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Review of how best to respond to expensive fertiliser nitrogen for use in 2022 (part two)

Authors
Pete Berry[1], Roger Sylvester-Bradley[1], Daniel Kindred[1], Sarah Clark[1], John Williams[1]

Technical reviewer
Paul Newell-Price[1]

[1]ADAS

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CONTENTS

1. Introduction

This is the second part of a two-stage review of how the arable cropping industry can best respond to the recent sharp increases in prices and availability of manufactured fertilisers.

Part 1 addressed how nitrogen rates should be changed in response to increases in nitrogen fertiliser prices and the impact of these changes on crop yield for the major arable crops – wheat, barley and oilseed rape. In addition to the report (Sylvester-Bradley and Kindred, 2021), this resulted in the AHDB online calculator, which farmers can use to estimate the impact of nitrogen fertiliser prices on nitrogen rate and yield.

Part 2, described in this report, assesses the impact on other aspects of fertiliser management. The report includes which crops, fields and nitrogen splits to prioritise; the influence of expected yield; any implications for management of organic materials; achieving milling and malting specification; the value of precision nitrogen use; calculating the nitrogen price; the management of other nutrients; and longer-term implications.

2. Review

2.1. Which crop species, fields and splits to prioritise for N inputs

Crops and fields

The AHDB nitrogen (N) rate calculator estimates how the N rate recommended by RB209 should be adjusted if the break-even ratio (BER) is different from 5 for a cereal crop or 2.5 for an OSR crop. This gives the economic optimum N rate that maximises the crop value over N fertiliser costs for each crop. If the farm has access to sufficient N fertiliser to apply at the economic optimum N rate then there is no need to prioritise one particular crop species or field over another. The exception to this is if a wheat crop is being targeted for a bread-making market (see section 2.4). However, if a farm has insufficient N fertiliser stocks to fertilise all fields at the optimum rate then it may be necessary to prioritise the inputs to particular crop species to maximise financial returns.

For each crop species, estimate the yield loss that would result from reducing N below the rate recommended by AHDB Nutrient management guide (RB209) (Table 1) then multiply this by the expected value of the grain or seed. If any crop type shows substantially greater financial losses per hectare than other crops, then consider limiting the amount that the N is reduced by for this crop.

Table 1. Effect on yield from reducing N rate below the RB209 recommended N rate (t/ha)

N rate reduction (kg/ha)	†Winter wheat (standard cereal curve)	††Winter barley	††Spring barley	††Winter oilseed rape
10	-0.05	-0.06	-0.06	-0.03
20	-0.12	-0.12	-0.14	-0.06
30	-0.19	-0.20	-0.24	-0.09
40	-0.27	-0.29	-0.37	-0.13
50	-0.36	-0.40	-0.55	-0.18
60	-0.47	-0.53	-0.64	-0.24
70	-0.59	-0.68	-0.88	-0.29
80	-0.72	-0.85	-0.99	-0.36
90	-0.87	-1.05	-1.10	-0.44
100	-1.04	-1.28	-1.35	-0.52

† Data from the standard cereal N response curve used to calculate the BER tables in RB209. Phase I of this project demonstrated that this agrees with recent wheat N response data
†† Data from recent N response curves reported in Phase I of this project (Figures 4.2-4.4)

Current guidance in RB209 for N splits

Wheat

Less than 120 kg N /ha: Apply in one dose by early stem extension.

120 kg N/ha or more: Apply 40 kg N/ha between mid-Feb and mid-March, except where there is a low risk of take-all and shoot numbers are high. Apply remaining N in 1 or 2 dressings during early stem extension.

Winter barley

Less than 100 kg N/ha: Apply as a single dressing by early stem extension.

100 to 200 kg N/ha: Apply half during late tillering and half at GS30-31.

200 kg N/ha or more: apply 40% during late tillering, 40% at GS30/31 and 20% at GS32.

Spring barley (new guidelines that will be added to RB209 in 2022)

Apply all nitrogen between the time of drilling and GS30, with at least 40 kg N/ha in the seedbed.

Oilseed rape

Autumn N

If the soil nitrogen supply (SNS) is 2 or lower and the crop is sown before mid-September, apply up to 30 kg N/ha in the autumn.

Spring N

If GAI is less than 1.5, or less than 2 with low SMN, apply half of the N between end Feb and March and half at green bud.

If GAI is above 1.5 to 2, then reduce first split to between zero and 40 kg/ha.

Apply any extra N for high expected yield between late green bud and flowering.

Reducing total nitrogen rate

If the total N rate is reduced below the rate currently recommended in RB209 (i.e. for a cereal BER of 5 or OSR BER of 2.5), the rate at each split should be reduced by the same proportion.

Exceptions to this rule include:

1. winter barley, spring barley and wheat with a high risk of take-all or low shoot number - for these crops the first split should be maintained at a similar level as would have been used before any reduction in N rate to account for a high BER.
2. Wheat targeted for bread making market for which the current RB209 guidance for both N rates and timings should be followed (see section 2.4)

It is important not to reduce the first N split to spring barley and winter barley, because the yield of these crops is strongly sink limited, which means they are heavily reliant on the crop achieving many seeds/m^2 and ears/m^2. Therefore, ensuring that tillering is not restricted by lack of N is particularly important for these crops.

