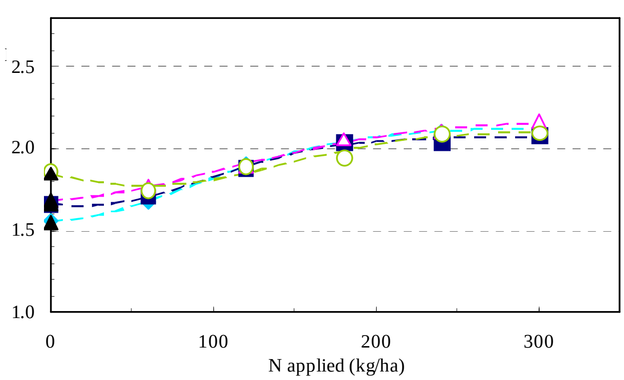
Grain yield (t/ha at 85% DM)



Statistics

	F probability
Nitrogen (N)	0.24
Variety (V)	0.16
N x V	0.81
CV%	20.10
Variance accounted for by curve fit:	0%

Grain N (%, dry basis)



Statistics

	F probability
Nitrogen (N)	<.001
Variety (V)	0.331
N x V	0.243
CV%	4.9

Variety effects	***Grain N at nil N***	***Optimum N (3:1)***	*SE Nopt*	*Change for BER=6:1*	***Grain yield at opt N***	***Grain N at opt N***
	kg/ha	*kg/ha*	*kg/ha*	*kg/ha*	*t/ha*	*% DM*
Athos	51	0	*	0	3.66	1.85
Golden Promise	56	0	*	0	3.79	1.68
Cocktail	53	0	*	0	3.91	1.66
Doyen	56	0	*	0	4.46	1.55
SED (N x V)					0.693	0.076
d.f.					46	46

2005 ADAS Rosemaund (offsite), Spring Barley

Grid Ref. SO654486

Soil Group	*Topsoil*	*Subsoil*	*Depth (cm)*	*Total N (%)*
Deep silty	Sandy clay loam	Bromyard	>90	ND

Previous crops	*-1 year*	*-1 residues*	*-2 years*	*-3 years*
	Spring beans	baled	Winter wheat	Spring beans

Varieties	Triumph	Golden Promise	Troon	Spire
1st year on RL	1980	<1980	2003	2002

Sowing date	*Over-winter rain*	*N application dates*		*Harvest*
	mm	*1st*	*2nd*	
4 April 2005	200	14 May	25 May	18 Aug

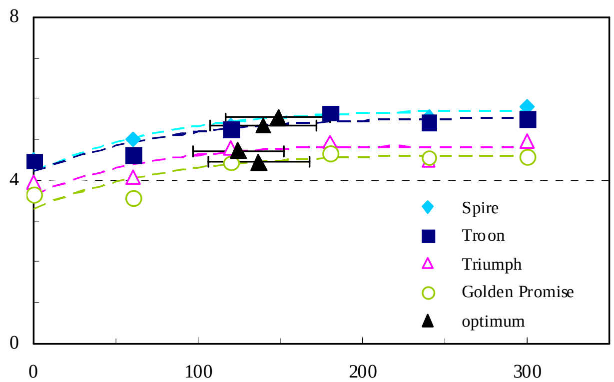
Comments: Good disease & weed control, some lodging

Soil N analysis and Nitrogen recommendations

Soil analysis date	*Crop N*	*Soil mineral N by depth (kg/ha)*			*Soil N Supply*	
	eye-estimate	*0-30 cm*	*30-60 cm*	*60-90 cm*	*Total*	
7 Mar	5	48	20	12	85	*kg/ha*

	Feed	*Malting*	
RB209 recommendation (by SNS Index)	40	30	*kg/ha*
RB209 recommendation (by SMN analysis)	120	80	*kg/ha*

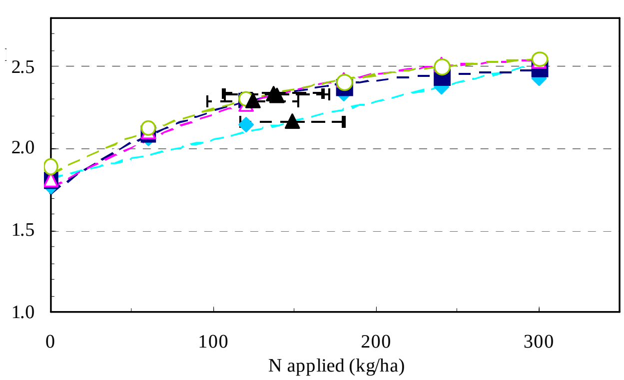
Grain yield (t/ha at 85% DM)



Statistics

	F probability
Nitrogen (N)	0.00
Variety (V)	<.001
N x V	0.50
CV%	4.50
Variance accounted for by curve fit:	76%

Grain N (%, dry basis)



Statistics

	F probability
Nitrogen (N)	<.001
Variety (V)	<.001
N x V	<.001
CV%	1.1

Variety effects	*Grain N at nil N*	*Optimum N (3:1)*	*SE Nopt*	*Change for BER=6:1*	*Grain yield at opt N*	*Grain N at opt N*
	kg/ha	*kg/ha*	*kg/ha*	*kg/ha*	*t/ha*	*% DM*
Golden Promise	59	137	31	-51	4.45	2.34
Triumph	61	124	28	-44	4.72	2.29
Spire	68	148	32	-52	5.54	2.17
Troon	69	139	32	-54	5.34	2.33
SED (N x V)					0.288	0.030
d.f.					36	36

Appendix

2005 Masstock, Fowlmere, Spring Barley

Grid Ref.	TL403474

Soil Group	*Topsoil*	*Subsoil*	*Depth (cm)*	*Total N (%)*
Shallow over chalk or li	Sandy clay loam	Calc loam over chalk	40	ND

