November 2021

Research Review No. 97

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

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This review was produced as a two-week project (1020116) that started in October 2021.
The work was funded by a contract for £2,500 from AHDB.

CONTENTS

1. Abstract

This is Part One of a two-part study to help cereal and oilseed growers respond appropriately to the large increases in prices of manufactured nitrogen (N) fertilisers for use in 2022. Part One considers adjustments to the total amounts of N to be applied.

Economic optimum amounts of fertiliser N decrease as the break-even price ratio (BER) between grain and fertiliser N increase. Current RB209 recommendations were devised for a BER of 5 kg cereal grain to 1 kg N and RB209 tables for BER adjustments extend to a N price of £1.40/kg. However, recent prices of fertiliser N have reached £2.00/kg and may go higher before spring 2022, so the RB209 tables have been extended here up to £2.50/kg N. Cereal grain and rapeseed prices have also been strong of late, so the tables have also been extended to prices of £350/tonne and £700/tonne respectively.

These new tables indicate that, if grain and rapeseed prices were held at £200/tonne and £400/tonne, the optimal change in use of ammonium nitrate fertiliser, due to an increase in its price from £345 (BER=5 & 2½) to £690/tonne (BER=10 & 5), is to reduce its use by 50 kg/ha N on cereals and by 70 kg/ha N on oilseeds. The resulting changes in yield would be -0.36 t/ha and -0.25 t/ha respectively. However, recent increases in oilseed prices to ~£500/tonne have mitigated this oilseed adjustment to -50 kg/ha N.

This review then considers whether new evidence justifies a change in the way that price adjustments are currently recommended in RB209. After describing conventional methods for determining N optima from results of experiments with fertiliser N on crop yields, responses to fertiliser N in recent experiments [(i) 46 on winter wheat, (ii) 6 on winter barley, (iii) 11 on spring barley, and (iv) 22 on winter oilseed rape] are compared with the standard responses used to determine current price adjustments in RB209.

It is concluded that the extended adjustment tables are satisfactory for winter wheat and for winter oilseed rape. They are also adequate for winter and spring barley at present, but some further consideration should be given to whether adjustments for barley should be somewhat less than for wheat.

Part Two of this study will be reported in January 2022 and will consider issues such as how to prioritise more expensive fertiliser N on particular fields and crops, meeting crop quality specifications, and maximising the value of recycled N from livestock and legumes.

2. Introduction

This is the first part of a two-stage study of how the arable cropping industry can best respond to the recent sharp increases in prices and availability of manufactured fertilisers. This first part just addresses use of nitrogen (N) fertilisers on the major arable crops, wheat, barley and oilseed rape. The second part of this study will be reported in January 2022, and will consider other arable crops, and other aspects of crop nutrition management that are affected by the sharp increase in prices.

2.1. Recent Trends in prices of fertilisers and crop produce

Associated with sharp increases in energy prices during 2021, and with limits on availability of natural gas, prices of manufactured N fertilisers have increased, and their availability for on-farm delivery has reduced.

Farmers and farm suppliers need guidance on how best to respond to these changes; their main concerns are to know whether, and by how much, they should reduce the rates of fertiliser N that they normally apply, and by how much this will reduce their crop yields.

The fertiliser experiments that have habitually been conducted on the major arable crops since the use of manufactured fertilisers began have regularly been reviewed in order to support farmers' decision-making on fertiliser use, and recommendations have been produced and regularly revised accordingly, currently published as the AHDB Nutrient Management Guide (RB209; AHDB, 2016).

2.2. What the Nutrient Management Guide (RB209) says at present

The current version of the AHDB Nutrient Management Guide (RB209) includes Tables 4.22 & 4.28 to show how N recommendations should be adjusted for changes in prices of fertiliser or crop produce. These tables were introduced in the 8th edition of RB209 (Defra, 2010 pages 106 & 116) from experimental evidence collated up to 2008; their content has not been revised since AHDB took responsibility for RB209. The tables were produced assuming the shape of the crop response around the optimum rate of fertiliser N is the same for all cereals and a different response curve is representative of all oilseeds.

These tables no longer address the current and expected range of prices for grains and fertilisers, so they are extended in Section 2, and effects on crop yields are tabulated.

It is also possible, with changes in varieties, and with further evidence since these tables were included in the 9th Edition of RB209 (AHDB, 2016) that the assumption of a standard response shape for all cereals and another for all oilseeds needs to be changed. Section 3 of this report therefore shows how N optima are defined and Section 4 shows how response curves from recent experiments compare with the standard response assumed in RB209 at present, and in the extended tables presented in Section 2.

3. Current RB209 adjustments extended for new prices

The tables provided below use the same N response parameters that were used to create Tables 4.22 (Cereals) and 4.28 (Oilseeds) in RB209, but they have been extrapolated to embrace the new range of prices for both grains and fertilisers.

3.1. Adjustments for N recommendations

Table 3.1: Extended version of Table 4.22 in RB209 to embrace current prices and trends for cereals.