It is also worth noting that the efficiency with which soil applied N is used by a wheat crop to produce yield decreases for applications after GS32. It has been shown that applications at GS32 or GS33 have 10% lower fertiliser recovery than earlier N applications (King et al., 2001). Therefore, at current high N fertiliser prices, it is prudent to minimise applications after GS32 for wheat destined for feed markets. RB209 does not recommend any N to be applied to winter or spring barley after GS32.

2.2. Influence of expected yield on adjustments for change in BER

A common uncertainty is how RB209 tables (4.21 and 4.28) for price-driven adjustments to N recommendations (and the AHDB online calculator) recognise differences in expected yields. RB209 recommendations for N applications to wheat, barley and oilseed rape already take expected yield into account, i.e. they adjust by 20 kg/tonne grain from 8 t grain/ha wheat or 6.5 t grain/ha winter barley, and adjust by 60 kg/tonne seed from 3.5 t seed/ha for oilseed rape. Adjustments for high or low expected yields can be up to 100 kg/ha N. Adjustments for prices are additional to and separate from adjustments for expected yield, and they do not depend on expected yield (Fig. 1), or on soil N supply or soil type. Current RB209 recommendations are set at BERs of 5 for cereals and 2.5 for oilseeds. The effect of fertiliser and grain prices on recommendations is the same whatever the yield level expected (and whatever the soil N supply or the soil type) because most response curves have the same shape in the region of their optima.

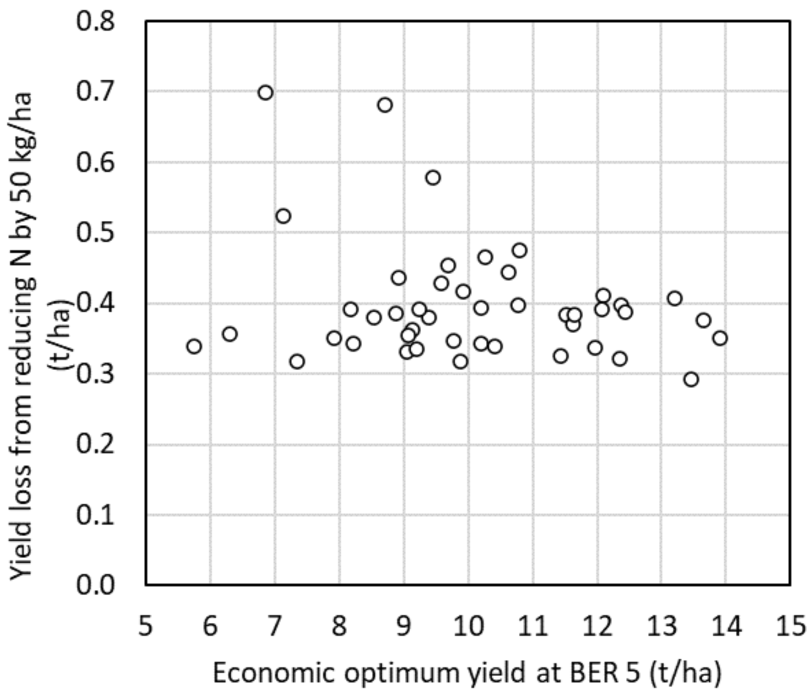

Figure 1. Lack of association between yield loss from reducing applied N by 50 kg/ha from the optimum amount at BER 5, and optimum yield at BER 5, for N response experiments on winter wheat at 45 sites.

As an example, the effect of increasing the BER from 5 to 10 results in a similar reduction in optimum N rate for any cereal crop (wheat or barley) of about 50 kg N/ha and a similar reduction in yield of about 0.3 to 0.5 t/ha. It may seem surprising that crops yielding 8 and 12 t/ha have the same recommended change in N rate and resulting change in yield, but as described above this is because cereal crops have a similar shaped N response curve near the economic optimum. This means that its necessary to reduce N rate by the same amount (from the old optimum at BER 5) to find the N rate at the new optimum (BER 10) at which the cost of an extra kg of N gives the same value in extra yield.

2.3. Nutrient supply from organic materials

Organic materials are valuable sources of crop available nutrients which can reduce the need for manufactured fertiliser applications to meet optimum crop demand. Applications need to be carefully managed to maximise their fertiliser value and minimise nutrient losses to the environment.

Understanding the nutrient content of organic materials and quantifying application rates are crucial for making best use of manure nutrients. The nutrient content of organic materials will depend on several factors. For livestock manures, the main determining factors include livestock type, feeding regime, diet, the amount of rainwater dilution that occurs during storage and the amount of bedding used. For digestates and composts, the source of the feedstock material and for biosolids the treatment processes are key factors.

Typical figures for the nutrient content of organic materials are available in AHDB's Nutrient Management Guide (2020). However, laboratory analysis can give a more accurate assessment of the nutrient content of organic materials for an individual source.

Nutrients in organic materials are present in two forms: (i) readily available soluble forms, which are immediately available to the crop and most at risk of loss to the environment and (ii) organic forms, which will only become available overtime following the mineralisation of organic matter in the soil.