Previous crops	*-1 year*	*-1 residues*	*-2 years*	*-3 years*
	Set aside	incorp	Winter wheat	Peas

Varieties	Golden Promise	Atem	Troon	Spire
1st year on RL	<1980	1980	2003	2002

Sowing date	*Over-winter rain*	*N application dates*		*Harvest*
	mm	*1st*	*2nd*	
15 March 2005	75	18 Mar	27 Apr	18 Aug

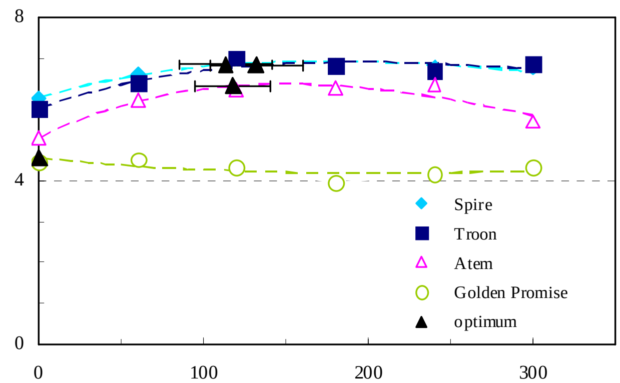
Comments: Good control of disease and weeds

Soil N analysis and Nitrogen recommendations

Soil analysis date	*Crop N*	*Soil mineral N by depth (kg/ha)*			*Soil N Supply*	
	eye-estimate	*0-30 cm*	*30-60 cm*	*60-90 cm*	*Total*	
15 Mar	0	0	0	0	63	*kg/ha*

	Feed	*Malting*	
RB209 recommendation (by SNS Index)	40	30	*kg/ha*
RB209 recommendation (by SMN analysis)	150	120	*kg/ha*

Grain yield (t/ha at 85% DM)



Statistics

	F probability
Nitrogen (N)	0.07
Variety (V)	<.001
N x V	0.05
CV%	7.00
Variance accounted for by curve fit:	83%

Grain N (%, dry basis)

Data not recorded

Variety effects	*Grain N at nil N*	*Optimum N (3:1)*	*SE Nopt*	*Change for BER=6:1*	*Grain yield at opt N*	*Grain N at opt N*
	kg/ha	*kg/ha*	*kg/ha*	*kg/ha*	*t/ha*	*% DM*
Atem	ND	118	23	-26	6.32	ND
Golden Promise	ND	0	>opt	0	4.56	ND
Spire	ND	113	28	-45	6.84	ND
Troon	ND	132	28	-46	6.82	ND
SED (N x V)					0.371	
d.f.					36	

2006 SAC Aberdeen, Spring Barley

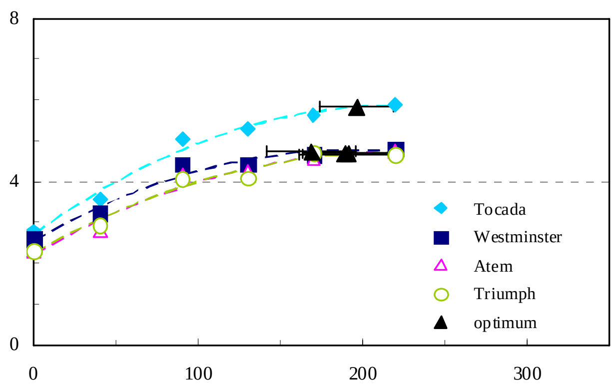
2006 SAC Aberdeen, Spring Barley					***Grid Ref.***	NJ824147	
Soil Group	***Topsoil***		***Subsoil***		***Depth (cm)***	***Total N (%)***	
Sandy	Sandy loam		Sand		50-60	0.35	
Previous crops	***-1 year***	***-1 residues***	***-2 years***	***-3 years***			
	Winter barley	baled	Spring barley	Spring barley			
Varieties	Atem	Triumph	Westminster	Tocada			
1st year on RL	1980	1980	2005	2005			
Sowing date	***Over-winter rain***	***N application dates***			***Harvest***		
	mm	*1st*	*2nd*				
16 April 2006	325	4 May	16 May		30 Aug		
Comments:	NA						

Soil N analysis and Nitrogen recommendations

Soil analysis date	***Crop N***	***Soil mineral N by depth (kg/ha)***			***Soil N Supply***	
	eye-estimate	*0-30 cm*	*30-60 cm*	*60-90 cm*	*Total*	
28 Jun	15	27	22	-	64	*kg/ha*

	Feed	***Malting***	
RB209 recommendation (by SNS Index)	125	100	*kg/ha*
RB209 recommendation (by SMN analysis)	90	70	*kg/ha*

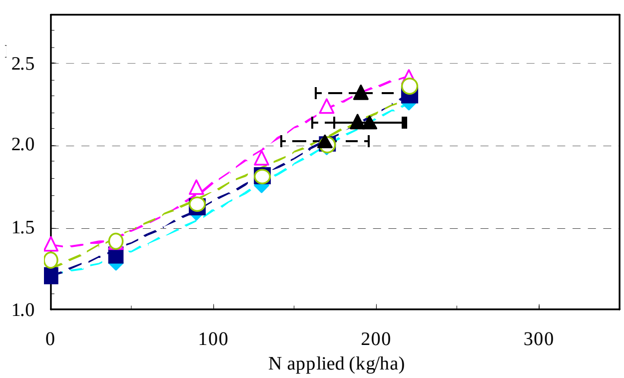
Grain yield (t/ha at 85% DM)



Statistics

	F probability
Nitrogen (N)	<.001
Variety (V)	<.001
N x V	0.37
CV%	6.70
Variance accounted for by curve fit:	91%

Grain N (%, dry basis)