Source of N	Fertiliser N content	Fertiliser Cost								
	%	£/tonne product								
Ammonium Nitrate	**34.5%**	**£173**	**£259**	**£345**	**£431**	**£518**	**£604**	**£690**	**£776**	**£863**
Urea	**46.0%**	**£230**	**£345**	**£460**	**£575**	**£690**	**£805**	**£920**	**£1,035**	**£1,150**
Urea-Ammonium Nitrate Liquid	**28.0%**	**£140**	**£210**	**£280**	**£350**	**£420**	**£490**	**£560**	**£630**	**£700**
Cost of fertiliser nitrogen	***£/kg N***	**£0.50**	**£0.75**	**£1.00**	**£1.25**	**£1.50**	**£1.75**	**£2.00**	**£2.25**	**£2.50**
	Grain sale price	**Change to recommendation for ALL CEREALS**								
	£/tonne	**kg/ha N**								
	50	**-50**	**-85**	**-115**	**-135**	**-155**	**-170**	**-185**	**-195**	**-205**
	75	**-20**	**-50**	**-75**	**-95**	**-115**	**-130**	**-140**	**-155**	**-165**
	100	**0**	**-30**	**-50**	**-70**	**-85**	**-100**	**-115**	**-125**	**-135**
	125	**15**	**-10**	**-35**	**-50**	**-65**	**-80**	**-90**	**-105**	**-115**
decrease	**150**	**25**	**0**	**-20**	**-35**	**-50**	**-65**	**-75**	**-85**	**-95**
increase	**175**	**30**	**10**	**-10**	**-25**	**-40**	**-50**	**-60**	**-70**	**-80**
	200	**35**	**15**	**0**	**-15**	**-30**	**-40**	**-50**	**-60**	**-70**
	225	**40**	**25**	**5**	**-5**	**-20**	**-30**	**-40**	**-50**	**-60**
	250	**45**	**30**	**15**	**0**	**-10**	**-25**	**-35**	**-40**	**-50**
	275	**50**	**35**	**20**	**5**	**-5**	**-15**	**-25**	**-35**	**-45**
	300	**55**	**35**	**25**	**10**	**0**	**-10**	**-20**	**-30**	**-35**

Values in Table 2.1 have been determined using the same response parameters as in Table 4.22 of RB209.

Table 3.2: Extended version of Table 4.28 in RB209 to embrace current prices and trends for oilseeds.

Source of N	Fertiliser N content	Fertiliser Cost								
	%	£/tonne product								
Ammonium Nitrate	34.5%	£173	£259	£345	£431	£518	£604	£690	£776	£863
Urea	46.0%	£230	£345	£460	£575	£690	£805	£920	£1,035	£1,150
Urea-Ammonium Nitrate Liquid	28.0%	£140	£210	£280	£350	£420	£490	£560	£630	£700
Cost of fertiliser nitrogen	*£/kg N*	£0.50	£0.75	£1.00	£1.25	£1.50	£1.75	£2.00	£2.25	£2.50
	Rapeseed sale price	Change to recommendation for ALL OILSEEDS								
	£/tonne	kg/ha N								
	200	0	-40	-70	-90	-110	-120	-130	-150	-160
	250	20	-20	-50	-70	-80	-100	-110	-120	-130
	300	40	0	-30	-50	-70	-80	-90	-110	-120
decrease	350	50	10	-10	-30	-50	-70	-80	-90	-100
increase	400	70	30	0	-20	-40	-50	-70	-80	-90
	450	80	40	10	-10	-30	-40	-60	-70	-80
	500	90	50	20	0	-20	-30	-50	-60	-70
	550	90	60	30	10	-10	-20	-40	-50	-60
	600	100	70	40	20	0	-10	-30	-40	-50
	650	110	70	50	20	10	-10	-20	-30	-40
	700	120	80	50	30	10	0	-10	-20	-30

Values in Table 2.2 have been determined using the same response parameters as in Table 4.28 of RB209.

The tables above are provided in the same format as is used in the AHDB Nutrient Management Guide (RB209).

However, for users who are more familiar with calculating their own BERs, it is also possible to present the same information in a more efficient graphical format (Fig. 2.1).

3.2. Yield effects

Whilst adjustments to recommendations set out in Sections 2.1 and 2.2 will maximise the margin over fertiliser cost, they will also cause decreases in grain production. These have been estimated in Table 2.3 using the same response functions as in Tables 2.1 and 2.2.

Table 3.3: Effect on grain yield of adjusting N applied from the optimum at a break-even price ratio of 5 kg grain per kg N for cereals or 2½ kg seed per kg N for oilseeds.

	CEREALS	OILSEEDS
Reduction in N applied, kg/ha	Effect on yield, t/ha	
0	0.00	0.00
-10	-0.05	-0.03
-20	-0.12	-0.06
-30	-0.19	-0.09
-40	-0.27	-0.12
-50	-0.36	-0.16
-60	-0.47	-0.21
-70	-0.59	-0.25
-80	-0.72	-0.31
-90	-0.87	-0.37
-100	-1.04	-0.43