2.3.1. Nitrogen

For manures with a high proportion of total nitrogen in the readily available form (e.g. slurries, poultry manures and digestates) applying organic materials at times when crops are actively growing will increase the nitrogen use efficiency by reducing the risk of nitrate leaching. Spreading liquid manures containing high concentrations of readily available N with precision application techniques such as band spreaders and shallow injectors instead of conventional surface broadcast applications will reduce the risk of ammonia emission, odour nuisance and crop contamination. Precision application techniques can therefore improve nitrogen supply to the crop and also allow liquid manures to be spread evenly across known bout widths. Applications of solid manure on tillage land should be incorporated within a few hours of application to reduce ammonia emissions.

2.3.2. **Phosphate and potash**

Applications of solid manure typically apply more phosphate (P_2O_5) and potash (K_2O) than is taken off by a crop in a single harvest year. For example a 40 t/ha application of cattle FYM will supply around 130 kg/ha of P_2O_5 and 376 kg/ha of K_2O. In comparison, a wheat crop yielding 10 t/ha (with straw incorporated) will typically remove 65 kg/ha of P_2O_5 and 55 kg/ha K_2O. Consequently, it is important to target solid manure applications to fields with low P and K status to maximise their nutrient value and reduce the risk of excessive soil P levels, which increase the risk of P losses to water.

2.3.3. **Application rates**

Accurately quantifying application rates is crucial for maximising the nutrient value of organic materials. There are three factors that control application rate: (i) the rate that material is pumped or discharged from the spreader; (ii) the spreading or bout width; and (iii) the forward speed of the application equipment. For broadcast slurry and solid manure applications, it is important to match bout widths from different applications to ensure even application across the field. In Nitrate Vulnerable Zones, the maximum quantity of organic material that can be spread to a field in any 12-month period is equivalent to 250 kg total N/ha. Under the Farming Rules for Water, which apply in England, applications must not exceed ‘soil or crop need’.

2.3.4. **Accounting for manure nutrients when planning manufactured fertiliser applications**

Crop available nutrient supply from contrasting manure application timings and methods can be calculated using the MANNER-*NPK* decision support tool or by reference to AHDB’s Nutrient Management Guide (RB209). It is important that the nutrients supplied by the manures are accounted for when calculating manufactured fertiliser application rates to ensure that crop nutrient requirements are not exceeded and the risks of nutrient losses to the environment are not increased. Nitrogen fertiliser applications should be adjusted for the crop to which the manures are applied. Phosphate and potash applications should be adjusted over the rotation. Table 2 gives the nutrients supplied by typical applications of a range of organic materials based on manure nutrient contents published in AHDB’s Nutrient Management Guide (RB 209). Slurries and digestates can usually be considered good sources of crop available nitrogen and solid manures supply proportionally more phosphate and potash than nitrogen. Under current fertiliser prices, the fertiliser replacement value of spring applied cattle slurry is estimated to be worth £4.65/m^3; cattle FYM £11.25/t; pig slurry £6.10/m^3; pig FYM £13.50/t; poultry manure £46/t; whole digestate £7.75/m^3; and biosolids £15/t. The values have increased by c.50% compared with 2020. It should be recognised that even if a substantial proportion of the crop N requirement is supplied by crop available N from manure, the same guidance for adjusting manufactured fertiliser N resulting from changes to BER still apply.

Table 2. Crop available nutrient supply and manufactured fertiliser replacement value from spring applied manures

Manure type	Application rate t/ha	Crop available N* (kg/ha)	Total phosphate (kg/ha)	Total potash (kg/ha)	Value 2020 (£/ha)**	Value 2022 (£/ha)***
Cattle slurry	35	32	48	88	95	165
Cattle FYM	40	24	128	376	265	450
Pig slurry	35	69	53	77	215	115
Pig FYM	35	25	210	280	270	470
Poultry manure	8	67	136	168	205	370
Whole digestate	25	72	53	43	115	195
Biosolids	20	33	220	12	160	300

* Assumes spring application timing

** Assumes value of fertiliser N@ 65p/kg, P_2O_5@ 61p/kg and K_2O @45p/kg

*** Assumes value of fertiliser N@ £1.45/kg, P_2O_5£1.10/kg and K_2O @73p/kg

2.3.5. Compliance with Farming Rules for Water

The Farming Rules for Water were introduced in England in April 2018 (Defra, 2018; SI 2018) to fulfil obligations on diffuse water pollution from agriculture under the Water Framework Directive (WFD, 2000) and help prevent deterioration of the status of surface and ground waters. Eight rules were published to reduce diffuse water pollution from agriculture in a way that minimised costs to the farming sector by focusing on nutrient use efficiency and soil management. Rule 1 (Regulation 4 of the Reduction and Prevention for Agricultural Diffuse Pollution (England) Regulations 2018) aims to ensure that 'all reasonable precautions' are taken to prevent diffuse water pollution following the application of organic manures and manufactured fertilisers. More specifically the rule states:

> 1a. Application to cultivated land must be planned in advance to meet soil and crop nutrient needs and not exceed these levels
>
> 1b. Planning must take into account where there is a significant risk of pollution and the results of testing for phosphorus (P), potassium (K), magnesium (Mg), pH and N levels in the soil, which must be done at least every 5 years. Soil N levels may be determined by assessing the soil N supply instead of testing the soil.