Statistics

	F probability
Nitrogen (N)	<.001
Variety (V)	<.001
N x V	0.864
CV%	4.6

Variety effects	***Grain N at nil N***	***Optimum N (3:1)***	*SE Nopt*	*Change for BER=6:1*	***Grain yield at opt N***	***Grain N at opt N***
	kg/ha	*kg/ha*	*kg/ha*	*kg/ha*	*t/ha*	*% DM*
Atem	28	191	28	-30	4.69	2.32
Triumph	26	189	28	-30	4.67	2.14
Tocada	29	196	22	-23	5.84	2.14
Westminster	27	169	27	-26	4.74	2.03
SED (N x V)					0.225	0.066
d.f.					46	46

2006 SAC Laurencekirk, Spring Barley

Grid Ref. NO682687

Soil Group	*Topsoil*		*Subsoil*		*Depth (cm)*	*Total N (%)*
Other mineral	Sandy clay loam		SCL/Luther		60-70	0.27
Previous crops	*-1 year*	*-1 residues*	*-2 years*	*-3 years*		
	Spring barley	baled	Winter wheat	Not known		

Varieties	Atem	Triumph	Westminster	Doyen
1st year on RL	1980	1980	2005	2004

Sowing date	*Over-winter rain*	*N application dates*		*Harvest*
	mm	*1st*	*2nd*	
13 April 2006	200	3 May	12 May	26 Aug

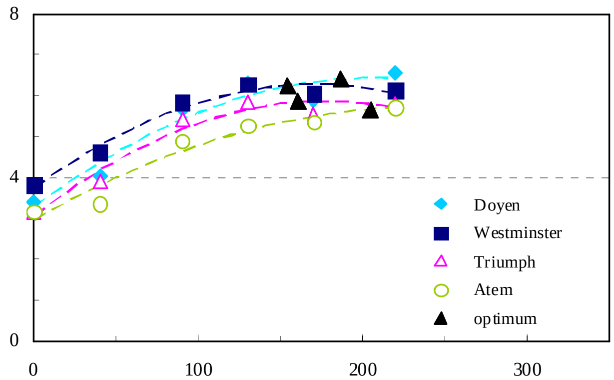
Comments: NA

Soil N analysis and Nitrogen recommendations

Soil analysis date	*Crop N*	*Soil mineral N by depth (kg/ha)*			*Soil N Supply*	
	eye-estimate	*0-30 cm*	*30-60 cm*	*60-90 cm*	*Total*	
26 Jun	15	38	28	-	81	*kg/ha*

	Feed	***Malting***	
RB209 recommendation (by SNS Index)	150	120	*kg/ha*
RB209 recommendation (by SMN analysis)	120	80	*kg/ha*

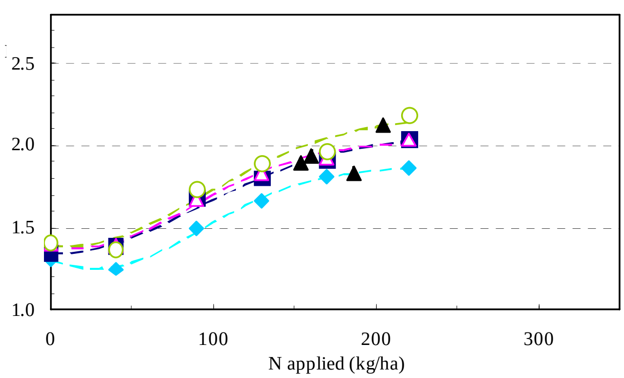
Grain yield (t/ha at 85% DM)



Statistics

	F probability
Nitrogen (N)	<.001
Variety (V)	<.001
N x V	0.95
CV%	9.40
Variance accounted for by curve fit:	80%

Grain N (%, dry basis)



Statistics

	F probability
Nitrogen (N)	<.001
Variety (V)	<.001
N x V	0.843
CV%	5

Variety effects	***Grain N at nil N***	***Optimum N (3:1)***	*SE Nopt*	*Change for BER=6:1*	***Grain yield at opt N***	***Grain N at opt N***
	kg/ha	*kg/ha*	*kg/ha*	*kg/ha*	*t/ha*	*% DM*
Atem	38	205	>opt	-29	5.67	2.12
Triumph	37	161	>opt	-16	5.85	1.94
Doyen	38	186	>opt	-19	6.41	1.83
Westminster	44	154	>opt	-17	6.26	1.89
SED (N x V)					0.390	0.069
d.f.					46	46

2006 NSDM York, Spring Barley

Grid Ref. SE715615

Soil Group	*Topsoil*		*Subsoil*		*Depth (cm)*	*Total N (%)*
Deep Silty	Silty clay loam		Deep Silty		>90	0.10
Previous crops	*-1 year*	*-1 residues*	*-2 years*	*-3 years*		
	Winter wheat	baled	Sugar beet	Spring barley		

Varieties	Atem	Triumph	Cocktail	Doyen
1st year on RL	1980	1980	2003	2004

Sowing date	*Over-winter rain*	*N application dates*		*Harvest*
	mm	*1st*	*2nd*	
13 April 2006	165	10 May	19 May	25 Aug

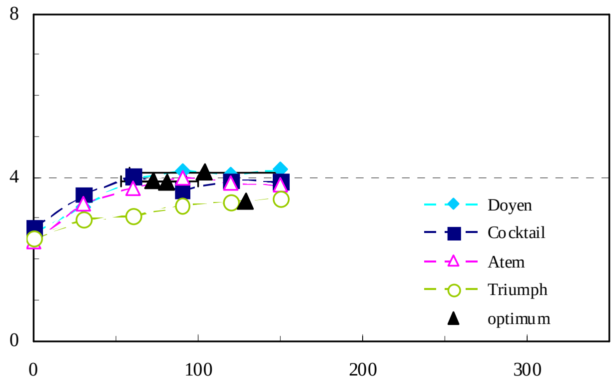
Comments: Standard disease control for mildew and Rhynchosporium

