Maximum Nitrogen (Nmax) Limits, and Exemptions from the Closed Spreading Period for Manufactured Nitrogen Fertilisers

ADAS report to Defra – supporting paper F1 for the consultation on implementation of the Nitrates Directive in England

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1. Introduction

This paper provides a science-based case for the setting of maximum nitrogen (Nmax) limits for the main agricultural crops grown in England. These limits form part of the revised Nitrate Vulnerable Zone (NVZ) Action Programme (AP) measures proposed by Defra. The Nmax limit is defined as the maximum nitrogen (N) rate that may be applied to the crop; it is the crop available N from all organic manures applied for the crop *plus* the nitrogen applied in manufactured fertilisers.

This paper also describes the proposed exemptions for applications of manufactured nitrogen fertilisers during the closed spreading period.

Nitrogen applications to land can be a major source of nitrogen pollution of the environment, including nitrates to waters. The main sources of applied nitrogen are from manufactured fertilisers and the crop available N from applications of organic manures.

The current 7th edition of the 'Fertiliser Recommendations for Agricultural and Horticultural Crops (RB209)' (Defra 2000) book (hereafter called RB209) contains the current national standard recommendations for the application of lime and major nutrients (including nitrogen) for all major field grown crops. It also contains standards for the nutrient content and N efficiency of a wide range of organic manures. The RB209 recommendations are based on the latest research evidence and scientific understanding of crop nitrogen requirements and the supply of N from all sources. Revision of the RB209 recommendations is currently ongoing taking account of new research information. The revised recommendations will be available during 2008.

The crop N requirement (the quantity of N that needs to be applied to the crop) is influenced by the crop type, the expected yield, any requirements of the target market for the crop produce (e.g. protein concentration, quality grade), and the economics of growing the crop. Crop management practices under the control of the farmer have steadily improved over several decades and have resulted in gradual increases in crop N requirements that may continue in future. Such practices include improved crop varieties with higher yield potentials, improved crop protection optimised drilling date, improved pest and disease control and the use of growth regulators to control lodging of cereals. Typical crop outputs on individual farms, and the nitrogen needed to achieve these outputs, are strongly influenced by the natural climatic and soil environments, both of which are outside the control of farmers.

The soil nitrogen supply (SNS) of a field is influenced by the previous cropping history and use of organic manures, as well as the soil type and excess winter rainfall. Soils vary in their typical SNS and in their ability to support high output crops. England contains a very wide range of soil types soils ranging from high yielding nitrogen responsive soils, to organic/peaty soils that have a high SNS and low crop N requirement. Shallow soils over chalk or limestone can support high crop yields and have been shown to have a high requirement for nitrogen. These soils represent approximately 9% of the total area of soils used for arable crop production within NVZs (ADAS, unpublished).

Organic manures contain variable amounts of crop available N that can wholly or partly meet the crop N requirement. Regular applications of manures over several years can contribute significantly to the SNS. It is very important that the crop available N from applied manures is taken into account when calculating the need for manufactured fertiliser N. The setting of manure N efficiency factors is an important element of the revised NVZ rules and proposals have been made elsewhere (Defra 2007).

2. Proposed Nmax limits and methodology

Within the proposed new framework of NVZ AP rules, farmers will be required to balance the foreseeable crop N requirement with the nitrogen supply from all sources including the SNS, crop available N from manure applications, and additions of manufactured fertiliser N. To this end, farmers will be required to demonstrate (via the use of field records) that they have undertaken the following mandatory steps when planning their nitrogen fertiliser applications:

- Assessed the soil nitrogen supply
- Assessed the nitrogen requirement of the crop, taking into account the soil nitrogen supply
- Assessed the crop available N supplied from applications of organic manures, complying with the relevant mandatory manure N efficiency values
- Calculated the need for manufactured fertiliser N by deducting the quantity of crop available N supplied from organic manures from the crop N requirement
- Complied with the Nmax rate for the crop type. Compliance will be checked by calculating the average application rate of nitrogen (kg/ha N) to the whole area of the crop grown on the farm. Crop available N from organic manures plus manufactured fertiliser N will be taken into account.

Nmax limits are proposed for the major crop types grown in England. These are summarised in Table 1. The subsequent sections provide a summary of the key evidence supporting the setting of these rates. The Defra publication '*Do your nitrogen applications comply with the farm average maximum nitrogen (Nmax) limits'* provides a step by step calculation guide for checking compliance on the farm.

Table 1. The maximum nitrogen (Nmax) limits

Crop	N max (kg/ha N)	Standard yield (t/ha)
Wheat, autumn or early winter sown	220[a,b,c]	8.0
Wheat, spring-sown	180[b,c]	7.0
Barley, winter	180[a,b]	6.5
Barley, spring	150[b]	5.5
Oilseed rape, winter	250[d,e]	3.5
Sugar beet	120	n/a
Potatoes	270	n/a
Forage maize	150	n/a
Field beans	0	n/a
Peas	0	n/a
Grass	360[f,g,h]	n/a

Exemptions

a. An additional 20kgN/ha is permitted on fields with a shallow soil type.
b. An additional 20kgN/ha is permitted for every tonne that expected yield exceeds ‘standard yield’.
c. An additional 40kgN/ha is permitted to milling wheat varieties.
d. This consists of a maximum autumn application of 30kgN/ha (allowed as exemption to the closed period for manufactured nitrogen fertiliser –see Annex A1) and a maximum spring application of 220kgN/ha.
e. The spring application can be increased by up to 30kgN/ha if expected yield is over 4.0t/ha.
f. An additional 40kgN/ha is permitted to grass to grass that is cut only.
g. An additional 40kgN/ha is permitted to grass in areas of a very good grass growth class.
h. Nmax for grass is 330kgN/ha until 31 Dec 2011.

The Nmax limits will be reviewed regularly by Defra and revisions may be issued either annually to reflect seasonal variations in weather or growing conditions, or to reflect evidence supporting increased crop N requirements due to improvements in crop varieties or other factors.