Current interpretation of Rule 1 by the Environment Agency restricts the timing of organic material applications in England to when there is a recommendation for manufactured nitrogen fertiliser in AHDB's Nutrient Management Guide. Consequently, autumn application of all manure types is only permitted for oilseed rape crops and grass. For all other crops organic manures should be applied in spring.

Spring applications pose several practical issues, especially for the application of solid manures to arable crops where topdressing is likely to result in crop damage. Also, there is a high risk of soil compaction from applications to medium and heavy soils with moisture deficits of less than 20 mm, which is often the case in early spring. The risks of ammonium-N and phosphorus contamination of surface runoff and drainage water is also greater when applications are surface applied to wet soils. Consequently, it may be necessary to delay slurry and applications until April and use bandspreading equipment to ensure even application to tramlines in order to comply with the Farming Rules for Water.

2.4. Milling wheat

The analyses carried out thus far in this report and recommendations given for adjustments to rates have been targeted at wheat grown for feed. When wheat is fertilised optimally for yield (at BER 5), grain protein concentrations of 11 % for feed varieties and 12 % for milling varieties would be expected on average. However, milling wheats have market specifications for higher protein concentrations, typically 13 %, and therefore extra N is required.

The current version of RB209 states that: "In some circumstances, an application of nitrogen may be economically worthwhile to boost the grain protein concentration. Typically, application of an extra 40 kg N/ha could increase grain protein by up to 1%."

Additional funding from UK Flour Millers has allowed more detailed consideration of the impact of the recommended reduced N rates resulting from a high BER on protein concentrations, and the impact of fertilising to achieve milling on gross margins. It should be noted that these analyses included impacts on protein concentration only; Hagberg Falling Number (HFN) and specific weight were not included, but likelihood of achieving these specifications should be taken into account when deciding whether to aim for milling markets. Millers may accept grain at less than 250s HFN or 76 kg/Hl specific weight, but at a reduced price to the full milling premium.

The AHDB Recommended List is a useful resource to understand likely milling performance of Group 1 and Group 2 milling varieties. All current Group 1 and Group 2 varieties have quoted HFN values above the milling specification of 250s, although this can be affected by weather conditions around harvest. Group 2 varieties generally achieve slightly lower (~0.5%) protein concentrations than the Group 1 varieties, so achieving the milling protein specification may be more difficult.

2.4.1. **Impact of reducing N on protein concentration**

Data from 26 N response experiments on milling wheats carried out as part of the AHDB LearN project between harvests 2014 and 2017 (Kindred et al., 2018) were used to investigate the impacts of reducing N applications on protein concentrations.

Firstly, the yield responses from these experiments were compared with the standard response curve used in RB209 (and Part 1 of this review). Figure 2 shows that the mean of these experiments coincides very closely with the RB209 standard curve, so continued use of adjustments for yield set out in Part 1 for milling wheats is justified.

The same exercise was carried out on protein responses from these experiments. Figure 3 shows that a reduction in N applied of 50kg N/ha from the optimum, as advocated in Part 1 when the BER increases from 5 to 10, reduced the protein concentration, on average, by 1%. As stated above, when fertilising to the optimum for yield, the protein concentration of a milling variety would be expected to be ~12%. Therefore, at a rate 50kg below this, protein concentration would be ~11%, and not acceptable for milling quality. Assuming the grower applied the additional RB209-recommended 40 kg N/ha to achieve milling, this would increase protein concentration back to 12% i.e. still 1% below the 13% typical milling specification.

This exercise assumes the grain price achieved would be as per feed wheat, so further analysis was carried out to determine whether milling premiums justify extra spending on fertiliser for breadmaking wheats.