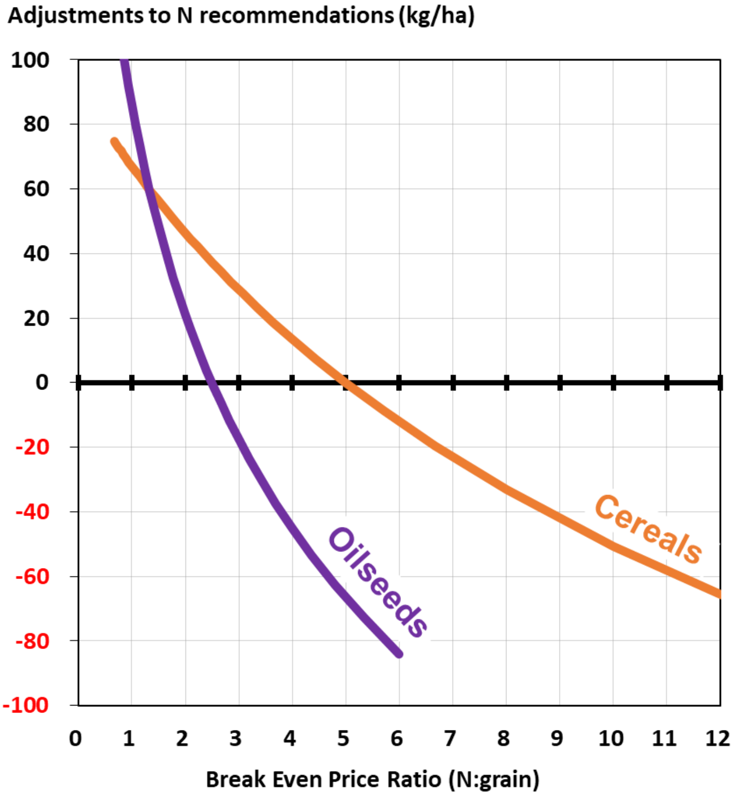

Figure 3.1: **How adjustments to fertiliser N recommendations presented in Tables 2.1 & 2.2 relate to the Break-Even price Ratios for cereals and oilseeds.**

4. Defining economic optimum fertiliser use

The purpose of this section is to describe how crops respond to fertiliser N, to show how economic optimum amounts of fertiliser N are determined from experimental evidence, and to explain how price changes affect these economic optima.

4.1. Summarising multi-level fertiliser experiments

Response experiments have been conducted on arable crops since World War II and before (Crowther & Yates 1941). Results show huge variability in fertiliser effects, but they predominantly show that the applications of fertiliser N increase crop yields with diminishing increments in yield with each additional N increment. In order to interpret these experiments, it is necessary to find a way of interpolating crop effects between the amounts of fertiliser that were tested. This is done by statistically fitting algebraically defined response curves to the yield data.

4.1.1. Response curves

After much debate through the 1960s and 1970s about the most appropriate form of response curve to use to describe yield responses to N, the linear plus exponential (LpE) function was adopted for derivation of the government's fertiliser recommendations for all combinable crops (George, 1984). [Note that a two split line function was adopted for sugar beet (Jaggard *et al*., 2009).] Current approaches to curve fitting are described in detail by Sylvester-Bradley *et al.* (2014).

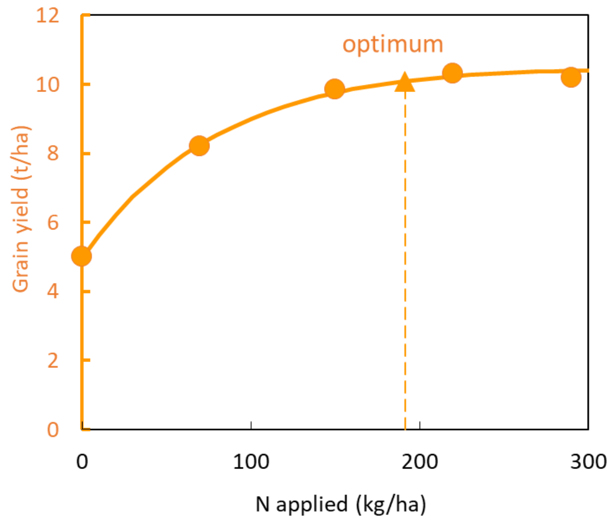

Figure 4.1: Example N response data and fitted LpE curve for an experiment on winter wheat at ADAS High Mowthorpe in 2005.

The LpE function takes the form:

$$y = a + b \times r^N + c \times N$$

where y is the yield in t/ha at 0.85 g/g DM, N is the total fertilizer N applied (kg/ha), and a, b, c and r are parameters determined by statistical fitting.

4.1.2. Determination of the optimum

The economic optimum (Nopt) is defined as the point at which the value of extra grain produced ceases to exceed the cost of the extra N applied. Nopt can be determined from parameters from the LpE function as follows:

$$Nopt = [Ln\{(P/1000 - c)/(b \times Ln\ r)\}]/Ln\ r$$

where P is the price ratio of N (£/kg) to grain (£/kg) or 'Break-Even Ratio' (BER), taken in the current version of RB209 as five. It is important to note that determination of Nopt does not depend on the 'a' parameter from the LpE function; it only depends on the b, c and r parameters.

The optimum yield (Yopt) at Nopt can then be determined by using the Nopt value in the LpE function above.

4.1.3. The break-even ratio (BER)

The BER increases as fertiliser prices increase and decreases as grain prices increase. Over the decades both have tended to vary together, so the BER used in fertiliser recommendations remained set at 3:1 from the inception of recommendations in 1967 until the 8th Edition of RB209 was published in 2010 when it was increased to 5:1.

