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Research needs on nitrogen and phosphate management in cereals and oilseeds

by

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Abstract

The HGCA has funded an agronomic R&D programme for some twenty years. Emphasis has been on research that could lead to improved farming practices in the short or medium term together with knowledge transfer to growers. A review of the programme on nitrogen and phosphorus and how it has related to Defra, SEERAD, BBSRC and commercial R&D has been conducted, and further R&D requirements identified, to add definition to the HGCA R&D Strategy 2007-10 introduced in January 2007.

There has been a significant HGCA-funded programme on nitrogen, concentrating on aspects that influence yield, grain quality and costs of production. This has complemented Defra and SEERAD research that has been devoted largely to environmental issues. Major HGCA-funded developments include canopy management in wheat and oilseed rape, evaluation of late application of nitrogen in breadmaking wheat, assessment of nitrogen requirement of barley for lager production and early prediction of grain quality in wheat. Defra and SEERAD research has covered losses of nitrogen from soil to water through nitrate leaching and from soil to air through denitrification (nitrous oxide) and volatilisation (ammonia).

There has been much less HGCA-funded research on phosphorus, reflecting the smaller perceived importance of this nutrient in crop production. The emphasis has been on methods for measuring or predicting the phosphorus status of individual crops. Defra on the other hand has funded a large programme on the main environmental issue associated with phosphorus, loss from soil to surface waters. Routes for loss have been identified and, for some situations, quantified.

Findings from HGCA-funded research have been communicated to growers and their advisers through workshops, conferences, roadshows, Topic Sheets and other publications.

Priority needs for further research or knowledge transfer were identified through meetings and discussions with those involved in cereals/oilseed rape R&D. Meetings were held with Rothamsted Research, ADAS, TAG, Reading University, Velcourt and AIC. In addition, views were sought from SAC and CCFRA. Many research or knowledge transfer requirements were proposed and, from these, seven were selected as generally considered important, relevant to growers and potentially suitable for HGCA funding. These seven requirements are listed below, not in general priority order though the first item has the widest importance:

1. Three aspects of soil nitrogen supply need attention:

   i. The different methods for quantifying soil nitrogen supply, by estimation, measurement or both, need to be validated and compared. The relative contributions of soil mineral nitrogen, nitrogen mineralised during spring and nitrogen taken up by the crop over winter need to be clarified. Guidance then is needed on the choice of method for different circumstances taking account of cost and the degree of accuracy to be expected.
      - There will be a need for field research, supported by desk study. Guidance for growers will then be needed.

ii. A method is needed for monitoring or modelling seasonal effects on soil nitrogen supply and for providing timely guidance on their impact on fertilizer recommendations.
    - This is likely to involve collection of climatic and soil data for the period September to March each year with subsequent interpretation and dissemination to growers/advisers via web site or email.

iii. The extent to which soil nitrogen is utilised by crops affects nitrogen use efficiency and is a key component of many recommendation systems. Factors that affect the utilisation of soil nitrogen should be identified with a view to improving nitrogen use efficiency. The assumption that soil mineral nitrogen is recovered by the crop with 100% efficiency (with around 60% as the corresponding figure for applied inorganic nitrogen) needs validation for different agronomic conditions for both cereals and oilseed rape.
    - Progress could be made using existing data and models such as SUNDIAL. However, additional field research also is likely to be required.

2. The need for current protein specifications for breadmaking wheat (usually minimum 13%) should be reviewed. Developments in varieties, in breadmaking techniques or in market requirements might allow the use of lower protein grain and smaller nitrogen applications.
- Initial action needed will be discussions with the baking industry on the potential opportunities for process changes.

3. Improving the nitrogen economy of oilseed rape will become more pressing if, as expected, a significant market for biodiesel develops. Methods for improving nitrogen use efficiency by oilseed rape, such as delayed or additional late nitrogen applications need evaluating. Possible interactions between nitrogen timing, green area index (GAI) development and variety in their effects on yield and optimum nitrogen rate need to be identified.
- Further field research supported by desk study would be needed. Subsequently, grower guidance would be necessary.