Soil N analysis and Nitrogen recommendations

Soil analysis date	*Crop N*	*Soil mineral N by depth (kg/ha)*			*Soil N Supply*	
	eye-estimate	*0-30 cm*	*30-60 cm*	*60-90 cm*	*Total*	
2 Feb	0	12	8	3	23	*kg/ha*

	Feed	*Malting*	
RB209 recommendation (by SNS Index)	150	120	*kg/ha*
RB209 recommendation (by SMN analysis)	150	120	*kg/ha*

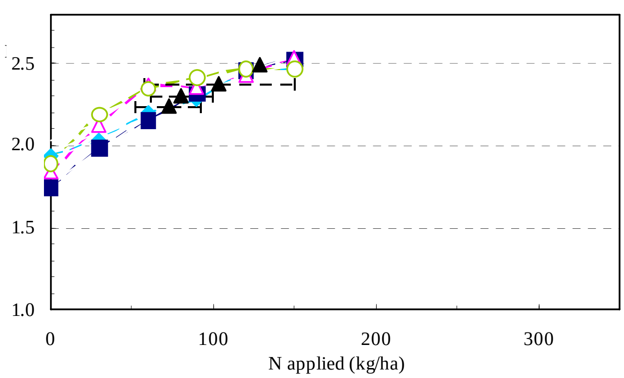
Grain yield (t/ha at 85% DM)



Statistics

	F probability
Nitrogen (N)	<.001
Variety (V)	0.00
N x V	0.97
CV%	14.00
Variance accounted for by curve fit:	52%

Grain N (%, dry basis)



Statistics

	F probability
Nitrogen (N)	<.001
Variety (V)	0.018
N x V	0.27
CV%	4.4

Variety effects	*Grain N at nil N*	*Optimum N (3:1)*	*SE Nopt*	*Change for BER=6:1*	*Grain yield at opt N*	*Grain N at opt N*
	kg/ha	*kg/ha*	*kg/ha*	*kg/ha*	*t/ha*	*% DM*
Atem	38	81	19	-14	3.89	2.30
Triumph	40	129	>opt	-69	3.41	2.49
Cocktail	41	73	20	-14	3.90	2.24
Doyen	44	104	46	-26	4.12	2.37
SED (N x V)					0.400	0.080
d.f.					46	46

2006 ADAS High Mowthorpe, Spring Barley

Grid Ref. SO484566

Soil Group	*Topsoil*		*Subsoil*		*Depth (cm)*	*Total N (%)*
Shallow over chalk	Silty clay loam		Panholes		45-60	0.26
Previous crops	*-1 year*	*-1 residues*	*-2 years*	*-3 years*		
	Winter wheat	baled	WOSR	Winter barley		

Varieties	Triumph	Atem	Cocktail	Tocada
1st year on RL	1980	1980	2003	2005

Sowing date	*Over-winter rain*	*N application dates*		*Harvest*
	mm	*1st*	*2nd*	
12 April 2006	200	18 May	6 Jun	23 Aug

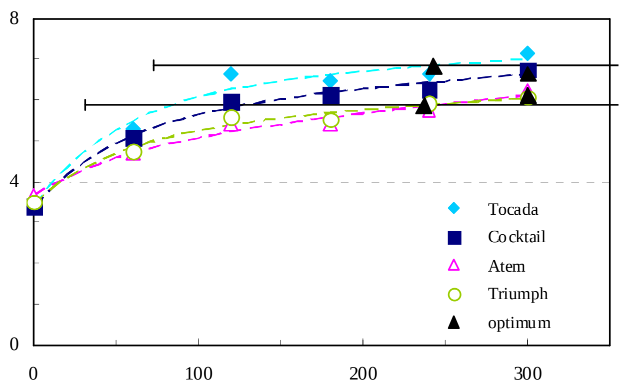
Comments: NA

Soil N analysis and Nitrogen recommendations

Soil analysis date	*Crop N*	*Soil mineral N by depth (kg/ha)*			*Soil N Supply*	
	eye-estimate	*0-30 cm*	*30-60 cm*	*60-90 cm*	*Total*	
9 Feb	0	29	30	-	58	*kg/ha*

	Feed	*Malting*	
RB209 recommendation (by SNS Index)	150	120	*kg/ha*
RB209 recommendation (by SMN analysis)	150	120	*kg/ha*

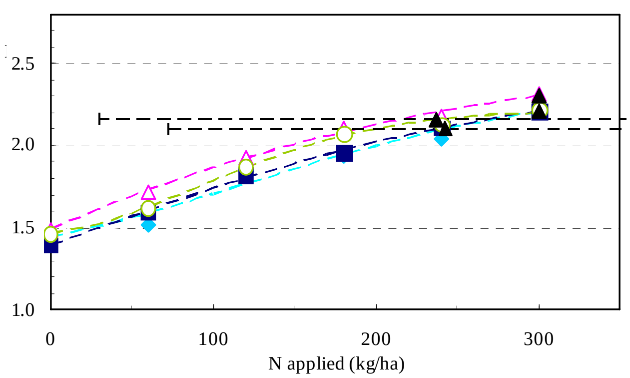
Grain yield (t/ha at 85% DM)



Statistics

	F probability
Nitrogen (N)	<.001
Variety (V)	<.001
N x V	0.05
CV%	5.40
Variance accounted for by curve fit:	91%

Grain N (%, dry basis)