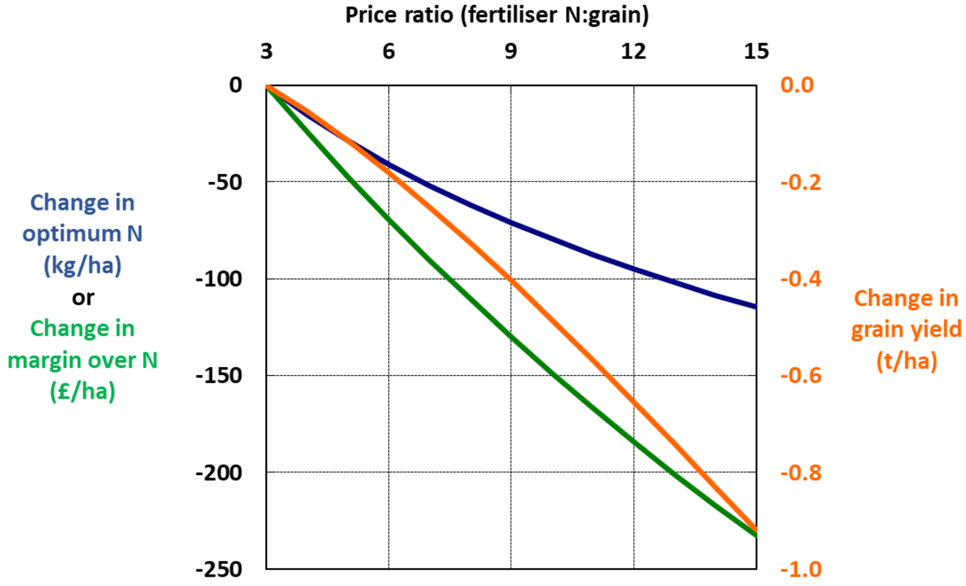

Figure 4.2: Based on the average shape of response for cereals in RB209, effects of increasing the break-even price ratio (BER) from 3:1 on optimum N, optimum grain yield and margin over N cost assuming grain price is £150/t.

As the BER increases, Nopt, Yopt and the margin of grain value over N cost all decrease (Fig. 2.2). However, the extent to which they decrease depends on the shape of the response to N, as described by the LpE function. The most influential LpE parameter on these effects is 'r', the next most influential is 'c', and the least is 'b', noting that the 'a' parameter has no influence at all. Thus, if the response to N is fairly 'flat' as for oilseeds (Fig. 3.3) the effect of a change in BER from say 5 to 8 will be larger than if the response to N changes 'sharply' i.e. over a small range of N applied as for cereal in Fig. 3.3.

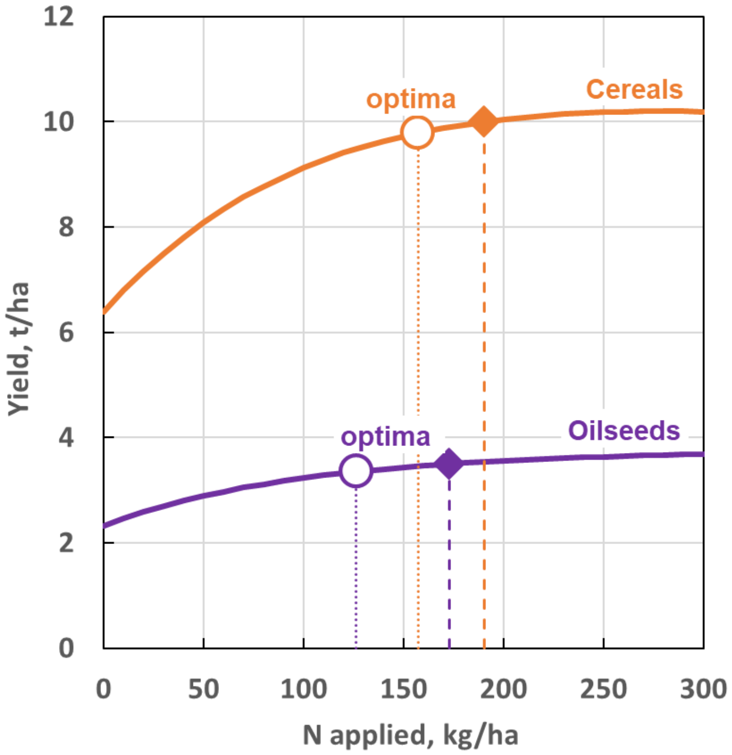

Figure 4.3: Average response shapes for cereals and oilseeds to applied N as used in the current version of RB209 showing optima at break-even price ratios (BER) of 5:1 and 2½:1 respectively (diamonds) and of 8:1 and 4:1 respectively (circles).

4.1.4. Variation in N responses

Most of the large variation in N responses and N optima is seen to be reflected in the values of the ‘a’ and ‘b’ parameters of the LpE function; much less variation is seen in the ‘c’ and ‘r’ parameters. Thus, the shapes of N responses are much less variable than their asymptotes and their intercepts.

The main factors seen to affect the shapes of yield responses to N are site and crop species. Most of the many experiments comparing varieties have found that allowing different values for the ‘r’ parameter between varieties is not justified.

However, it is to be expected that experiments where high N amounts reduce crop yields (through increased lodging or disease) will show a sharper change in N responses than experiments where little or no lodging occurs.

Thus, the prime question addressed here is whether, after a recent focus of experimentation on non-wheat cereals, especially on barleys which are more prone to lodging than wheats, there might be sufficient evidence to recommend different adjustments for changes in BER than are currently provided in RB209.