4. The biological basis for grain protein concentration as a retrospective indicator of nitrogen supply needs to be established. Any other practical indicators need to be identified for both cereals and oilseed rape. Once methods are established, guidance for growers in their use is needed.
- Progress could be made using existing data. It is unlikely that new field research would be necessary.

5. Guidance is needed on the relative benefits of standard values and chemical analysis in estimating the nitrogen and phosphorus concentrations in livestock manures. Where analysis is preferred, guidance also is needed on sampling methods and on the interpretation of analytical reports. Actions in this area need to be co-ordinated with developments in MANNER software.
- The need here is for clear guidance based on existing data. There should be no need for new field research.

6. The genetic potential of crops for improved nitrogen uptake and utilisation should be better exploited. More routinely gathered information is needed on nitrogen use

efficiency in different crop varieties. Variety testing for Recommended Lists should include field trials at more than one rate of applied nitrogen to provide relevant data.

- An amendment to the current protocol for RL testing would be needed to include a number of field trials at more than one rate of applied nitrogen. Initially, this might be applied to winter wheat and winter oilseed rape.

7. The basis for phosphorus recommendations in England and Wales is the soil P index. In the current edition of RB209, index 2 is set as the target for arable crops but it is not clear that this index is most appropriate for all soil and crop conditions. Critical soil phosphorus concentrations to meet economic and environmental objectives need to be identified for a range of soils. Conditions that affect the critical concentration need to be identified.

- New field research would be required but this would be routine in nature with a low risk of not obtaining necessary data.

8. Growers need greater awareness of the environmental issues associated with phosphorus and of the ways in which phosphorus can move from soils to water. Clear guidance is needed on identification of high-risk fields and farming practices and on practical mitigation methods.

- No field research would be needed. The requirement is for clear guidance based on existing data.

1. Introduction

The HGCA has conducted an extensive agronomic R&D programme on cereals and oilseed rape since the mid-1980s. Emphasis has been on research that could lead to improved farm practices in the short to medium term. Crop nutrient research within this programme has concentrated on nitrogen, sulphur and phosphorus covering mainly production aspects (Appendices 1 and 2). This has complemented research funded by Defra and SEERAD where, in recent years, the emphasis has been on environmental issues.

Nitrogen and phosphorus have been identified as priority areas in the HGCA R&D Strategy 2007-10. Consequently, there was a need to review completed and current research and to identify any areas where additional information or knowledge transfer was required. This review is particularly relevant in the light of two current developments – the replacement of Defra *RB209 Fertiliser Recommendations* and the review of NVZ Action Programmes – both of which should be completed in or by 2008.

For both nitrogen and phosphorus, the grower must decide the amount and form to apply and the timing of applications to a particular crop, taking into account other sources of nutrients and any specific market requirements. At the same time, growers must comply with statutory requirements in NVZs and for Cross Compliance and with management options within Environmental Stewardship. As controls on nitrogen and phosphorus applications may be increased in future, growers should be aware of relevant environmental issues and prepared for their possible impact on farm operations.

2. Approach and information sources

HGCA research is funded largely by growers so it seemed appropriate to begin with their needs in respect to nitrogen and phosphorus and then to assess to what extent existing science meets these needs. Where existing science is adequate, there may be a need for improved knowledge transfer. Where the science is inadequate, there may be a case for HGCA research funding. Research funded by HGCA is reported in Research Reviews, in final or annual Project Reports, and in Topic Sheets or Project Progress summaries intended for growers. Lists of those relevant to nitrogen and phosphorus are in Appendices 1 and 2 respectively. The main findings of Defra funded research were summarised in the report of Project ES0127 available at www.defra.gov.uk (Defra 2006). Lists of relevant Defra projects (reports for some of which also are available at www.defra.gov.uk) are in Appendices 3, 4 and 5.

BBSRC spends approximately twice as much as Defra on plant and crop science but currently funds very little, if any, research on nitrogen and phosphorus as crop nutrients. The recent review of BBSRC-funded research (BBSRC 2004) does not mention nitrogen or phosphorus and contains only one minor reference to crop nutrition.