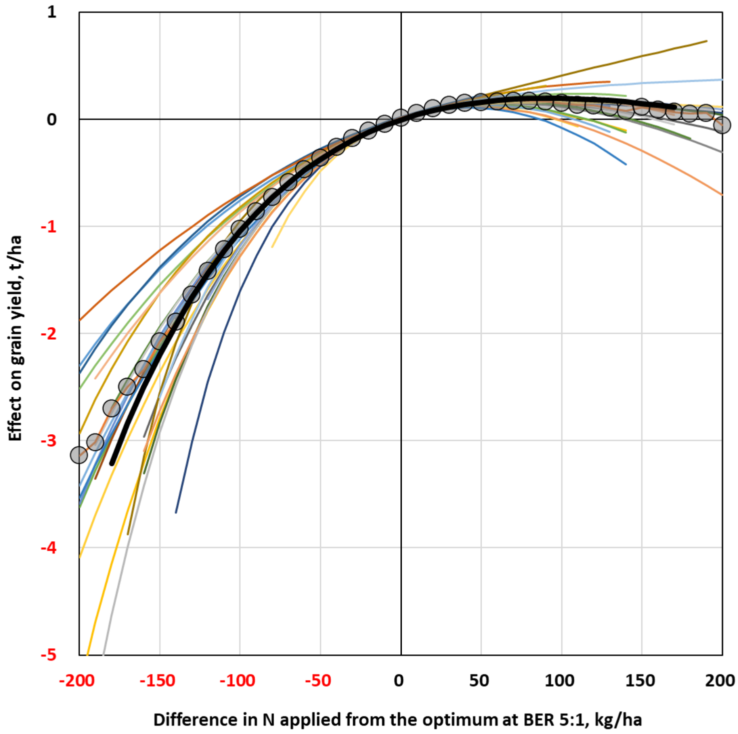

Figure 2. Effects on grain yield of altering N applied from the optimum amount at a break-even ratio (BER) of 5:1 kg grain per kg N for (i) N response curves (fine lines) fitted to yield data from 26 winter milling wheat experiments conducted between harvest 2014 and harvest 2017, (ii) their mean (grey circles), and (iii) the standard response curve for cereals (bold line) used to adjust N recommendations in RB209 since 2008

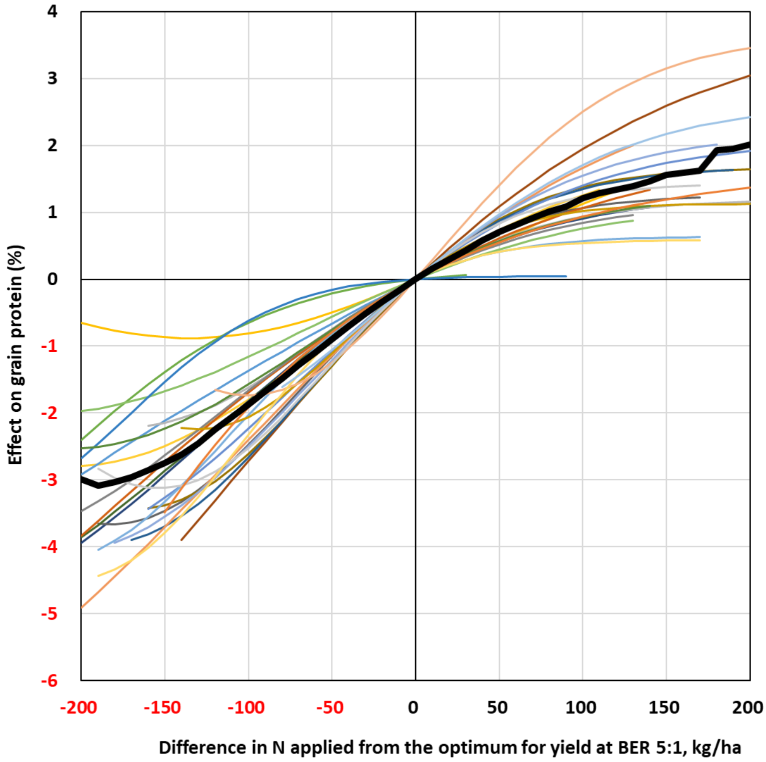

Figure 3. Effects on grain protein of altering N applied from the optimum amount at a break-even ratio (BER) of 5:1 kg grain per kg N for (i) N response curves (fine lines) fitted to protein concentration data from 26 winter milling wheat experiments conducted between harvest 2014 and harvest 2017, and (ii) their mean (bold back line)

2.4.2. **Impact of fertilising for milling on margins over N costs**

To understand whether a milling premium justifies fertilising to achieve 13% protein when fertiliser prices are high, a number of scenarios were modelled. It was assumed that a milling wheat yielding 9 t/ha would require 200 kg N/ha to achieve optimum yield plus 40 kg N/ha to bring its protein concentration up to 13%. The margin over N cost was modelled at increasing BERs, representing increasing N costs but a constant feed wheat price of £200/t. The differences in margin over N costs between achieving feed and milling protein specifications were determined at a number of milling wheat premiums, from £10/t to £40/t.

Figure 4 shows that as fertiliser prices (and BERs) increase, the benefit of fertilising to achieve a milling protein specification is reduced. When the milling premium is £30/t, the increase in BER from 5 to 10 has reduced the benefit of growing milling wheat over feed wheat from about £230/ha to £160/ha. The difference might not be as much as one might have expected because the calculations factor in the increase in yield that fertilising for milling quality gives compared with feed wheat when fertilised at BER 10. So in many cases it will still be economically justified to target milling quality, particularly if premiums are £30/t or more.

However, if the decision is marginal on farms, for example, where proteins are not achieved consistently over seasons, or where there is a risk of low HFN or specific weight, then the recent fertiliser price increases may now move the risk/benefit balance to a point where targeting milling quality cannot be justified.