4.2. Data used to check what RB209 is currently recommending

Multi-site, multi-season data were collated from recent series of N response experiments funded by AHDB, Defra, LINK, TSB, Yara, CF Fertilisers, Syngenta, Limagrain, Koch, CF Fertilisers, BASF and others. Publicly available reports all crops are by Roques *et al.* (2016), for winter wheat are by Kindred *et al.* (2018) and Sylvester-Bradley *et al.* (2015), for winter barley are by Kendall et al. (2017), for spring barley are by Kendall *et al*. (2021), and for oilseed rape are by Berry & Spink (2009) and Sylvester-Bradley et al. (2015).

Some experiments included factorial comparisons with N timings, varieties, or other nutrients. It was generally found that differences in shape of responses were mainly between site-seasons (rather than within site-seasons) i.e. curves fitted to a series of varieties all compared within the same trial (site-season) had the same or very similar ‘c’ and ‘r’ parameters for the LpE function. To avoid an impression of spurious precision in the evidence base for the crops where multiple varieties were being tested only one representative response curve was selected from each site-season for this review.

Table 4.1: Datasets used to inform adjustments

Crop type	Winter wheat	Winter Barley	Spring Barley	Winter Oilseed Rape
No. of N Response trials included	46	6	11	22

These selected responses are reported in Section 4 below.

5. Recent arable crop responses

To determine whether adjustments to N recommendations for cereals and oilseeds in the current version of RB209 are still appropriate, this section presents N responses curves collated from more recent experiments on each major cereal type and oilseed rape (Table 3.1) and compares them with the standard response curves used.

5.1. Winter wheat

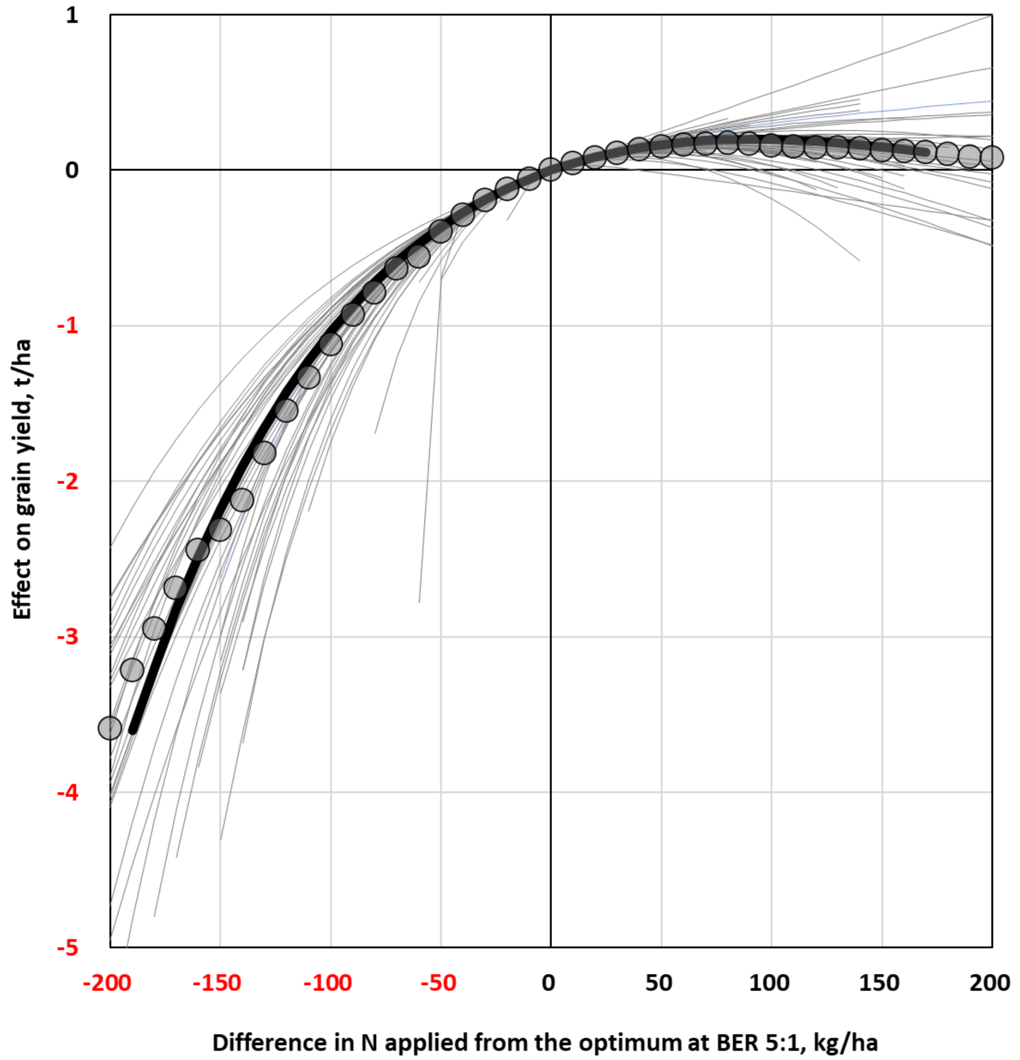

Figure 5.1: Effects on grain yield of altering N applied from the optimum amount at a break-even ration (BER) of 5:1 kg grain per kg N for (i) N response curves (fine grey lines) fitted to yield data from 46 winter wheat experiments conducted between harvest 2009 and harvest 2015, (ii) their mean (grey circles), and (iii) the standard response curve (bold line) used to adjust N recommendations in Table 4.22 of RB209 since 2008.