Statistics

	F probability
Nitrogen (N)	<.001
Variety (V)	<.001
N x V	0.694
CV%	3.6

Variety effects	*Grain N at nil N*	*Optimum N (3:1)*	*SE Nopt*	*Change for BER=6:1*	*Grain yield at opt N*	*Grain N at opt N*
	kg/ha	*kg/ha*	*kg/ha*	*kg/ha*	*t/ha*	*% DM*
Atem	46	300	*	-161	6.13	2.30
Triumph	44	237	206	-113	5.88	2.16
Cocktail	40	300	*	-153	6.64	2.21
Tocada	43	243	170	-96	6.85	2.10
SED (N x V)					0.285	0.052
d.f.					36	36

2006 Masstock, Fowlmere, Spring Barley

Grid Ref. TL403474

Soil Group	***Topsoil***		***Subsoil***		***Depth (cm)***	***Total N (%)***
Shallow over chalk	Sandy clay loam		Chalk		60	0.15
Previous crops	***-1 year***	***-1 residues***	***-2 years***	***-3 years***		
	Peas	incorp	Winter wheat	Peas		

Varieties	Atem	Triumph	Cocktail	Doyen
1st year on RL	1980	1980	2003	2004

Sowing date	***Over-winter rain***	***N application dates***		***Harvest***
	mm	*1st*	*2nd*	
27 February 2006	75	16 Mar	18 Apr	30 Aug

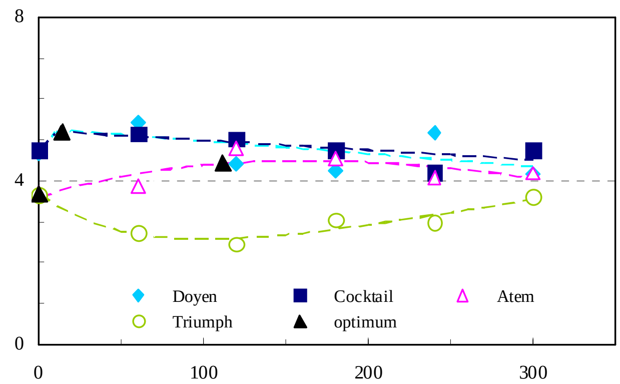
Comments: NA

Soil N analysis and Nitrogen recommendations

Soil analysis date	***Crop N***	***Soil mineral N by depth (kg/ha)***			***Soil N Supply***	
	eye-estimate	*0-30 cm*	*30-60 cm*	*60-90 cm*	*Total*	
7 Feb	0	13	20	-	34	*kg/ha*

	Feed	***Malting***	
RB209 recommendation (by SNS Index)	120	80	*kg/ha*
RB209 recommendation (by SMN analysis)	120	80	*kg/ha*

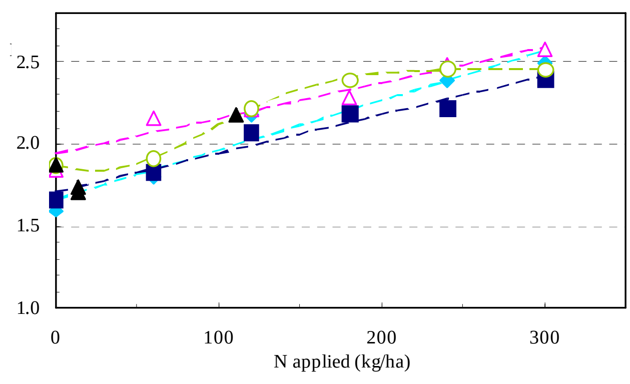
Grain yield (t/ha at 85% DM)



Statistics

	F probability
Nitrogen (N)	0.51
Variety (V)	<.001
N x V	<.001
CV%	10.70
Variance accounted for by curve fit:	0%

Grain N (%, dry basis)



Statistics

	F probability
Nitrogen (N)	<.001
Variety (V)	<.001
N x V	0.273
CV%	5.2

Variety effects	***Grain N at nil N***	***Optimum N (3:1)***	*SE Nopt*	*Change for BER=6:1*	***Grain yield at opt N***	***Grain N at opt N***
	kg/ha	*kg/ha*	*kg/ha*	*kg/ha*	*t/ha*	*% DM*
Atem	58	111	>opt	-42	4.42	2.18
Triumph	58	0	>opt	0	3.66	1.87
Cocktail	67	14	>opt	-2	5.17	1.74
Doyen	64	14	>opt	-2	5.21	1.71
SED (N x V)					0.334	0.091
d.f.					32	35

2007 SAC Aberdeen , Spring Barley

Grid Ref. NJ773278

Soil Group	*Topsoil*		*Subsoil*		*Depth (cm)*	*Total N (%)*
Sandy	Sandy loam		sandy loam/Insch		70-75	0.36
Previous crops	*-1 year*	*-1 residues*	*-2 years*	*-3 years*		
	Spring barley	baled	Spring barley	Potatoes		

Varieties	Triumph	Atem	Westminster	Waggon
1st year on RL	1980	1980	2005	2005

Sowing date	*Over-winter rain*	*N application dates*		*Harvest*
	mm	*1st*	*2nd*	
3 April 2007	325	18 Apr	26 Apr	04 Sep

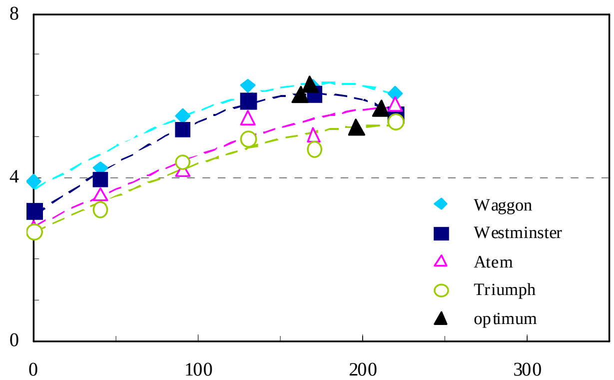
Comments: NA

Soil N analysis and Nitrogen recommendations

Soil analysis date	*Crop N*	*Soil mineral N by depth (kg/ha)*			*Soil N Supply*	
	eye-estimate	*0-30 cm*	*30-60 cm*	*60-90 cm*	*Total*	
21 May	5	33	30	-	68	*kg/ha*