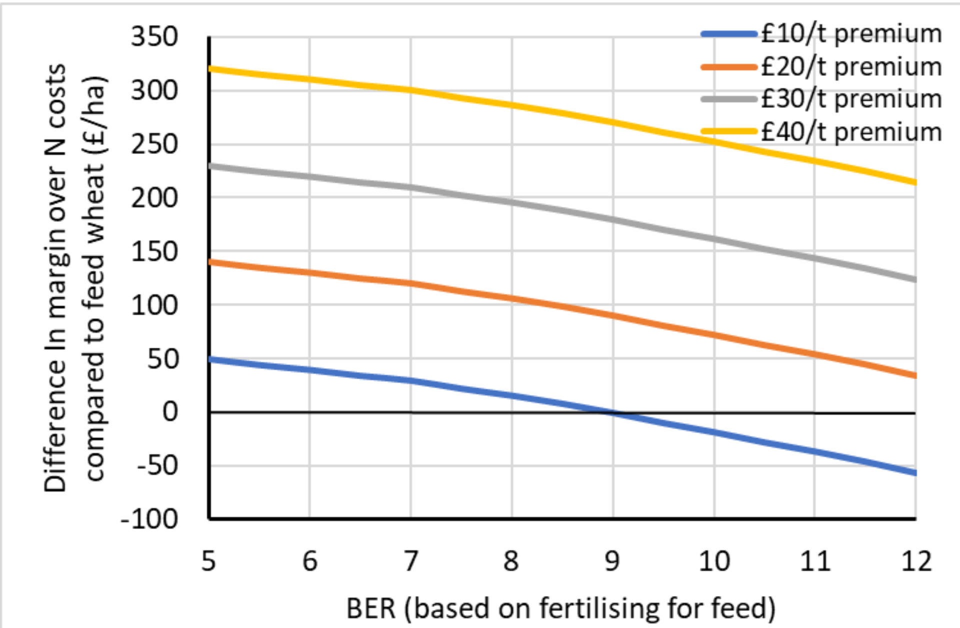

Figure 4. The difference in margin over N costs for a milling wheat achieving 13% protein compared to feed wheat fertilised at the optimum rate for increasing break even ratios (representing increasing fertiliser prices from £1/kg N to £2.40/kg N) for different milling premium scenarios

2.5. Malting barley

Nitrogen fertiliser guidance for malting winter and spring barley is to use the fertiliser N rate table for malting barley, which includes N rates that are 30 kg N/ha less than the N rates recommended for feed winter and spring barley. These rates are appropriate for crops with a target grain N% of about 1.8%. For crops with a lower grain N% target it is recommended to reduce the N rate by a further 30 kg N/ha for each further reduction in grain N% required. For example, if the target grain N% is 1.6% then the N fertiliser rate should be reduced by a further 60 kg/ha compared with the rates given in the malting barley table designed to achieve a grain N% target of 1.8%. It should be recognised that previous experience is particularly important for judging how much fertiliser N is required to achieve different grain N%. For example, AHDB Report No 635 showed that approximately two thirds of spring barley field trials achieved a grain N% of 1.8% or less when fertilised at N rates appropriate for feed. The information given above for spring barley uses the recently updated guidance derived from AHDB Report No 635 (Kendall et al., 2021).

If the estimated BER is greater than 5 then the following steps are recommended to estimate the N rate for malting barley with grain N% targets of 1.8% or less:

i. Estimate the reduction in N rate required for a high BER using either the AHDB calculator or look up tables in Sylvester-Bradley & Kindred (2021).
ii. Independently of (i), estimate the reduction in N from the N rate recommended for feed barley that would normally be applied for your malting barley crop if BER was about 5.
iii. Apply the largest N rate reduction estimated by (i) and (ii), but NOT both N rate reductions added together.
iv. The exception to (iii) will be if the N rate reduction is estimated to reduce the grain N% to below the target grain N%. Assume that a reduction in N rate of 30 kg N/ha reduces grain N% by 0.1% to help to estimate this. If it is estimated that reducing the N rate to account for a high BER will reduce the grain N% to below the target, then reduce the N rate by less.

Example for spring malting barley

- Calculate the BER based on the price of N fertiliser and anticipated value of the grain (including the expected malting premium). If the BER is 5:1 then follow current guidance in RB209. If it is different to BER 5 then see below as an example of what to do
- BER estimated at 10:1, therefore recommended to reduce N rate from that recommended for feed barley by 50 kg N/ha
- Normal practice for this example case study would be to reduce the N rate recommended by feed by 30 kg N/ha to achieve malting specification
- Action: reduce N rate by 50 kg N/ha

- Check: Reducing the N rate by 50 kg N/ha is likely to result in a grain N% almost 0.1% lower than would be achieved from normal practice of reducing N rate by 30 kg N/ha. If there is a risk that this will reduce the grain N% below the minimum level for the target market, then only reduce by 30 kg N/ha

There is also a smaller malting barley market for grain with high N concentration used for grain distilling. Grain destined for this market needs to follow guidance similar to that given for milling wheat (see section 2.4). Table 3 below provides guidance values to help estimate whether it is economically justifiable to target higher grain N%. Fertilising at the RB209 recommended N rate for feed will result in a range of grain N% depending on season, farm and field. Some crops will achieve the higher grain N% targets without any N adjustment, whilst other crops may require additional N. Use your experience of typical grain N% that your crops usually achieve when fertilised at RB209 recommended N rates for feed quality at a BER of 5, together with the figures in Table 3 summarising the impact of greater N rates on grain N% and yield, along with the N cost, grain value, premium value and the grain N% at which a premium will be paid to estimate if increasing N rate to achieve target grain N% is economically justified.