In Fig. 4.1 the mean of recent experiments coincides very closely with the RB209 standard curve, although some variation in the shapes of recent N responses is apparent, so there will be some imprecision resulting from using the RB209 adjustment table.

5.2. Winter barley

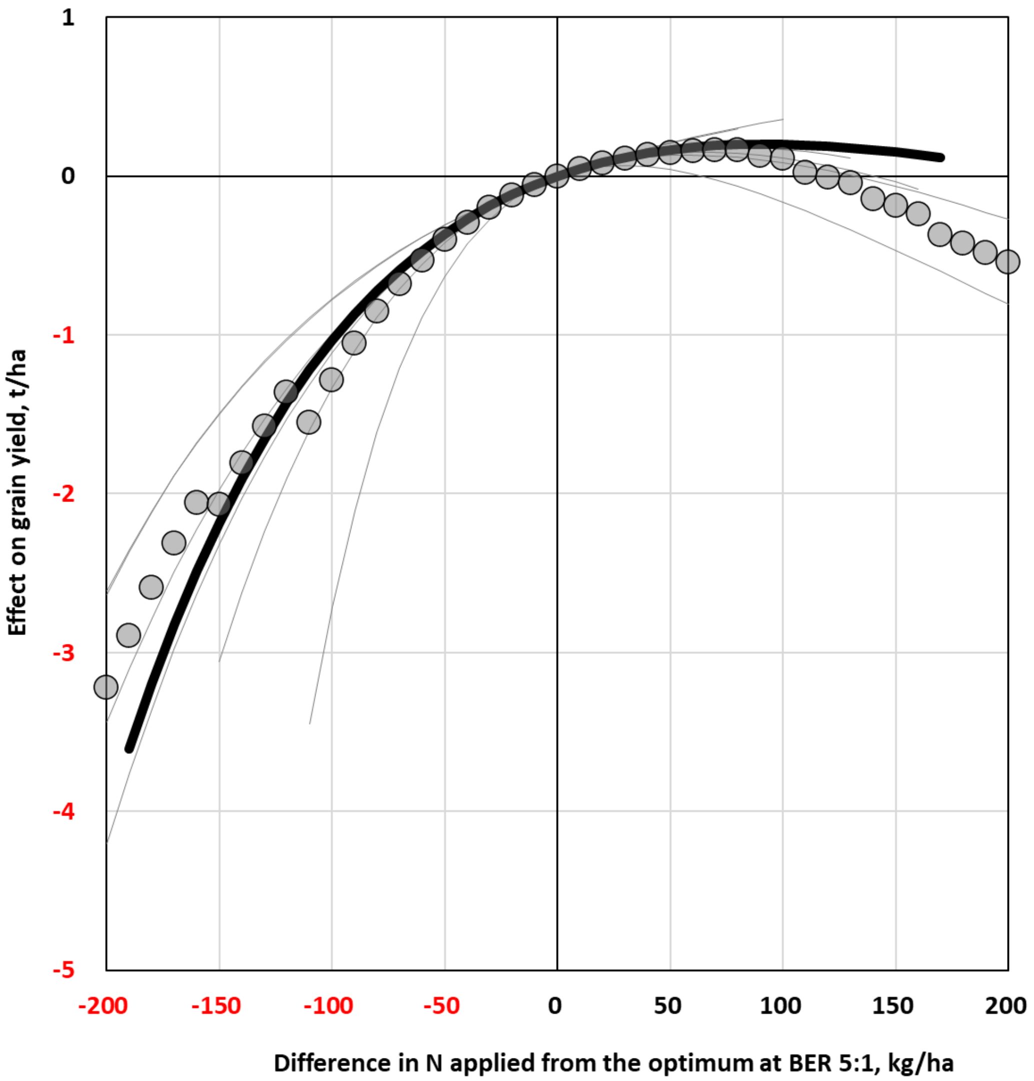

Figure 5.2: Effects on grain yield of altering N applied from the optimum amount at a break-even ration (BER) of 5:1 kg grain per kg N for (i) N response curves (fine grey lines) fitted to yield data from 6 winter barley experiments conducted between harvest 2014 and harvest 2016, (ii) their mean (grey circles), and (iii) the standard response curve (bold line) used to adjust N recommendations in Table 4.22 of RB209 since 2008.

Few N response experiments have been conducted on winter barley since 2008. In Fig. 4.2 the mean of the six selected recent experiments coincides well with the RB209 standard curve for cereals, although, as with wheat, some variation in the shapes of recent N responses is apparent, so there will be some imprecision resulting from using the RB209 adjustment table. However, the imprecision only becomes significant when the deviation from Nopt at BER 5 is outside the range of approximately -80 to +100 kg/ha.