	Feed	*Malting*	
RB209 recommendation (by SNS Index)	125	100	*kg/ha*
RB209 recommendation (by SMN analysis)	90	70	*kg/ha*

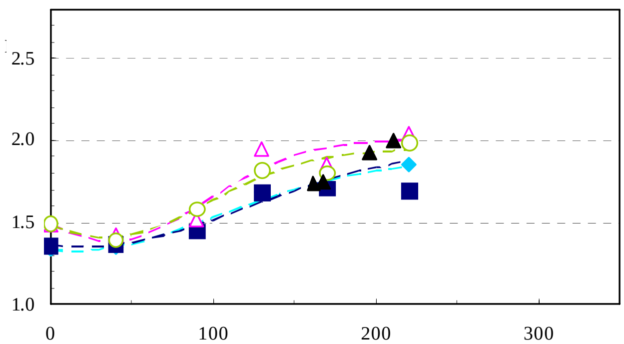
Grain yield (t/ha at 85% DM)



Statistics

	F probability
Nitrogen (N)	<.001
Variety (V)	0.00
N x V	1.00
CV%	18.70
Variance accounted for by curve fit:	61%

Grain N (%, dry basis)



Statistics

	F probability
Nitrogen (N)	<.001
Variety (V)	0.002
N x V	0.937
CV%	8.8

Variety effects	*Grain N at nil N*	*Optimum N (3:1)*	*SE Nopt*	*Change for BER=6:1*	*Grain yield at opt N*	*Grain N at opt N*
	kg/ha	*kg/ha*	*kg/ha*	*kg/ha*	*t/ha*	*% DM*
Atem	35	211	>opt	-17	5.70	2.00
Triumph	34	196	>opt	-18	5.24	1.93
Waggon	44	168	>opt	-13	6.29	1.75
Westminster	37	162	>opt	-10	6.04	1.73
SED (N x V)					0.726	0.117
d.f.					46	46

2007 SAC Laurencekirk, Spring Barley

Grid Ref. NO729752

Soil Group	*Topsoil*		*Subsoil*		*Depth (cm)*	*Total N (%)*
Other mineral	Sandy silt loam		sandy silt loam/Laurencekirk		75-80	0.25
Previous crops	*-1 year*	*-1 residues*	*-2 years*	*-3 years*		
	Spring barley	baled	Spring barley	Spring barley		

Varieties	Triumph	='Site data'!R51C7	Publican	Doyen
1st year on RL	1980	#N/A	2007	2004

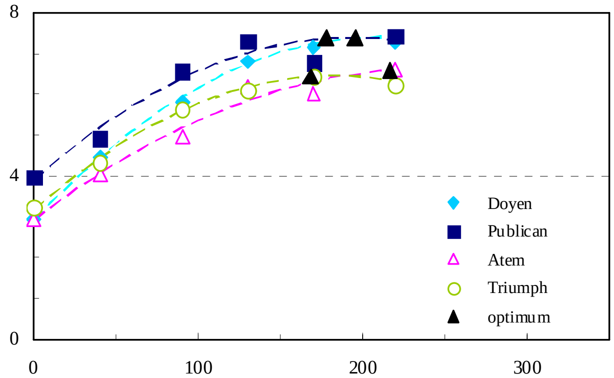
Sowing date	*Over-winter rain*	*N application dates*		*Harvest*
	mm	*1st*	*2nd*	
29 March 2007	325	17 Apr	4 May	30 Aug

Comments: NA

Soil N analysis and Nitrogen recommendations

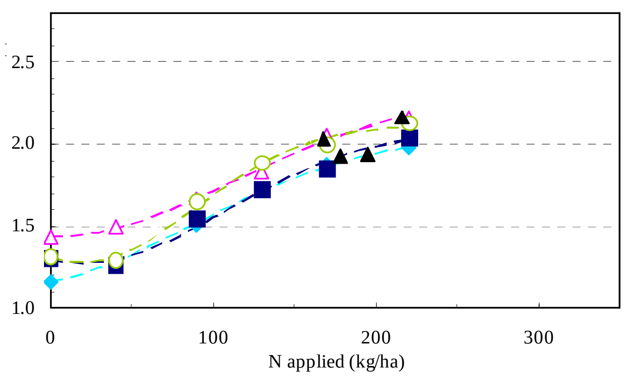
Soil analysis date	*Crop N*	*Soil mineral N by depth (kg/ha)*			*Soil N Supply*	
	eye-estimate	*0-30 cm*	*30-60 cm*	*60-90 cm*	*Total*	
18 May	5	38	34	-	77	*kg/ha*
				Feed	**Malting**	
	RB209 recommendation (by SNS Index)			150	120	*kg/ha*
	RB209 recommendation (by SMN analysis)			150	120	*kg/ha*

Grain yield (t/ha at 85% DM)



Statistics	*F probability*
Nitrogen (N)	<.001
Variety (V)	<.001
N x V	0.08
CV%	6.90
Variance accounted for by curve fit:	92%

Grain N (%, dry basis)



Statistics	*F probability*
Nitrogen (N)	<.001
Variety (V)	<.001
N x V	0.813
CV%	5.9

Variety effects	*Grain N at nil N*	*Optimum N (3:1)*	*SE Nopt*	*Change for BER=6:1*	*Grain yield at opt N*	*Grain N at opt N*
	kg/ha	*kg/ha*	*kg/ha*	*kg/ha*	*t/ha*	*% DM*
Atem	36	216	>opt	-23	6.59	2.16
Triumph	36	168	>opt	-15	6.44	2.03
Doyen	29	195	>opt	-15	7.38	1.93
Publican	44	178	>opt	-16	7.37	1.92
SED (N x V)					0.313	0.081
d.f.					46	20