Table 3. Impact of increasing N rate above RB209 recommendation on grain N% and yield

Deviation in N rate from RB209 recommendation for feed at BER 5:1 (kg/ha)	**Impact on grain N%**	**Impact on yield (t/ha)**
-50	-0.17	-0.55
-30	-0.10	-0.24
0	0.00	0.00
30	0.10	0.09
60	0.20	0.11
90	0.30	0.08
120	0.40	0.03

2.6. Estimating the cost of N fertiliser

The cost of N fertiliser can be valued on the purchase price or the market price of N fertiliser at the time when the N is applied or when N rate decisions are being made. Even if N fertiliser has been purchased at a low price, it may be more appropriate to value it at its current market price as this represents its replacement cost. This then allows the farmer to rationally evaluate other options such as selling some of the fertiliser or storing some of it for use on next season’s crops. Which approach for valuing N fertiliser is best economically depends on many factors including; capacity to store fertiliser, price of fertiliser and the predicted price of crops next season. It must also be recognised that the commercial transport of fertiliser should be carried out by a company registered and operating under FIAS standards.

Under the five-point plan it is illegal to sell ammonium nitrate without the correct documentation: https://www.gov.uk/government/publications/secure-your-fertiliser/secure-your-fertiliser. The tables in parts 1 and 2 of this report summarising the impact of changes to BER on optimum N rate and the effect of changes to N rate on crop yield can be used to help evaluate the best approach.

The cost of N in fertiliser products containing multiple nutrients can be estimated by assuming the cost of N in a multi-nutrient product is the same as the cost of N in a N only fertiliser product. For nitrogen-sulphur products, the value of the sulphur is likely to represent less than 5% of the total value of the product due to its lower value and generally smaller proportional content compared with N. In this case it will be appropriate to attribute the total product cost to N only.

2.7. Value of precision N application

As the cost of N fertiliser rise and the economic N rate comes down, the value of being more precise with N management increases. The lower down the shoulder of the N response curve the economic optimum is, the greater the costs are of using the incorrect N rate, especially from under application resulting in lost yield. There is greater potential to detect differences in N status in crops grown at lower N rates, as a small change in N rate is likely to give a noticeable difference in 'greenness' or measured N concentration in the leaves. At normal N rates such differences are often masked as the crop already is at the top of the response curve and has sufficient N, so small differences in N availability make little physiological difference to the crop. The potential to use canopy greenness to monitor N status is greatest for crops which have reduced N applications to early splits.

At lower optimal N rates it will be more worthwhile to closely monitor the crop, either visually, using hand-held sensors such as the N Tester, tractor mounted sensors, UAVs or satellite imagery. Appropriate interpretation of absolute numbers from such sensors is not necessarily straight-forward but can be a useful guide to assess whether the crop has sufficient N or not. Such an approach may most usefully be deployed if an area in the field (that is representative of the whole field in terms of soil type and aspect) is fertilised with more and less (e.g. applying 50 kg N/ha more and less to alternate tramlines as in the LearN project; Kindred et al., 2018) as the effects of applying more will be evident. If little visual difference can be seen then confidence can be taken that the crop is not overly deficient, if the difference is large then the appropriate N rate should be reconsidered.

Any activity that leads to more precise consideration of N rates should be more worthwhile at high prices, including soil mineral N testing. Soil mineral N testing should be targeted at fields where the supply of plant-available nitrogen in the soil could be unusually large (for example, above 120 kg N/ha in arable rotations) or uncertain (e.g. due to a very high or low yielding previous crop).

Where variable rate N applications are used on an absolute basis (e.g. OSR), then growers would be advised to check whether adjustments have been made to the algorithms, or whether they can be made. Using variable rate N on a relative basis around a pre-set average rate shouldn't be affected by the price of fertiliser, assuming that the principles and parameters for varying rates are sound.

Any N fertiliser technologies that reduce losses of N to the environment will be of greater value when N fertiliser prices are high.

2.8. Management of other nutrients

The reductions in N rate that result from the current high N prices are estimated to cause only modest reductions in crop yield (generally less than 5%). Therefore, the crop requirement for non-N nutrients should remain relatively unchanged and existing guidelines for other nutrients should continue to be followed. If supplies of other nutrients are reduced to sub-optimal levels, this is likely to limit yields further and reduce nitrogen use efficiency.

There may be some instances where the new N fertiliser guidelines result in low N recommendations, e.g. OSR crops containing a large amount of N in the canopy post-winter may have N recommendations of less than 100 kg N/ha. Applying a nitrogen-sulphur compound in this situation may result in inadequate S supply to these crops particularly where the risk of sulphur deficiency is moderate or high (light soil and/or high over-winter rainfall). In such cases additional application of sulphur from other sources should be considered.