3. EVIDENCE FOR THE PROPOSED Nmax LIMITS

3.1 Arable crops

3.1.1 Wheat, autumn and early winter sown (feed)

Winter wheat is the main arable crop in England, grown on 42% of the total area of crops, set-aside and fallow (Table 1). Due to varietal improvements and better general management, wheat grain yields have increased steadily over the last 20-30 years at approximately 2% per year. During the 1980s, the average national wheat grain yield was around 6t/ha, but is now 8t/ha. Figure 1 shows the trend of increasing UK average wheat yields since 1970 (Defra, 2005). The Cereal Production Survey (Defra, 2005) indicates that the most common *farm average* wheat yield is currently between 8 and 9t/ha, but that nearly 5% of the wheat area has a farm average yield of over 10t/ha. Yields of 10t/ha and over from individual fields are therefore common now and likely to increase in future.

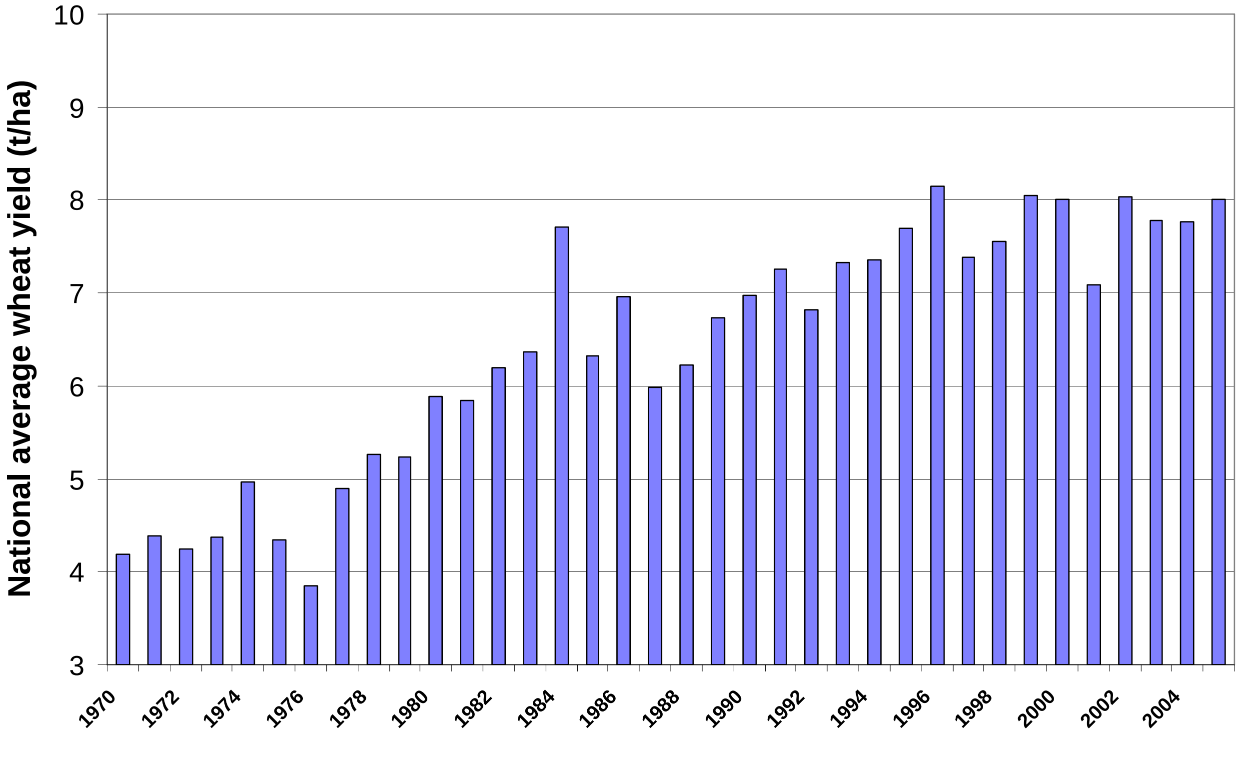

Figure 1. Annual average wheat grain yields in the UK.

Current RB209 recommendations for feed wheat (Defra, 2000) are based on a large number of replicated small plot nitrogen response experiments carried out between 1980-1999. The highest RB209 recommended rate is 240kg/ha N when grown on shallow soils over chalk, where the parent rock is within 40cm of the soil surface. Higher rates are recommended if the grain N concentration of past crops has been below the critical value of 2.0% N in grain dry matter. Where the grain N concentration differs to this critical value, the recommendation may be increased or decreased by 30kg/ha N per 0.1% difference.

These RB209 recommendations also apply to so-called spring wheat varieties that are sown in autumn or early winter.

3.1.2 Research evidence

Over many years, a very large research effort has been dedicated to understanding the nitrogen requirements of winter wheat grown in England, including many studies examining the crop N requirement and the optimum application rate of N for optimum yield. Sylvester-Bradley (1993) reported that winter wheat yielding 8t/ha had a typical crop N uptake at harvest of 175kg/ha N (135kg/ha in grain, 40kg/ha in straw). A similar crop N uptake (181kg/ha N) can be calculated using the critical value of 2.0% grain N that is part of the current RB209 recommendations. This recommendation is based on the results from 271 site years of replicated small plot nitrogen response experiments (ADAS, unpublished). In multi-site studies to characterise and benchmark the growth of wheat, the HGCA (1998) reported a higher value of 244kg/ha N at harvest in grain plus straw. Based on a grain N concentration of 2.0% (in 100% DM) and a Nitrogen Harvest Index of 75%, it can be calculated that the crop N uptake at harvest will change by 23kg/ha per t/ha of grain yield.

Many replicated small plot experiments have been carried out to determine the optimum N rate to winter wheat depending on the field characteristics. Goodlass *et al.,* (1996) reviewed the results of 271 data from experiments carried out between 1981 and 1994. Economic optimum N rates (Nopt) were determined for each site using a linear plus exponential (LEXP) curve fitting function (Sylvester-Bradley *et al,* 1984). Nopt rates for the whole dataset varied from 0 to 377kg/ha N. 18% of experiments had Nopt values above 240kg/ha and 10% were above 300kg/ha N. For winter wheat following winter wheat (i.e. low SNS), the mean Nopt values were higher on shallow soils (231kg/ha N) than on other soil types (160 to 204 kg/ha N). These data were examined by Goodlass *et al.* (2002) using a multiple regression approach to identify the parameters that had most effect on the crop N requirement. A model based on the soil N supply, soil type and over-winter rainfall accounted for 40% of the variation in the Nopt rate. The results of this analysis are central to the current RB209 recommendation system for wheat and the SNS Index system that is used for all tillage crops.