SEERAD fund research at the Scottish Crop Research Institute, SAC and MLURI. A review of strategy was published recently (Scottish Executive 2005). Current research relevant to nitrogen and phosphorus is limited and largely incorporated in projects on organic farming, legume agronomy, application of sewage sludge and climate change

(Scottish Executive 2006a, 2006b, 2006c). SEERAD are involved as part-funders of LINK projects, for example the current 'GREEN grain' project in which HGCA also is involved.

A significant amount of crop nutrient research has been conducted by commercial organisations and this is referred to where appropriate.

An entirely grower-oriented approach may miss some longer-term issues that are evident to researchers or policy makers but are less so to farmers. For these issues, identified separately, a collaborative effort of several funding agencies, including HGCA, may be appropriate.

The review of existing research was the basis for discussions with organisations involved in crop research. Meetings were held with ADAS, Rothamsted Research, The Arable Group, Reading University, Velcourt and AIC to identify areas where further research or knowledge transfer were needed. Views also were provided by SAC and by CCFRA.

3. Nitrogen

3.1 Background

In Great Britain, 2004/2005, around 447,000 t N were applied in fertilizers to wheat and barley and around 104,000 t to oilseed rape (BSFP 2006). The total purchase cost to growers was some £250 million.

Virtually all cereal and oilseed rape crops receive fertilizer nitrogen and the rates applied have increased somewhat since 1998 (Table 1).

Table 1. Application of fertilizer nitrogen in Great Britain (BSFP 2006).

	Crop area receiving N (%)		Average field rate (kg N/ha)		Overall rate (kg N/ha)	
	1998	2005	1998	2005	1998	2005
Winter wheat	99	99	183	197	182	195
Winter barley	99	98	136	144	135	142
Spring barley	97	97	95	105	92	102
Oats	96	92	100	106	96	97
Winter oilseed rape	100	99	204	206	203	205
Spring oilseed rape	99	98	115	153	114	150

Statutory controls on nitrogen applications exist in NVZs but not elsewhere. The main NVZ controls on fertilizer nitrogen are closed periods but manures are limited in the rate that can be applied. The NVZ Action Programmes in England and in Scotland are under review currently and changes are likely to be finalised during 2007.

3.2 Amount of nitrogen to apply for yield

Nitrogen supply is a strong determinant of crop yield. In round terms, application of nitrogen at the economically optimum rate doubles yield of the crop (when compared to a crop receiving no applied nitrogen). Owing to the diminishing returns type relationship between yield and nitrogen supply, application of half the optimum nitrogen rate reduces yield by around 10%. Such a yield reduction is not visible even where it occurs in adjacent experimental plots. Growers will not be aware therefore whether or not their applications of nitrogen are really optimal for their particular crops.

3.2.1 Recommendation systems (additional information in Appendix 6)

There are two main methods for deciding the amount of nitrogen to apply for yield:

i. Difference method where estimates are made of crop total nitrogen requirement and of the nitrogen contribution from non-applied sources (mineralization of soil organic nitrogen, deposition, recent crop residues). The amount to be applied is the difference between total requirement and the sum of these other contributions. This process of estimation may be explicit or, more usually, components may be hidden within standard tables (as in RB209) or in models (as in SUNDIAL). Manures can be regarded as applied nitrogen sources (perhaps this is preferable if they are to be valued alongside fertilizers) or as one of the 'non-applied' sources.

ii. Crop measurement method where non-destructive measurements are made on the crop at, or immediately before, application time to estimate nitrogen status. The amount of nitrogen to be applied is then taken from tables that in turn derive from empirical field experimentation. This method is less common but is used, for example, in canopy management and in the tractor-mounted Yara N-Sensor.

Optimum nitrogen rates estimated by both of these methods are subject to inevitable errors due to uncertainties in nitrogen supply from non-fertilizer sources (in the case of the difference method) and to unforeseeable weather effects between application and harvest (in both methods).

Several mathematical models have been developed to incorporate principles of crop nitrogen nutrition and to provide fertilizer recommendations. For cereals and oilseed rape, these include SUNDIAL developed at Rothamsted and N Plan originally developed by Fisons and now operated by Yara. SUNDIAL is a dynamic model to which current season data can be entered as they become available and N Plan is a static model that is run before nitrogen application. SUNDIAL was incorporated with WELL_N™ from Warwick HRI in Nitrogen-FRS (Project Report No. 258, 2001).