2007 NSDM York, Spring Barley

Grid Ref. SE720629

Soil Group	*Topsoil*		*Subsoil*		*Depth (cm)*	*Total N (%)*
Deep Silty	Silty clay loam		Deep Silty		>90	0.11
Previous crops	*-1 year*	*-1 residues*	*-2 years*	*-3 years*		
	Winter wheat	baled	Sugar beet	Spring barley		

Varieties	Triumph	Atem	Westminster	Doyen
1st year on RL	1980	1980	2005	2004

Sowing date	*Over-winter rain*	*N application dates*		*Harvest*
	mm	*1st*	*2nd*	
19 March 2007	242	19 Apr	10 May	24 Aug

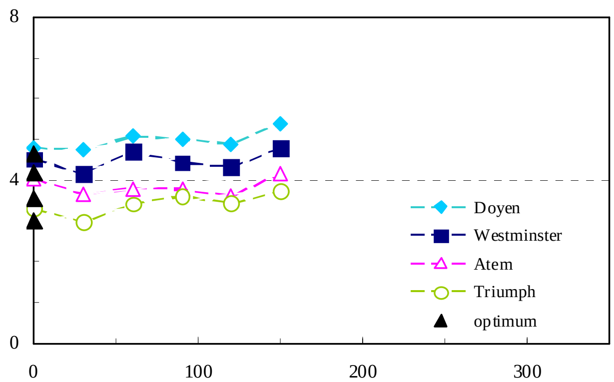
Comments: Standard disease control for mildew and Rhynchosporium

Soil N analysis and Nitrogen recommendations

Soil analysis date	*Crop N*	*Soil mineral N by depth (kg/ha)*			*Soil N Supply*	
	eye-estimate	*0-30 cm*	*30-60 cm*	*60-90 cm*	*Total*	
18 Feb	0	13	8	3	25	*kg/ha*

	Feed	*Malting*	
RB209 recommendation (by SNS Index)	150	120	*kg/ha*
RB209 recommendation (by SMN analysis)	150	120	*kg/ha*

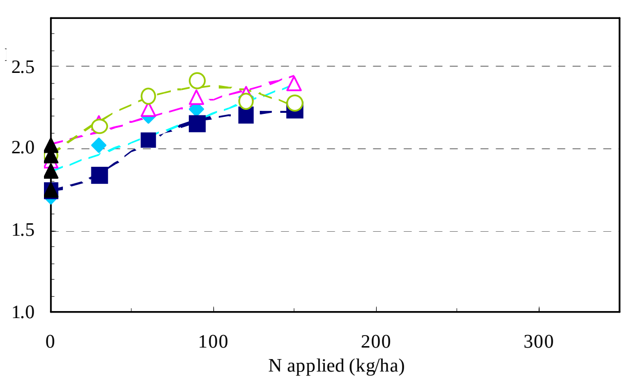
Grain yield (t/ha at 85% DM)



Statistics

	F probability
Nitrogen (N)	<.001
Variety (V)	<.001
N x V	0.62
CV%	8.30
Variance accounted for by curve fit:	0%

Grain N (%, dry basis)



Statistics

	F probability
Nitrogen (N)	<.001
Variety (V)	<.001
N x V	0.394
CV%	5.8

Variety effects	*Grain N at nil N*	*Optimum N (3:1)*	*SE Nopt*	*Change for BER=6:1*	*Grain yield at opt N*	*Grain N at opt N*
	kg/ha	*kg/ha*	*kg/ha*	*kg/ha*	*t/ha*	*% DM*
Atem	66	0	>opt	0	3.54	2.02
Triumph	55	0	>opt	0	3.01	1.96
Doyen	70	0	>opt	0	4.64	1.86
Westminster	67	0	>opt	0	4.19	1.75
SED (N x V)					0.282	0.103
d.f.					46	46

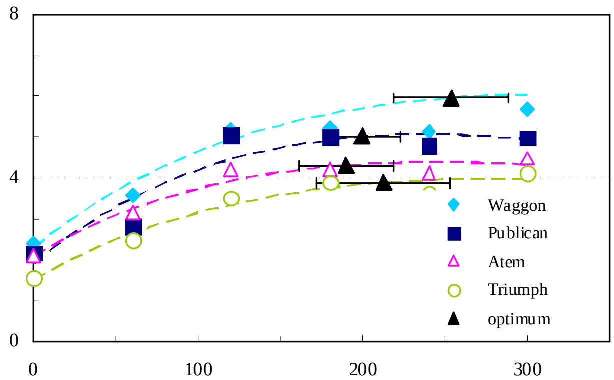
2007 ADAS High Mowthorpe, Spring Barley

2007 ADAS High Mowthorpe, Spring Barley						***Grid Ref.***	SE895675
Soil Group	***Topsoil***		***Subsoil***			***Depth (cm)***	***Total N (%)***
Shallow over chalk or li	Silty clay loam		Panholes			45-60	0.42
Previous crops	***-1 year***	***-1 residues***	***-2 years***	***-3 years***			
	Winter wheat	baled	Winter wheat	WOSR			
Varieties	Triumph	Atem	Publican	Waggon			
1st year on RL	1980	1980	2007	2005			
Sowing date	***Over-winter rain***	***N application dates***				***Harvest***	
	mm	*1st*	*2nd*				
9 March 2007	400	2 May	24 May			23 Aug	
Comments:	No lodging or leaning						

Soil N analysis and Nitrogen recommendations

Soil analysis date	***Crop N***	***Soil mineral N by depth (kg/ha)***			***Soil N Supply***	
	eye-estimate	*0-30 cm*	*30-60 cm*	*60-90 cm*	*Total*	
21 Mar	0	52	32	-	84	*kg/ha*
				Feed	***Malting***	
	RB209 recommendation (by SNS Index)			150	120	*kg/ha*
	RB209 recommendation (by SMN analysis)			120	80	*kg/ha*