Reviewing the results of 20 replicated small plot nitrogen response experiments on shallow chalk soils (11 winter wheat, 9 winter barley), Grylls *et al.* (1997) found that Nopt rates ranged from 192 up to 301kg/ha N but were mostly in the range 240 to 250kg/ha; optimum crop yields at these rates averaged 6.6 to 6.8t/ha. The high crop N requirement of winter cereals grown on these soil types was attributed to poor recovery of fertiliser N by the crop, and low mineralisation of soil N during the season. Bloom *et al.* (1988) found that the apparent recovery of applied fertiliser N was less than 100% and varied from 43 to 88%. The current RB209 recommendations for winter cereals are based on recoveries of 55% (shallow soils), 60% (other soil types) and 70% (light sand soils).

Dampney (2006) reported the results of 9 replicated small plot experiments (mostly on deep medium/heavy soils) carried out between 2003-2005. Each experiment compared the nitrogen requirement of 2 modern high yielding wheat varieties with 2 older, outclassed and lower yielding varieties. The research showed that the mean fitted Nopt for the modern varieties was 258kg/ha N, which was 29kg/ha higher than the mean RB209 recommendation (229kg/ha N). The mean fitted Nopt for the older varieties was 225kg/ha N which was very close to the RB209 recommendation. For 6 of the 18 response curves (modern varieties only), the Nopt was over 280kg/ha N and for 4 of these it was over 300kg/ha N. These data indicate that the current RB209 recommendations are underestimating the crop N requirements of modern wheat varieties that have a higher yield potential than older varieties. On average, the modern varieties yielded 9.1t/ha compared to 8.1t/ha for the older varieties.

Dampney also showed that there was a statistically significant relationship ($p<0.05$) between the difference in Nopt and Yopt (the yield obtained at Nopt) for each variety compared to the lowest yielding variety at each site. On average, the Nopt increased by 17.3kg/t of yield (Figure 2). It was concluded that the higher crop N requirement of the modern varieties was due to the higher yields that were achieved. Wilson *et al.* (1996) reported the results of 20 field experiments and showed that the fertiliser N requirement could be expressed as 35kg/ha N per t/ha of grain yield, less the soil N supply (as kg/ha).

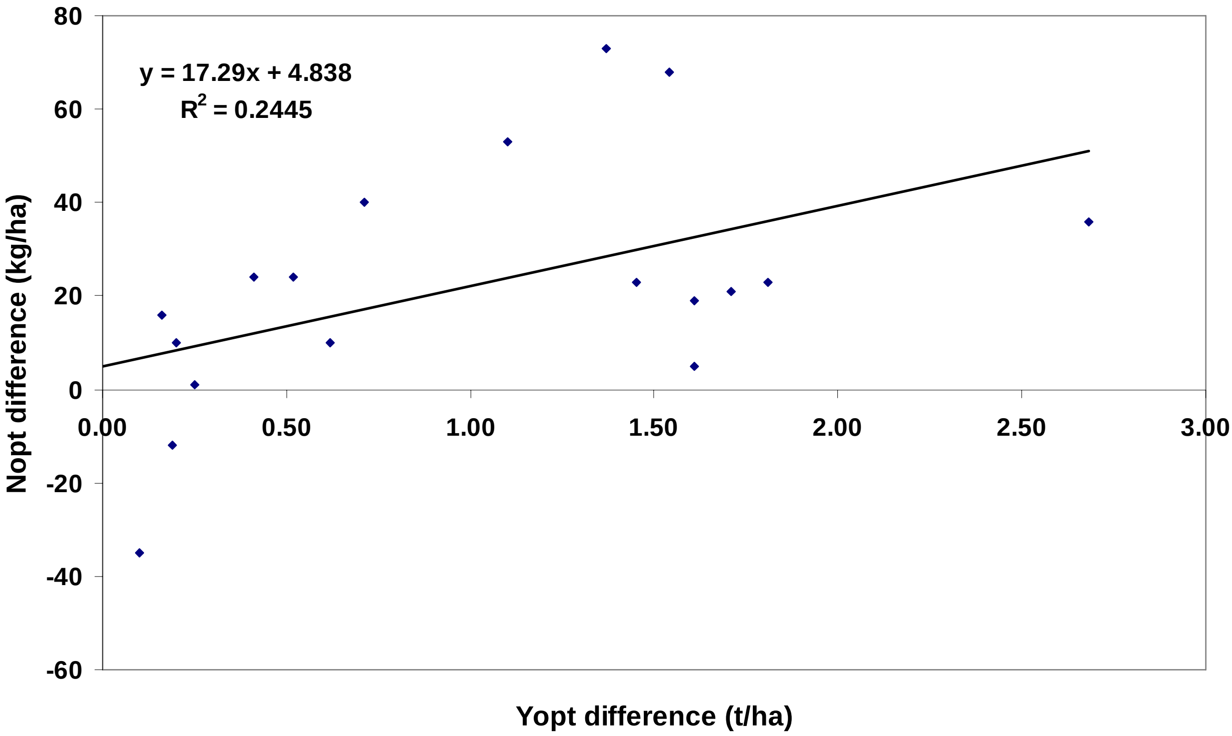

Figure 2. Effect of winter wheat yield on the economic optimum N rate.

In summary:

1. Winter wheat is the dominant arable crop grown in England. Extensive and detailed research has been carried out over many years to determine economic optimum N rates.
2. A typical wheat crop that is correctly fertilised will yield 8.0t/ha and will remove around 180kg/ha N in crop produce. Higher yielding crops will typically remove a further 23kg/ha for each t/ha of grain yield.