2.9. Potential longer-term impacts

Applying less N fertiliser will reduce the nitrogen balance (N inputs minus N offtake in grain and straw) after harvest. This can be estimated for the average UK crop using information about the UK national yield, the grain N concentration (AHDB Cereal Quality survey), the ratio of N contained in the grain to the total crop (N harvest index) and assuming that 65% of the non-grain crop biomass is removed if the field is baled. The current N balance for different crops, assuming the straw is removed (except for OSR), are +16 kg/ha for wheat, +5 kg/ha for spring barley, +30 kg/ha for winter barley and +80 kg/ha for OSR. The change in N balance can be estimated if the N fertiliser rate is reduced by 50 kg N/ha by assuming the yield reductions summarised in Table 1 and a grain N% reduction of 0.17% for cereals and 0.3% for OSR. This estimates a reduction in N balance of about 30 kg N/ha for the cereal crops and 40 kg N/ha for OSR. These changes would make the N balance slightly negative for winter wheat and spring barley, neutral for winter barley and less positive for OSR. The reduction in N balance is smaller than the reduction in N fertiliser rate because the reduced fertiliser rate reduces the N taken off from the field due to lower yield, lower grain N% and slightly less N in the straw. It should be recognised that the malting barley rates are unlikely to be reduced as much because they are often already reduced to achieve malting specifications (see section 2.5)

Whether the smaller N residues will have a detectable impact on the SNS for the following crop depends on several factors including; the yield of the crop harvest in 2022, the amount of mineralisation/immobilisation that occurs after harvest and the amount of hydrologically effective winter rainfall. Previous research has shown that reducing the rate of fertiliser by about 50 kg N/ha has a relatively modest impact on the SNS for the following crop (Defra Report IS0223). Over the short term (1 to 3 years) it is unlikely that the use of moderately lower N rates will on their own have a large enough impact to justify a change in N rates for the following crop. However, they should be taken into consideration along with other factors when estimating SNS for following crops.

If N fertiliser prices remain high for several years, then this could have an impact on the SNS in some rotations, particularly those with a high proportion of cereal crops. This is because the N balance is likely to become negative for winter wheat and spring barley and the effects of this will accumulate over years. The result of this will be a reduction in organic N levels, less N mineralisation and smaller SNS. The figures estimated represent the UK national average, therefore it should be expected that some farms will have a greater negative N balance and impacts on SNS may develop faster.

3. Conclusions

Split prioritisation. If the total N rate is reduced below the rate currently recommended by RB209 for a cereal BER of 5 or oilseed rape BER of 2.5, then it is recommended that the rate at each split is reduced by the same proportion. Exceptions to this rule include: i) wheat with a high risk of take-all or low shoot number, winter barley and spring barley, for which the first split should be maintained at a similar level as would have been used before any reduction in N rate to account for a high BER, ii) Wheat targeted for the bread-making market for which the current RB209 guidance, for both N rates and timings, should be followed (see below).

Organic materials. Estimate the crop available nutrient supply from different manure types, application timings and methods using the MANNER-*NPK* decision support tool or RB209.

Impact of expected yield. The expected yield of a crop does not affect how its N rate should be adjusted according to fertiliser price, nor the amount of yield loss that results from using a lower N rate.

Milling wheat. In most cases, it will be economically justifiable to target milling quality, particularly if premiums are £30/t or more. However, on farms where proteins are not achieved consistently over seasons, or where there is a risk of low HFN or specific weight, then the recent fertiliser price increases may now move the risk/benefit balance to a point where targeting milling quality cannot be justified.

Malting barley. If the estimated BER is greater than 5 then i) estimate the reduction in N rate required for a high BER, ii) independently of (i), estimate the reduction in N from the N rate recommended for feed barley that would normally be applied for your malting barley crop if BER was 5, iii) apply the largest N rate reduction estimated by (i) and (ii) but NOT both N rate reductions together.

Value of precision N application increases with greater fertiliser costs. Therefore, estimate the soil N supply as accurately as possible and make use of proven technologies for maximising the precision of N applications and minimising losses of N to the environment.

Management of other nutrients. Maintain inputs of non-N nutrients to minimise the risk of reducing N use efficiency and further yield reductions.

Implication for following crops. It is unlikely that the use of moderately lower N rates will, on their own, have a large enough impact to justify a change in N rates for the following crop. However, they should be taken into consideration, along with other factors when estimating SNS for following crops.

4. Further work required

- Part 1 of this report concluded that the shape of N response curves of winter wheat, winter barley and spring barley are similar enough to be described by a single standard cereal curve. However, there was some uncertainty for spring barley which showed evidence of having a steeper N response curve, which if proven would mean smaller N reductions in response to high BER than winter wheat or winter barley. However, there were only 11 recent N response curves to analyse which was insufficient to conclude that the spring barley N response is different from other cereals. Further work should analyse a greater number of spring barley N response curves by including pre-2010 datasets to test whether the standard cereal N response curve is appropriate for spring barley.
- Field experiments to better understand which N splits should be prioritised for any N reductions for cereals and OSR.
- Investigate the potential for changes in crop and fertiliser management to improve fertiliser use efficiency, such as little and often N splits, liquid N vs solid N, and the use of different N products.
- Evaluate the potential longer-term impacts of applying less fertiliser on factors such as soil organic matter, N mineralisation, soil N supply, crop yield and quality.
- Economic analysis to understand the most appropriate method for valuing N fertiliser.

5. Acknowledgements

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