SUNDIAL was evaluated by a limited number of users and brought to an adequate stage of development several years ago. Some technical updating and a means of user support are needed if the investment already made in SUNDIAL is to be exploited.

Various recommendation systems have been compared in field experiments where the optimum nitrogen rate was measured (though these measurements also are subject to significant errors). If this exercise were done on a wide scale, it seems unlikely that any method would provide estimates of the optimum rate that were within 20% of the measured value on at least 80% of occasions. The unavoidable errors attached to any fertilizer recommendation, including those in RB209 and in SAC guidelines, often are not appreciated. Nevertheless, using a recognised recommendation system is likely to optimise crop performance when done consistently over a number of fields and years (Project Report No. 258, 2001).

Many nitrogen recommendation systems, including RB209, incorporate assumed values for fertilizer cost and grain price and do not allow the user to vary these. This can be a problem where recommendations systems remain in use without change for several years. Growers either need access to systems where these values can be varied or greater guidance on how to adjust recommendations.

3.2.2 Soil nitrogen supply

Soil nitrogen supply (SNS) is the total supply of nitrogen to the crop from all sources other than fertilizers and manures applied for the current crop. SNS is a component of many nitrogen recommendation systems. Although simple in concept, SNS presents problems in reliable estimation. In late winter, SNS largely comprises soil mineral nitrogen (that can be estimated or measured subject to inevitable sampling errors), nitrogen already taken up by an autumn-sown crop (that can be estimated) and nitrogen becoming available through mineralization in spring (that can be estimated but often is ignored).

Estimates of SNS in RB209 are derived from soil type, previous cropping and winter rainfall and are used to identify an index that identifies the appropriate recommendation. These estimates and the index boundaries will be reviewed during the preparation of a successor to RB209 in 2007/8.

Alternatively, soil mineral nitrogen can be measured to quantify one major component of SNS (Research Review No. 58, 2006). A significant benefit from adjusting nitrogen application by measuring soil mineral nitrogen was found in spring barley (Project Report No. 134, 1996) and in oilseed rape (Project Report No. OS49, 2001). On the other hand, recent work (so far unpublished) by TAG has revealed little relationship between soil mineral nitrogen in February and optimum nitrogen rate in winter wheat where soil mineral nitrogen was in the range 0 – 120 kg N/ha.

Research Review No. 58 made a number of recommendations concerning soil mineral nitrogen testing. The need for improved guidance on sampling and interpretation of results was identified. Further research was suggested on the relative recoveries of soil and fertilizer nitrogen from different soil depths and on the prediction of soil nitrogen mineralization between late winter/early spring and the peak of nitrogen uptake by the crop. Mineralisation of nitrogen between drilling of spring barley and harvest was identified as a significant factor in Project Report No. 46.

Estimates of SNS at monitored sites, or use of meteorological data in models, could be used to provide regional or national adjustments to nitrogen recommendations in a particular season. Defra funded the development of a prototype SNS calculator for advisory purposes (NT2501). However, funding has not been available to develop ideas to a usable stage. A centrally operated model using soil mineral nitrogen data from a series of reference sites could provide growers with adjustments to standard recommendations for a particular season.

Improved guidance could be given on the amount of soil nitrogen taken up over winter by autumn sown crops. RB209 provides estimates based on shoot numbers/m^2 for cereals and plant height for oilseed rape. Some commercial organisations use photographs of crops containing different amounts of nitrogen to help in estimating. As the amount contained in the crop can be as great as, or greater than, the amount present as soil mineral nitrogen (especially in oilseed rape), a widely agreed and tested method would be helpful. Recent relatively warm winters have led to oilseed rape crops containing 120+ kg N/ha in January/February. It is not clear if this makes a full contribution to soil nitrogen supply and is equivalent to the same amount of nitrogen applied in fertilizer later in spring.

Current RB209 recommendations for cereals and oilseed rape are based on assumptions of 100% recovery of soil mineral nitrogen and 60% recovery of applied fertilizer nitrogen. These assumptions need validation for different agronomic conditions as any deviation would have significant effects on nitrogen application recommendations.