5.3. Spring barley

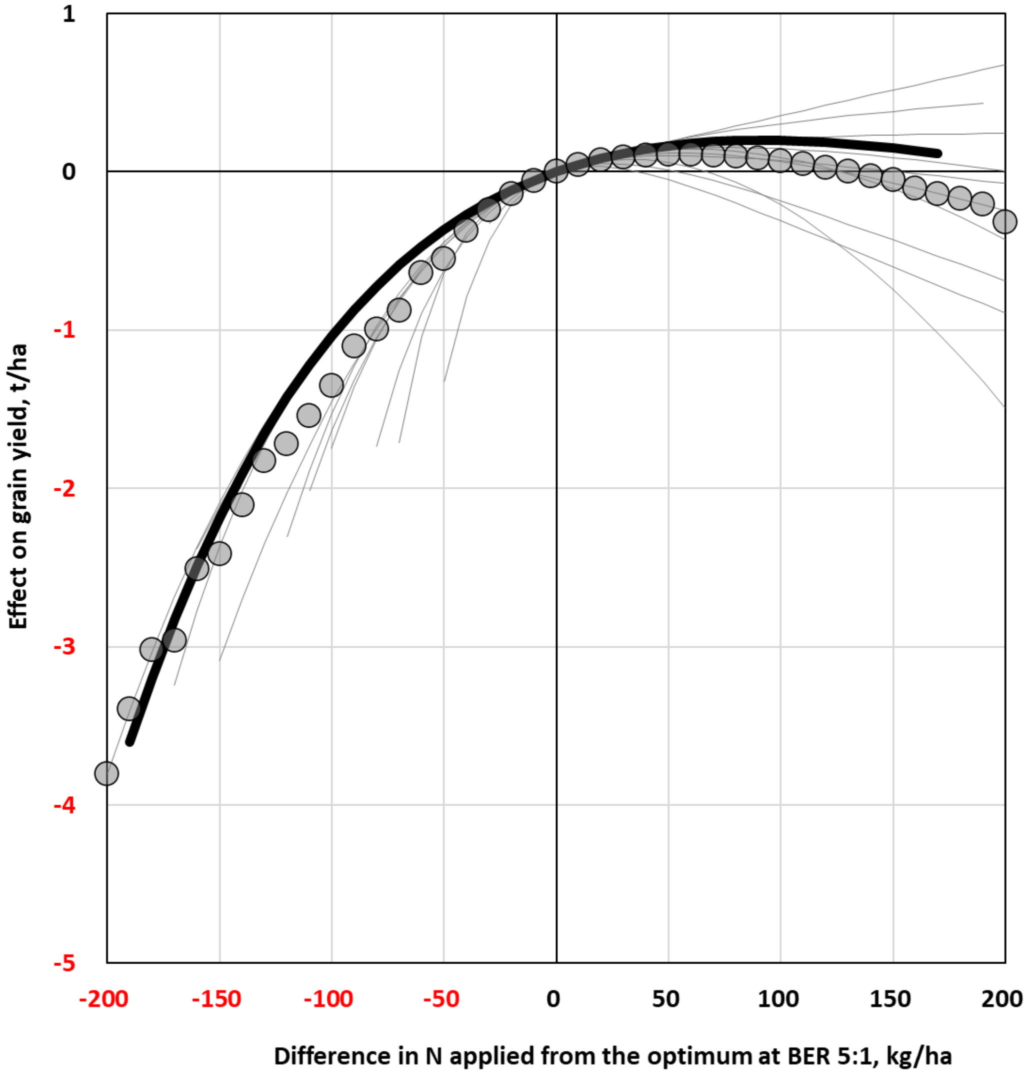

Figure 5.3: Effects on grain yield of altering N applied from the optimum amount at a break-even ration (BER) of 5:1 kg grain per kg N for (i) N response curves (fine grey lines) fitted to yield data from 11 spring barley experiments conducted between harvest 2018 and harvest 2020, (ii) their mean (grey circles), and (iii) the standard response curve (bold line) used to adjust N recommendations in Table 4.22 of RB209 since 2008.

The N response experiments reported in Fig. 4.3 are derived from a recent project funded by AHDB and conducted by ADAS and SRUC in harvest years 2018, 2019 & 2020. The mean of the 11 selected recent experiments shows a possible need for slightly larger adjustments than are derived from the RB209 standard curve for cereals. As with winter wheat and winter barley, some variation in the shapes of recent N responses is apparent, so there will be some imprecision resulting from using a single adjustment table. The imprecision becomes significant when the deviation from Nopt at BER 5 is outside the range of approximately -40 to +80 kg/ha.