3. It has been shown that optimum N rates increase with yield potential. Due to improved varieties, national average yields have increased from 6t/ha in the 1980s to 8t/ha now, and are increasing by about 2% per year. Although achieving the yield potential will not always be possible due to variations in yield-limiting factors such as general crop management and weather, nearly 5% of the national wheat area has a farm average yield of over 10t/ha.
4. The highest recommendation in the current edition of RB209 is 240kg/ha N though this can be adjusted upwards if the grain N concentration of previous crops is below the critical value of 2.0% N.
5. The highest N rates are needed on shallow soils which can grow high yielding crops but which have an inherent poor recovery of applied nitrogen, in addition to low rates of mineralisation of soil N during the season. It is estimated that these soils cover approximately 9% of the arable area of England (ADAS, unpublished).
6. The key factors influencing the N requirement of individual crops are the soil nitrogen supply (SNS), soil type and over-winter rainfall. Research has also shown that applied N is not used with 100% efficiency. Current RB209 recommendations assume that the recovery of applied N by the crop is between 55 to 70% depending on the soil type.
7. The proposed Nmax limit for feed wheat (autumn and early winter sown) is 220kg/ha (+20kg/ha if grown on shallow soils) but with a yield adjustment factor of 20kg/ha N for each t/ha yield above the standard yield (8.0t/ha). This adjustment factor is lower than the extra nitrogen removed by higher yielding crops (23kg/ha for each t/ha of grain yield), and thus reflects the environmental objective.

3.2 Wheat, autumn and early winter sown (milling)

Approximately 30% of the wheat area is sown with a Group 1 or 2 wheat variety (Figure 3) intended for the home or export market where a financial premium for quality may be obtained (HGCA, unpublished). These crops are managed to achieve specified grain quality characteristics, which includes a target for grain protein concentration (usually 13.0% protein in 100% DM for the home market, or 12.5% for the export market). More N is usually needed to achieve optimum yield with the target protein concentration, than is required to achieve optimum yield alone.

Current RB209 nitrogen recommendations for the yield of milling wheat are the same as for feed wheat, except that higher rates are recommended based on a critical value of 2.2% grain Nin dry matter, rather than the 2.0% grain N value appropriate for feed wheat. Where the grain N concentration differs to this critical value, the nitrogen recommendation may be increased or decreased by 30kg/ha N per 0.1% difference.

Where extra N is needed to increase the grain protein concentration, RB209 currently recommends the use of extra N above that need for optimum yield. The specific wording says that '*In some circumstances, application of up to 40kg/ha nitrogen in addition to that given in the table may be economically worthwhile to boost the grain protein concentration.'*

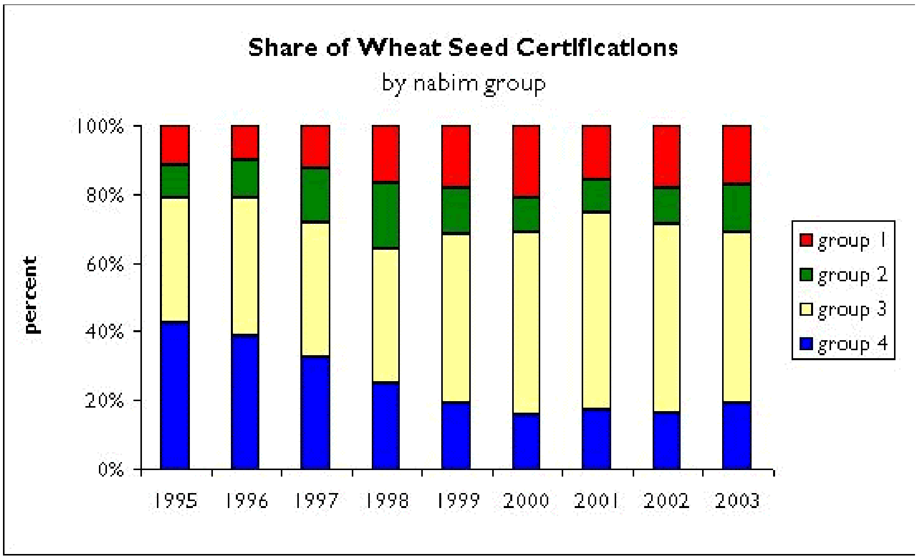

Figure 3. Proportion of nabim[1] wheat variety groups (HGCA)

3.2.1 Research evidence

The crop N requirement of milling wheat grown for both yield and quality can be calculated based on a target of 13% grain protein (2.28% grain N). A typical crop yielding 8t/ha at harvest would contain a total of 207kg/ha N (155kg/ha in the grain, 52kg/ha in the straw). For higher yielding crops, the total crop N uptake at harvest would increase by 26kg/ha per t/ha of yield. This is higher than the proposed yield adjustment factor of 20kg/ha per t/ha of yield.

From examination of small plot nitrogen response experiments, ADAS (unpublished) found that the Nopt rate for milling wheat was typically associated with a grain N concentration of 2.2% N. This is equivalent to 12.5% protein which is less than the typical market requirement. In experiments studying the nitrogen requirements of 16 modern Group 1 and 2 varieties with an average yield of 9.1t/ha, Dampney (2006) found that the grain protein concentration at the Nopt rate averaged 12.8%. In 6 out of 16 cases, more than 280kg/ha N was needed to achieve 13% protein concentration, and in 4 out of 16 cases, over 300kg/ha N was required.

Research has shown that application of extra N above the Nopt rate will consistently increase the protein concentration. Research has shown that extra N applied late in the life cycle of the crop and in addition to the Nopt rate applied for yield, gave consistent increases to the grain protein concentration that also improved the milling and baking quality of the flour (Dampney, 1995). Extra N (40kg/ha) applied as a urea solution to the crop foliage increased the grain protein concentration by 0.66%, or by 0.34% if applied as ammonium nitrate prills (Dampney, 2006).

[1] nabim is the National Association of British and Irish Millers

In summary:

1. Application of the Nopt rate appropriate for feed wheat will not usually be sufficient to achieve the target of 13% grain protein that is required by the milling wheat market. The N rate needed to achieve both optimum yield and a protein concentration of 13% is thus higher than the N rate needed for optimum yield alone.
2. The proposed Nmax limit for milling wheat varieties is the Nmax limit for winter wheat (feed) plus an extra 40kg/ha N.

3.3 Winter barley

The current RB209 (Defra, 2000) recommends up to 200kg/ha N for winter barley grown on shallow soils. There is an upwards trend of the UK average yield which was 6.5t/ha in 2005 (Defra, 2005). As with winter wheat, winter barley is grown on a wide range of soil types, including nitrogen responsive shallow soils that occupy approximately 9% of the arable area in England.