There are three aspects of soil nitrogen supply that require further work:

i. **The different methods for quantifying soil nitrogen supply, by estimation, measurement or both, need to be validated and compared. The relative contributions of soil mineral nitrogen, nitrogen mineralised during spring and nitrogen taken up by the crop over winter need to be clarified. Guidance then is needed on the choice of method for different circumstances taking account of cost and the degree of accuracy to be expected.**
There will be a need for field research, supported by desk study. Guidance for growers will then be needed.

ii. **A method is needed for monitoring or modelling seasonal effects on soil nitrogen supply and for providing timely guidance on their impact on fertilizer recommendations.**
This is likely to involve collection of climatic and soil data for the period September to March each year with subsequent interpretation and dissemination to growers/advisers via web site or email.

iii. **The extent to which soil nitrogen is utilised by crops affects nitrogen use efficiency and is a key component of many recommendation systems. Factors that affect the utilisation of soil nitrogen should be identified with a view to improving nitrogen use efficiency. The assumption that soil mineral nitrogen is recovered by the crop with 100% efficiency (with around 60% as the corresponding figure for applied inorganic nitrogen) needs validation for different agronomic conditions for both cereals and oilseed rape.**
Progress could be made using existing data and models such as SUNDIAL. However, additional field research also is likely to be required.

3.2.3 Canopy management

The canopy management concept in which inputs, especially nitrogen, are adjusted to optimise crop canopy development was described for wheat in Project Report Nos. 159 and 235, and for oilseed rape in Project Report Nos. 409 and OS49 and the ongoing project no. 3277.

In wheat, the benefit of canopy management was estimated at £10/ha, taking account of reduced nitrogen and fungicide usage and improved crop performance. Reduced water use also was reported (Project Report No. 235).

In oilseed rape, no yield benefit was found from pre-flowering canopies larger than LAI 1.75 or GAI 3.0 (Project Report No. OS49). Most growers include an early application in their fertilizer nitrogen programme but this may be omitted in many cases to achieve optimum canopy size (Project Report No. OS49). The canopy management work with oilseed rape indicated the potential benefits of later, and sometimes smaller, applications of nitrogen. Beneficial effects of delaying nitrogen application on root growth have been found but not consistently (Project Report No. 402, 2006). The lack of increase in national oilseed rape yield since the mid-1980s, despite genetic improvement over the same period, may be due partly to nitrogen management (Berry and Spink 2006).

One potential difficulty is the assessment of canopy size on-farm. This was tested in Project Report No. 235 for wheat. For oilseed rape, BASF offer a service where digital images of the crop can be submitted to a web site (www.totaloilseedcare.co.uk/GAI/index.html) and the GAI calculated and displayed.

Research findings on canopy management were communicated to growers in the Sector Challenge project of 1998 – 2000 (Sylvester-Bradley *et al*. 2000). Guidance to growers based on HGCA-funded research has been given for oilseed rape (Topic Sheet No. 37, 2000) and for winter wheat (Topic Sheet No. 40, 2000).

Canopy management guidelines need to be updated to take account of changes in varieties of both cereals and oilseed rape. For oilseed rape, canopy management and timing of nitrogen applications need to be considered together (see section 3.4).

3.2.4 Cultivations

Mineralisation of soil organic nitrogen is affected by cultivation; generally mixing and aerating soil promotes the process. A move from ploughing to minimum cultivation will change the amount of soil nitrogen becoming available. This is sometimes used to justify autumn application of nitrogen for winter cereals, particularly in Scotland. The two HGCA Research Reviews on minimum cultivation (No. 5 in 1988 and No. 48 in 2002) do not cover crop nutrient aspects.

Relevant research was conducted by Letcombe Laboratory, ADAS and Rothamsted in the 1970s and 1980s. However, this related mainly to direct drilling whereas current practice is minimum cultivation in its various forms. Nitrogen supply to the crop over winter and in spring tended to be smaller with direct drilling than with ploughing.

Changes to cultivation methods also could affect best practices for soil sampling for both mineral nitrogen and phosphorus.

The impact of minimum cultivation techniques on soil supply of nitrogen and phosphorus, and accessibility of these nutrients to crops, should be reviewed so as to provide improved guidance to growers. Attention should be given to any likely effects on best soil sampling practices.