5.4. Winter oilseed rape

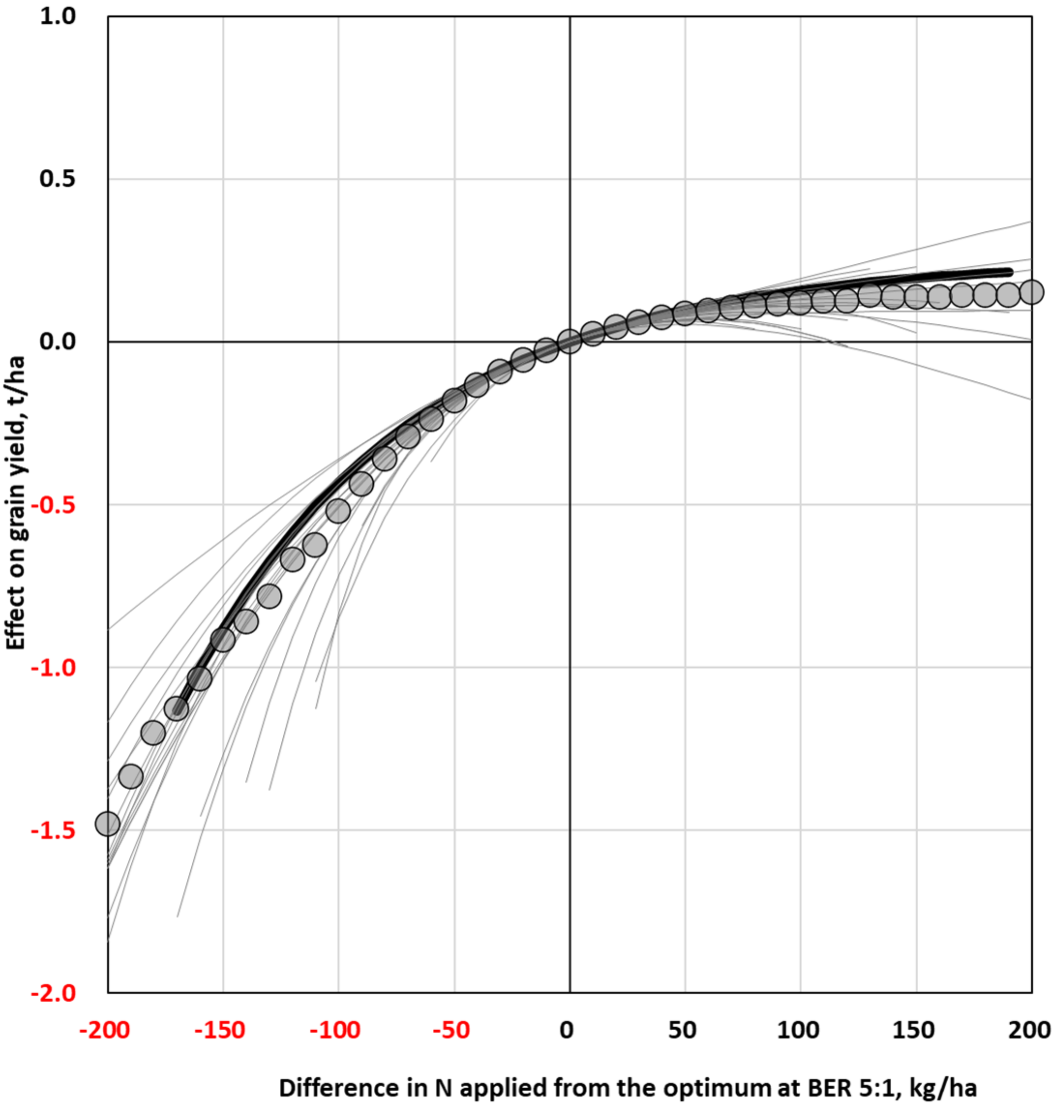

Figure 5.4: Effects on rapeseed yield of altering N applied from the optimum amount at a break-even ration (BER) of 2½:1 kg seed per kg N for (i) N response curves (fine grey lines) fitted to yield data from 22 experiments conducted between harvest 2006 and harvest 2013, (ii) their mean (grey circles), and (iii) the standard response curve (bold line) used to adjust N recommendations in Table 4.28 of RB209 since 2008.

The N response experiments reported in Fig. 4.4 are derived from projects funded by Defra, AHDB, Syngenta, BASF, & CF Fertilisers and conducted by ADAS in harvest years between 2006 and 2013. The mean of the 22 selected experiments shows very similar adjustments to those derived from the RB209 standard curve for oilseeds. The shapes of these N responses appear to vary somewhat less than for the cereals, so imprecision resulting from using the existing adjustment table in RB209 would appear to be slight.

6. Discussion

The new tables in Section 2 indicate that, if grain and rapeseed prices were £200/tonne and £400/tonne respectively, the optimal change in use of ammonium nitrate fertiliser, due to doubling its price from £345 (BER=5 for cereals & 2½ for oilseeds) to £690/tonne (BER=10 & 5), is to reduce its use by 50 kg/ha N on cereals and by 70 kg/ha N on oilseeds. Effects on yield would be relatively small at -0.36 t/ha and -0.25 t/ha respectively (Table 2.3). However, recent increases in oilseed prices to ~£500/tonne have mitigated the need to adjust fertiliser N recommendations for oilseeds to -50 kg/ha N (Table 2.2).

6.1. Crop response differences

The new evidence assembled here: (i) 46 experiments on winter wheat, (ii) 6 on winter barley, (iii) 11 on spring barley, and (iv) 22 on winter oilseed rape, appears to justify maintaining the way that price adjustments to recommendations are currently provided in RB209. The standard response curves used to determine these price adjustments relate well to the average response curves of all four crop types. The only question arising from this analysis is whether the slightly greater yield penalties from adjusting N applied to barley (greater than is predicted by the standard curve used for all cereals) indicate that adjustments for barley should be somewhat less than for wheat.

6.2. Further questions to be addressed in Part Two

Part Two of this study will consider further issues raised by the increased expense of fertiliser N such as:

- Milling wheat management … & malting barley
- Which crops and fields to prioritise with expensive N
- Which split(s) to prioritise
- The value of 'free N' from organic manures and legumes
- Product choice, e.g. Compounds v. straights; urea, AN & UAN, ±urease inhibitors.
- How to regard the value of fertilisers bought at different prices
- The value of precision in N decision-making
  - SNS analysis v Field Assessment Method
  - Over-winter-rainfall adjustments, cover-crop adjustments,
  - Leaf & grain analysis
  - Can variable rate N help?
- Implications for fertiliser rates next season (due to lower residues) and longer-term implications for N management if N prices remain high

Part Two will be reported in January 2022.

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