3.3.1 Research evidence

Significant research has been carried out on the nitrogen requirements of winter barley but it is also assumed that the key principles of crop N requirement for yield, the soil N supply and the uptake of the nitrogen by the crop, are similar for winter barley as for winter wheat.

Sylvester-Bradley (1993) reported that the typical crop N uptake at harvest of a winter barley crop yielding 6.0t/ha was 135kg/ha N (100kg/ha in grain, 35kg/ha in straw). This is equivalent to 146kg/ha N for a crop yielding the national average yield of 6.5t/ha. HGCA (2006) concluded that by harvest, a typical crop has taken up a total of 181kg/ha N, based on the benchmark yield of 8.8t/ha. The benchmark grain N concentration was 1.8% N. This is equivalent to a crop N requirement of 20kg/ha N for each t/ha of grain yield (15kg/ha in grain, 5kg/ha in straw), based on a Nitrogen Harvest Index of 75%.

At 9 experimental sites, Grylls *et al.* (1997), studied the response to nitrogen of winter wheat and winter barley grown on shallow soils over chalk. The Nopt rates for winter barley varied from 192 to 301kg/ha N with an average of 245kg/ha; the average yield was 6.8t/ha. Based on the results of 76 replicated small plot experiments on a range of soil types, Grylls and Archer (1984) found that the median Nopt for winter barley was c.15kg/ha higher for crops grown on shallow soils compared to some other soil types.

Richards *et al.* (1996) studied winter barley responses to nitrogen at 7 sites, all on deep sandy or clay soils (no shallow soils). The fitted Nopt rates ranged up to 189kg/ha N with a mean of 142kg/ha.

Lord and Vaughn (1987) summarised the results from 85 field experiments on feed winter barley. In one series of 36 experiments on feed winter barley, they concluded that the mean Nopt rate was over 180kg/ha N for crops that did not lodged, and 140kg/ha where lodging did occur. In a second series of 49 experiments, the mean Nopt rate was over 200kg/ha N for crops that did not lodged, and 110kg/ha where lodging did occur.

In summary:

1. A typical winter barley crop that is correctly fertilised will yield 6.5t/ha and will remove around 146kg/ha N in crop produce. Higher yielding crops will typically remove a further 20kg/ha for each t/ha of grain yield.
2. As for winter wheat, the economic Nopt for winter barley has been found to be higher for crops grown on shallow soils than on any other mineral soils. It is estimated that these soils cover approximately 9% of the arable area of England (ADAS, unpublished).
3. The proposed Nmax limit for winter barley is 180kg/ha (+20kg/ha if grown on shallow soils) but with a yield adjustment factor of 20kg/ha N for each t/ha yield above the standard yield (6.5t/ha). This is the same as the quantity of extra nitrogen removed by higher yielding crops (20kg/ha for each t/ha of grain yield), and is thus nitrogen-neutral.

3.4 Spring-sown wheat

When considering the nitrogen requirements of spring wheatt varieties sown in late autumn/early winter need to be distinguished from those sown in the spring. Spring wheat varieties have no vernalisation requirement (a cold period to initiate normal development), so they may be sown before, during or after the winter period. This will influence the yield expectation and thus the crop N requirement. In practice, most spring wheat is now sown in late autumn and overlaps with late autumn-sown winter wheat in terms of sowing date and performance. In the national recommended list for cereals and oilseeds (HGCA, 2006), late autumn-sown spring wheat varieties are described as yielding between 6 and 14% below winter wheat varieties sown at the same time. Most spring wheat is grown for the milling wheat market with market requirements for grain quality as have been described for winter wheat (milling).

Current RB209 recommendations (Defra, 2000) are the same for winter wheat as for autumn and early winter-sown spring wheat. This reflects the similar crop N requirements of these crops. For spring-sown wheat, the current maximum RB209 recommendation is 160kg/ha N (grown for feed) and 200kg/ha (grown for milling). Spring-sown wheat is grown on a wide range of soil types, including nitrogen responsive shallow soils.

3.4.1 Research evidence

Sylvester-Bradley (1993) reported that the typical crop N uptake at harvest of spring wheat (feed) yielding 6.0t/ha was 130kg/ha N (100kg/ha in grain, 30kg/ha in straw). This is equivalent to 158kg/ha N for a crop yielding the national average yield of 7.3t/ha.

The nitrogen requirements of spring wheat were studied at 14 sites between 1989-1991 on a range of soil types and sowing dates between October and March (Webb *et al.* 1995). Although grain yields were lower from the later sowing dates, there was no change in the Nopt rate due to the delayed sowing. This was found to be due to a decrease in the recovery of fertiliser N by the crop where sowing was delayed. The mean Nopt for all sites and sowing dates was 175kg/ha N, and the mean optimum yield was 6.3t/ha. Webb *et al. a*lso reported a strong relationship between Nopt and the yield increase due to nitrogen application – the rate of increase in Nopt was c.30kg/ha for very 1t/ha of yield increase.

Webb and Sylvester-Bradley (1995) reported results from 8 experiments where the nitrogen requirements of a winter wheat variety was compared with that of a spring wheat variety, both sown in late autumn (November). Overall there was no consistent difference in the Nopt rate (mean 172kg/ha N) or the optimum yield achieved (6.9t/ha).

In summary:

1. A typical crop of spring-sown wheat will have a total crop N uptake at harvest of 158kg/ha N, based on the national average yield of 7.3/ha.
2. Current RB209 recommendations for spring-sown wheat are closely related to those for winter wheat, but allow for a slightly lower yield output and poorer efficiency of use of applied nitrogen due to the later sowing date.
3. The proposed Nmax limit for spring-sown wheat (feed) is 180kg/ha but with a yield adjustment factor of 20kg/ha N for each t/ha yield above the standard yield (7.0t/ha). Up to an extra 40kg/ha N is allowed if a milling variety is being grown.