3.2.5 Livestock manures

Livestock manures are applied to significant minorities of cereal and oilseed rape crops. In 2004/2005, percentages of crop areas receiving manures were 13% for winter wheat, 21% for winter barley, 33% for spring barley, 17% for oats, 44% for rye/triticale/durum, 11% for winter rape and 9% for spring rape (BSFP 2006).

In recent years, Defra has funded much of the research into nutrient aspects of manures (Appendix 4). The work was prompted by the need to minimise nitrate leaching and the recognition that manure use is a major part of the problem. Research findings were used to develop the MANNER manure nitrogen advisory software that is available to growers via ADAS. HGCA participated in a LINK project (LK0904, 1998 – 2002) (Project Report No. 303, 2003) that dealt with manure nitrogen utilisation. It was found that the fertilizer replacement value was not affected by rate of manure application but differed between materials. Significant amounts of nitrogen were released in the second year after application. This extended nitrogen release is not taken into account in RB209 and not fully in MANNER. This project also demonstrated that liquid slurries could be top-dressed to cereals successfully. Main findings of the project were presented to growers in Project Progress No. 6 and Topic Sheet No. 64.

On average, growers make some allowance for the nitrogen contribution from manures (Table 3, based on BSFP 2006), possibly prompted by NVZ requirements. However, effective accounting for the nitrogen contribution from manures is restricted by lack of knowledge of the amount and release characteristics of the nitrogen applied. The nitrogen concentration in manures can be measured by laboratory analysis or, in the case of slurry, the available nitrogen concentration can be measured on-farm (see Appendix 6). However, the validity of analyses depends on obtaining a representative sample of the manure. This can be impossible for some solid manures (see Fig 1) in which case standard values should be used. Growers and advisers need guidance on sampling methods, the interpretation of analytical reports (these vary widely in units, bases and format) and on when the use of standard values may be more appropriate.

Fig 1. Example of pig FYM where representative sampling would be impractical

Guidance is needed on the relative benefits of standard values and chemical analysis in estimating the nitrogen and phosphorus concentrations in livestock manures. Where analysis is preferred, guidance also is needed on sampling methods and on the interpretation of analytical reports. Actions in this area need to be co-ordinated with developments in MANNER software.
The need here is for clear guidance based on existing data. There should be no need for new field research.

3.2.6 Interactions with fungicides

It is known that crop response to applied nitrogen is affected by fungal infections. Successful control of infection increases crop yield potential and response to nitrogen. Interest in nitrogen interaction with fungicides reawakened with the introduction of strobilurins. Growers reported that these fungicides prolonged green tissue near to crop maturity. The possibility of an associated increase in nitrogen uptake by wheat late in crop development was assessed in Project Report No. 221, 2000. It was reported that use of strobilurins could increase crop yield and nitrogen uptake and that soil nitrogen supply in the subsequent year could be depleted to some extent.

However, in a subsequent project, no effects of stobilurins relative to conventional fungicides were found on nitrogen uptake, residual soil nitrogen or fertilizer nitrogen requirement of the subsequent crop (Project Report No. 280, 2002). Research findings from these projects were presented to growers in Topic Sheet No. 68.

Use of strobilurins in spring malting barley was found to increase yield and to dilute grain nitrogen (Project Report No. 250, 2001). Where grain was produced for lager with required nitrogen concentration within a specified band, higher nitrogen rates than usual of around 150 kg N/ha could be needed to avoid too low grain concentrations. Preliminary results from Project No. 2660 (Annual Project Report 2005) indicated that rates up to 175 kg N/ha sometimes could be justified, in this case for Optic. Results for malting barley were issued to growers in Topic Sheet No. 81, 2004/2005.

At present, 'fungicide x nitrogen' interactions do not appear to be a research priority for HGCA.