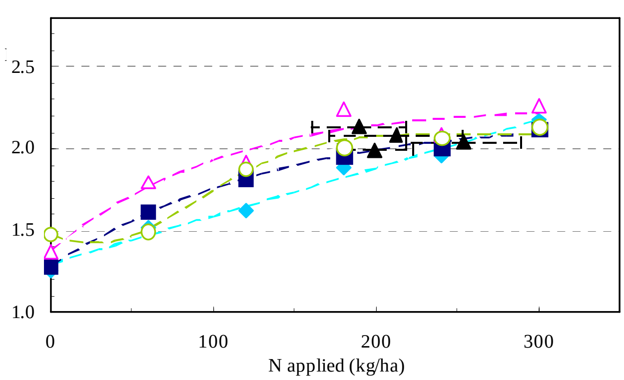
Grain yield (t/ha at 85% DM)



Statistics

	F probability
Nitrogen (N)	<.001
Variety (V)	<.001
N x V	<.001
CV%	5.20
Variance accounted for by curve fit:	83%

Grain N (%, dry basis)



Statistics

	F probability
Nitrogen (N)	<.001
Variety (V)	<.001
N x V	0.225
CV%	6.4

Variety effects	***Grain N at nil N***	***Optimum N (3:1)***	*SE Nopt*	*Change for BER=6:1*	***Grain yield at opt N***	***Grain N at opt N***
	kg/ha	*kg/ha*	*kg/ha*	*kg/ha*	*t/ha*	*% DM*
Atem	24	190	29	-42	4.31	2.13
Triumph	19	212	41	-51	3.88	2.08
Publican	23	200	23	-32	5.01	1.99
Waggon	25	254	35	-48	5.96	2.04
SED (N x V)					0.325	0.103
d.f.					36	36

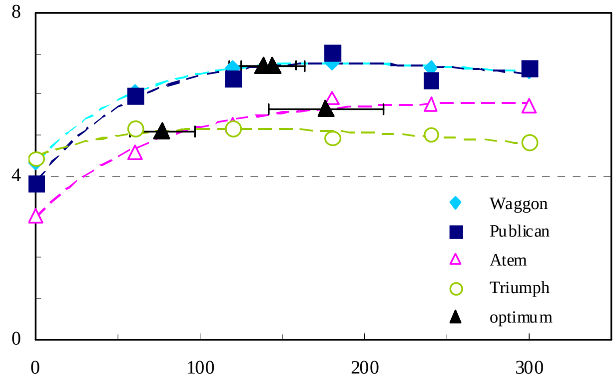
2007 Masstock, Fowlmere, Spring Barley

2007 Masstock, Fowlmere, Spring Barley					*Grid Ref.*	TL403474
Soil Group	*Topsoil*		*Subsoil*		*Depth (cm)*	*Total N (%)*
Shallow over chalk or li	Sandy loam		Chalk		40-60	0.16
Previous crops	*-1 year*	*-1 residues*	*-2 years*	*-3 years*		
	Winter oats	baled	Peas	Winter wheat		
Varieties	Triumph	Atem	Publican	Waggon		
1st year on RL	1980	1980	2007	2005		
Sowing date	*Over-winter rain*	*N application dates*			*Harvest*	
	mm	*1st*	*2nd*			
13 March 2007	200	28 Mar	4 May		09 Aug	
Comments:	NA					

Soil N analysis and Nitrogen recommendations

Soil analysis date	*Crop N*	*Soil mineral N by depth (kg/ha)*			*Soil N Supply*	
	eye-estimate	*0-30 cm*	*30-60 cm*	*60-90 cm*	*Total*	
6 Feb	0	19	16	-	35	*kg/ha*
				Feed	***Malting***	
	RB209 recommendation (by SNS Index)			150	120	*kg/ha*
	RB209 recommendation (by SMN analysis)			150	120	*kg/ha*

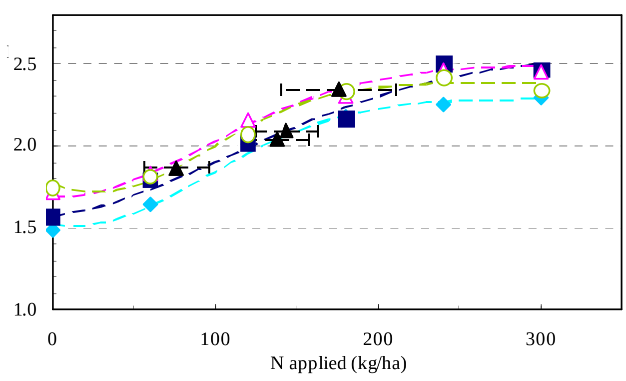
Grain yield (t/ha at 85% DM)



Statistics

	F probability
Nitrogen (N)	<.001
Variety (V)	<.001
N x V	0.01
CV%	9.00
Variance accounted for by curve fit:	81%

Grain N (%, dry basis)



Statistics

	F probability
Nitrogen (N)	<.001
Variety (V)	0.02
N x V	0.126
CV%	9.3

Variety effects	*Grain N at nil N*	*Optimum N (3:1)*	*SE Nopt*	*Change for BER=6:1*	*Grain yield at opt N*	*Grain N at opt N*
	kg/ha	*kg/ha*	*kg/ha*	*kg/ha*	*t/ha*	*% DM*
Atem	44	176	35	-44	5.65	2.34
Triumph	66	77	20	-27	5.10	1.87
Publican	51	144	19	-25	6.71	2.09
Waggon	55	138	20	-26	6.71	2.04
SED (N x V)					0.411	0.174
d.f.					33	36