3.5 Spring barley

The current RB209 (Defra, 2000) recommends up to 150kg/ha N for spring barley. There is an upwards trend of the UK average yield which was 5.5t/ha in 2005 (Defra, 2005). Spring barley is grown on a wide range of soil types, including nitrogen responsive shallow soils. However, due to the lack of scientific evidence, there is no separate RB209 recommendation for spring barley grown on shallow soils. Although lodging has been a significant limitation on achieving high crop yields, the use of improved varieties and plant growth regulators now means that lodging is rare.

3.5.1 Research evidence

Sylvester-Bradley (1993) reported that the typical crop N uptake at harvest of spring barley yielding 5.0t/ha is 115kg/ha N (85kg/ha in grain, 30kg/ha in straw). This is equivalent to 127kg/ha N for a crop yielding the national average yield of 5.5t/ha.

In results from 51 small plot replicated field experiments carried out between 1981-84 (ADAS, unpublished), Nopt rates ranged from 59 to over 240kg/ha N. Optimum crop yields were up to 8.0t/ha (median 5.7t/ha). At some sites, crop lodging occured which reduced crop yield and the Nopt rate. Nopt rates were found to vary widely and were highly dependent on the yield response to N. Where drought conditions occurred, this resulted in the optimum yield and Nopt rate being highest on moisture retentive shallow soils over chalk and lowest on sandy soils. At sites where there was no crop lodging, the median value of Nopt was 149kg/ha N (119kg/ha N where lodging occurred). Overthrow (2005), reporting results from 5 field experiments, also concluded that Nopt rates were around 150kg/ha N for a mean yield of c.7.0t/ha.

Johnson (1984) reviewed the results of a large number of field experiments on a range of soil types, including shallow soils over limestone. He concluded that responses on non-sandy mineral soils at a low level of soil nitrogen supply ranged from 100kg/ha N to over 180kg/ha N. Experiments on shallow soils over limestone showed an Nopt of at least 140kg/ha N.

In summary:

1. A typical crop of spring barley will have a total crop N uptake at harvest of 127kg/ha N, based on the national average yield of 5.5/ha.
2. The proposed Nmax limit for spring barley is 150kg/ha but with a yield adjustment factor of 20kg/ha N for each t/ha yield above the standard yield (5.5t/ha).

3.6 Winter oilseed rape

The current RB209 (Defra, 2000) recommends up to 30kg/ha N applied in the 'seedbed', and up to a further 220kg/ha applied in the spring. These recommendations are based on a standard yield of 3.5t/ha of seed. Where previous experience indicates that yields of 4t/ha and over can realistically be achieved, the recommended rate of spring applied nitrogen may be increased by up to 30kg/ha. The UK average yield of oilseed rape is 3.2t/ha (Defra, 2005).

3.6.1 Research evidence

Sylvester-Bradley (1993) reported that the typical crop N uptake at harvest of a winter oilseed rape crop yielding 3.2t/ha was 260kg/ha N (105kg/ha in seed, 155kg/ha in straw).

The response of winter oilseed rape to seedbed (autumn) and spring nitrogen was studied at 27 replicated small plot field experiments between 1988 and 1990 (ADAS, unpublished). All experiments were located on medium or heavy soils following a previous cereal crop (i.e. a low soil N supply). There were no sites located on shallow soils. Nopt rates were calculated from fitted response curves using a linear plus exponential curve fitting function (Sylvester-Bradley *et al,* 1984). The average Nopt rate was 191kg/ha in the absence of seedbed N, or 180kg/ha where 30kg/ha of seedbed N was applied. The average seed yield was 3.3t/ha and a linear relationship was found between the optimum yield and the Nopt rate. Holmes and Ainsley (1979) also found that N optima rose by 50kg /ha N per tonne of yield. The relationship between Nopt and seed yield is very relevant to the setting of Nmax rates as UK yields are expected to rise by about 0.1t/ha per year due to new higher-yielding varieties and improved crop management practices (Spink and Berry, 2004).

Winter oilseed rape is a common break crop grown on nitrogen responsive shallow soils. There is no separate recommendation for shallow soils in RB209 due to the lack of experimental evidence. However, understanding developed from research on winter wheat (see section 3.1) would suggest that a higher Nopt rate might be appropriate for oilseed rape grown on shallow soils than on other mineral soil types.

Chalmers *et al.* also found unique yield increases from seedbed N where the stubble or straw from the preceding cereal crop was incorporated into the soil. These responses can be explained by the large uptake of N into the crop during this period – Archer (1985) reported uptake of up to 80kg/ha N before the onset of winter. The yield responses from seedbed N could not be achieved from increased use of spring N.

In summary:

1. A typical crop of winter oilseed rape will have a total crop N uptake at harvest of 260kg/ha N, based on the national average yield of 3.2/ha. Of this, 105kg/ha will usually be removed as seed.

2. The proposed Nmax limit for winter oilseed rape is 30kg/ha N in the autumn plus 220kg/ha in the spring for a standard yield of 3.5t/ha. The spring rate may be increased to 250kg/ha N if the justifiable expected yield is over 4.0t/ha.

3.7 Forage maize

The current RB209 (Defra, 2000) recommends up to 120kg/ha N for forage maize where organic manures are *not* applied for the crop. Although organic manures are commonly applied before drilling maize, this is not always the case. The Nmax limit must therefore allow for the practical circumstance where forage maize is grown in the absence of any application of organic manures.

3.7.1 Research evidence

Dilz *et al.* (1994) and Schroder *et al.* (1993) have shown that forage maize yielding 11t/ha of dry matter is associated with an offtake of around 120-130kg/ha N. Typical yields of forage maize DM in England are around 12t/ha.

Most nitrogen response experiments have been carried out in situations of high soil N supply due to past applications of organic manures. These data are not summarised here. This has resulted in only limited information on the optimum nitrogen requirements of maize at low levels of SNS where organic manures have not been applied. Froment (1998) reported an Nopt of 148kg/ha N from a single trial but on a potentially responsive shallow chalk soil.

3.8 Potatoes

Current RB209 recommendations (Defra, 2000) for potatoes are based on the length of the growing season and the variety group. Different varieties have different inherent characteristics of 'haulm longevity' (i.e. the growth period of green leaves and stems). Varieties with a long haulm longevity tend to be vigorous and have a lower nitrogen requirement (e.g. Cara); those with a short haulm longevity need more N to maximise crop yields. Potatoes are also grown for different markets (e.g. earlies, second earlies, maincrop). This influences the planned length of the growing season, expected crop yield and thus the nitrogen requirement.

The current RB209 maximum N rate is 270kg/ha N for short haulm varieties grown for 90-120days. The average national yield is 45t/ha of potato tubers (Defra, 2005).

3.8.1 Research evidence

Sylvester-Bradley (1993) reported that the typical crop nitrogen uptake at harvest of maincrop potatoes yielding 40t/ha was 200kg/ha N (100kg/ha in tubers, 100kg/ha in haulm). This is equivalent to 225kg/ha N for a crop yielding the national average yield of 45t/ha.

Several authors have reported that potatoes can respond up to 250-300kg/ha N.

- Johnson *et al.* (1992) investigated the nitrogen requirements of the indeterminate (vigorous) variety Cara at 11 field experimental sites on sand and peat soils. Replicated small plot trials. Nopt rates varied from 0 to 320kg/ha N.

- Goodlass and Johnson (1997) reported the results of 23 small plot replicated field experiments carried out between 1987-1993, examining the effect of nitrogen on tuber size. Production of large tubers can provide a premium for farmers. Nopt rates were reported that varied depending on the tuber size required by the market (230kg/ha N for 45-85mm tubers; 112kg/ha N for 45-65mm tubers; 292kg/ha N for 65-86mm tubers).
- Neeteson and Wadham (1987) analysed 99 potato response experiments and found that in nearly two-thirds of cases the 95% confidence interval for the Nopt rate was more than 300kg/ha N.
- Bailey *et al.* (1992) reported results from nitrogen response experiments on irrigated sandland in 1990 and 1991. The results showed that applications below 250kg/ha were sometimes associated with a yield loss.
- Allison and Allen (2004) reported the results of field experiments carried out between 2001-2003. Nopt rates were not based on fitted curves but were defined as the smallest rate of N application above which there was no significant difference in tuber yield. On this basis Nopt rates did not exceed 200kg/ha N.

3.9 Sugar beet

The current RB209 (Defra, 2000) recommends up to 120kg/ha N. The average yield in the UK is 57.3t/ha of roots, adjusted (Defra, 2005).

3.9.1 Research evidence

Jaggard *et al.* (1995) reported that the typical removal of nitrogen at harvest of sugar beet yielding 50t/ha was 200kg/ha N (70kg/ha in roots, 130kg/ha in tops and crowns). This is equivalent to 228kg/ha N for a crop yielding the national average yield of 57t/ha.

Allison (1996) reported results of 34 replicated small plot field experiments carried out on a range of soil types between 1986 and 1988. The average yield was 53t/ha of clean beet with an overall mean Nopt of 97kg/ha N (range from 0 to 158kg/ha). Further field studies at 7 sites between 2000-2001 showed Nopt rates of up to 120kg/ha (Malnou *et al.,* in press).

4. Grass

The current RB209 (Defra, 2000) bases recommended N rates for intensively managed grassland on the soil nitrogen supply (SNS) status, Grass Growth Class (GGC) and grass management (grazed or cut grass). The maximum total annual recommendations are summarised in Table 2.

Table 2. RB209 annual nitrogen recommendations for grassland (Defra, 2000)

	SNS Status		
	Low	Moderate	High
Grazing – dairy cattle			
Average GGC	380	340	300
Good GGC	420	380	340
Very Good GGC	460	420	380
Grazing – other livestock			
Average GGC	330	290	250
Good GGC	370	330	290
Very Good GGC	410	370	330
All cut	420	380	340

Table 3. Definition of Grass Growth Classes

Soil available water	Soil types	Rainfall (April to September inclusive)		
		up to 300 mm	300 – 400 mm	over 400 mm
Low	Light sand soils and shallow soils (not over chalk)	Very poor	Poor	Average
Medium	Medium soils, deep clay soils, and shallow soils over chalk	Poor	Average	Good
High	Deep silty soils, peaty soils and soils with groundwater (e.g. river meadows)	Average	Good	Very Good

- Mean summer rainfall (April to September) is usually about half of annual rainfall.
- For sites above 300m altitude, reduce the growth class by one. This is because lower temperatures will restrict growth.

For grazed grass, the RB209 recommendations are based on the GGC and SNS status, but in addition allow for 40kg/ha per year of recycled N during grazing. The scientific evidence for this allowance is given in 4.1.1 below. The GGC is based on soil type, summer rainfall and altitude (see Table 3). Yields for the Average GGC are given as typically around 10-11t/ha DM for grazed grass, or 13-14t/ha as silage (4 cuts). Figure 4 shows the distribution of GGCs within the revised NVZs boundaries in England and Wales (ADAS, unpublished). The proportions of the grassland area in each GGC are Very Good (5%), Good (20%), Average (57%), Poor (16%) and Very Poor (1%).

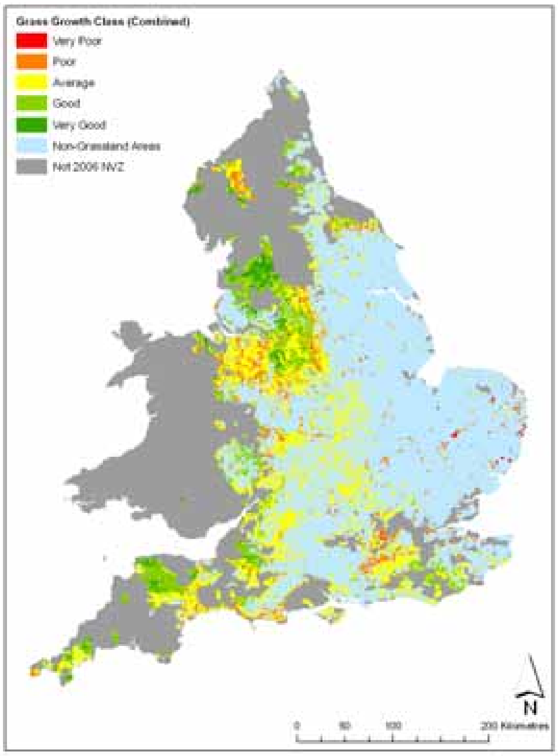

Figure 4. Revised NVZ boundaries and distribution of Grass Growth Classes in England and Wales, based on km grid squares with over 50% of agricultural land as grassland (ADAS, unpublished)

Current RB209 recommendations for dairy grazing are 340kg/ha N (Very Poor, Poor or Average GGC), 380kg/ha N (Good GGC) and 420kg/ha N (Very Good GGC) per year at a Moderate SNS. Most established grassland is at a Moderate or High SNS status.

4.1.1 Research evidence

Grassland can produce very high yields of dry matter. Thomas *et al.* (1991) summarised much research data and reported that potential yields of grass dry matter (DM) depended on the likelihood of water shortage occurring during the summer. The soil type and summer rainfall of the grassland was therefore used to develop the Grass Growth Class scheme that is an important part of current RB209 recommendations. They reported that potential annual DM yields of up to 16.0t/ha of conserved grass (silage or hay) could be achieved in 8 out of 10 years following optimal use of nitrogen on Very Good GGC grassland, but only 12.6t/ha on grassland of Very Poor GGC (Table 5). Amounts consumed by livestock will be lower than these values due to losses under grazing or during the conservation process.

Table 4. Probable yields of grass dry matter (t/ha) in different Grass Growth Classes.

	Conserved (t/ha DM)	Grazed (t/ha DM)
Very Good	16.0	14.3
Good	15.4	12.8
Average	14.3	11.4
Poor	13.4	10.5
Very Poor	12.6	9.6

High yields of grass DM are reflected in a potentially high crop N requirement. Under a 4 week cutting system on reseeded swards, Hopkins *et al.* (1990) reported a mean crop N uptake at harvest of 295kg/ha N following application of 300kg/ha N, and 367kg/ha N uptake from 450kg/ha N. ADAS (unpublished) showed that the maximum crop N uptake of established swards was in the range 300-400kg/ha N. These values can be considered typical of an Average GGC and would be higher for the higher DM yields likely to be achieved in Good and Very good GGCs.

In studies with intensively cut grass where the SNS was low following arable cropping, Morrison *et al.* (1980) reported a mean Nopt of 388kg/ha per year, giving a mean DM yield of 10.9t/ha. There was a strong relationship between Nopt and yield. Hopkins *et al.* (1990) reported results from 16 experimental sites comparing the response to nitrogen of permanent grass and reseeded ryegrass swards. Under a 4 week cutting interval, reseeded swards gave higher optimum yields (mean 11.1t/ha DM) than the permanent swards (mean 8.8t/ha DM). Nopt rates were correspondingly higher for the reseeded swards (mean 363kg/ha N) than the permanent swards (mean 281kg/ha N). These data confirm the relatively high potential yields and crop N requirement of reseeded grass swards compared to established grassland.

ADAS (unpublished) summarised the results of 133 replicated small plot field experiments on cut grass carried out between 1970 and 1986. The mean Nopt rate was higher (452kg/ha N) in the first year following reseeding, than for established grassland (357kg/ha N). The mean optimum yield was 12.4t/ha DM. There was a significant relationship (r^2=63.5%) between the DM yield increase due to nitrogen and the Nopt, mainly influenced by the optimum yield. This illustrates that optimum N rates will be higher on grassland in the better GGCs where potential yields are higher.

Nitrogen recycling under grazing systems is a crucially important process though allowing for this source of potentially crop available N is complicated by losses of nitrogen due to ammonia volatilisation, and the uneven distribution of excreta across the grazed area. Research at 5 sites comparing the nitrogen response of grassland under grazing and cutting management was reported by Baker (unpublished). Mean Nopt rates were 344kg/ha N under cutting and 276kg/ha N under grazing. Current RB209 recommendations for grazed grass allow for 40kg/ha N per year of crop available N from animal excreta directly deposited by grazing animals.

The proposed Nmax limit for grassland is 360kg/ha per year – this reduces to 330kg/ha in 2012 to allow time for farmers to modify their manure handling systems and overall nitrogen management in order to comply with the new requirements. The Nmax limit may be increased by 40kg/ha N for grassland that is cut only throughout the season, or for grassland that is in a Very Good Grass Growth Class. The Nmax limit is calculated as the average nitrogen application rate across the whole area of managed grassland on the farm, excluding rough grazing.

5. Exemptions from the closed spreading period for manufactured nitrogen fertilisers

The revised NVZ Action Programme rules include a closed spreading period for manufactured nitrogen fertilisers from 15 September to 31 January (fields in grass), or 1 September to 31 January (fields not in grass), unless there is a justifiable crop N requirement during the closed period. Any fertiliser nitrogen applied during the closed period must not result in the total rate of applied N (crop available N from manures plus fertiliser N) being greater than the Nmax limit.

The following crops may have a justifiable crop N requirement during the closed spreading period. Therefore, applications of manufactured fertiliser N are allowed during the closed period for these crop types, up to the maximum total N rate shown.

Crop	Maximum total N rate (kg/ha)	Evidence and justification
Winter oilseed rape	30	Research evidence (see 3.6).
Grazed grass	80	Application in September to October as part of late season extended grazing management to maximise duration of the grazing period. IGER (2005) have shown that extended grazing gives good production levels but with nitrate leaching losses that may be of concern. Losses of ammonia may be less relative to conventional systems which would be an important benefit.
Asparagus	50	Recommended for third and subsequent years with application potentially at start of the closed period (early September).
Broccoli, purple sprouting broccoli	100	Nitrogen may be needed in order to meet the colour quality specifications of the market. The requirement is comparable to that recommended for over-wintered cauliflowers (HDC 1999, HDC 2002).
Cabbage, over-wintered spring	100	Nitrogen may need to be applied in order to meet the colour quality specifications of the market.
Cauliflowers, winter hardy/Roscoff	100	Needed to meet quality specifications of the market Research evidence from HDC (1999 and 2002).
Leeks	40	Nitrogen may need to be applied in order to meet the colour quality specifications of the market.
Onions, bulb	40	Nitrogen may need to be applied in order to meet the colour quality specifications of the market.
Onions, over-wintered salad	40	Nitrogen may need to be applied in order to meet the colour quality specifications of the market.
Parsley	40	Nitrogen may need to be applied in order to meet the colour quality specifications of the market.

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