3.2.7 Retrospective assessment of nitrogen supply

A retrospective assessment of the adequacy or otherwise of nitrogen supply to a crop helps growers in future decisions and provides confirmation of past nitrogen policy. For wheat, RB209 provides one such assessment based on grain nitrogen concentration. Standard concentrations are given of 2.0% N and 2.2% N for feed and breadmaking wheat respectively (100% dry-matter basis). 'Where concentrations are above or below these values, fertiliser rates should be adjusted by 30 kg N/ha per 0.1% difference in grain nitrogen'. Questions have been raised on the current extent to which growers use such an assessment and on the physiological basis for this particular method. Grain yield or a combination of yield and grain nitrogen concentration may offer alternative methods of assessment.

No similar method for retrospective assessment of nitrogen use is available for oilseed rape.

The biological basis for grain protein concentration as an indicator of nitrogen supply needs to be established. Any other practical methods of assessment need to be identified for both cereals and oilseed rape. Once methods are established, guidance for growers in their use is needed.
Progress could be made using existing data. It is unlikely that new field research would be necessary.

3.2.8 Optimum rate of application

The optimum rate of nitrogen application provides the maximum economic benefit to the grower. This is an apparently simple concept and the optimum rate is easily calculated from regression equations fitted to yield response data. However, usually (almost invariably) only the purchase cost of nitrogen and the value of the grain or rapeseed are taken into account. Not taken into account are other components of the total nitrogen cost (soil acidification and possibly part of spreading and fungicide costs) and any volume-related costs incurred in grain drying and storage.

There are costs attached to over- or under-applying nitrogen relative to the optimum rate. As the optimum rate is never known with any accuracy before nitrogen application, these costs appear to the grower as risks. It is often assumed that the costs of a small over-application are lower than those of an under-application. This can lead to 'insurance' application by the grower in an attempt to reduce the risk to margins. However, the relative costs of under- and of over-application change with nitrogen and grain prices and with the shape of the response curve.

There are some indications from TAG trials that the shape of the response curve can differ among wheat varieties. Where the slope of the yield response curve changes little around the optimum nitrogen rate, a small change in the ratio of nitrogen to grain price can have a relatively large effect on the optimum. In this case, applying a rate significantly different to the optimum can result in only a small change in margin.

Existing data could be used to quantify the risk to margins of under- and over-application of nitrogen for the main varieties. There also is a need for wider understanding of the meaning of an optimum nutrient rate and of the unavoidable uncertainties in any estimates of the optimum.

3.3 Specific market requirements

Cereal grain and rapeseed are produced for several uses, often with specific quality requirements that are affected by crop nutrition. Phosphorus appears to have no significant effects but nitrogen supply affects grain protein concentration. In cereals, the main quality issues at present are protein concentrations for breadmaking wheat and for malting barley. In future, protein concentration for bioethanol production may become an important issue. There are no apparent rapeseed quality issues associated with nitrogen or phosphorus supply.

3.3.1 Breadmaking wheat

Around 5.4 million tonnes of domestically produced wheat, with a value of some £500 million, is used annually for breadmaking. Nitrogen for breadmaking wheat has been researched for several decades but has come to the fore again recently with the introduction of varieties like Xi19 and Malacca. These varieties appear to require more than the usual amount of nitrogen to combine optimum yield and a satisfactory protein concentration.

Early projects in the HGCA programme evaluated late-applied foliar urea for improving grain protein and baking quality (Project Report Nos. 14, 54, 109). In Project Report No. 109, effects of foliar urea at GS75 and of extra soil applied ammonium nitrate at GS33 were compared. Both applications increased grain protein concentration but foliar urea appeared the most effective. Similar results were reported in Project Report Nos. 121 and 400. Efficacy of foliar urea has been reviewed recently in Research Review No. 47 and elsewhere (Gooding 2005, Gooding *et al.* 2007) with much the same conclusions. It seems unlikely that further field research on efficacy is needed but guidance to advisers and growers on the relative benefits of foliar urea and additional soil-applied nitrogen would be helpful. It is possible that leaf scorch often associated with foliar urea (Fig 2) could be reduced through plant breeding for low urease activity or through urease inhibitor additives to the fertilizer (Research Review No. 47).

Fig 2. Leaf scorch following application of urea solution

Effects of varietal changes on requirement for applied nitrogen were evaluated in Project Report 400 and in the Annual Project Report for project 3084. Grain yields of modern Class 1 and 2 wheats (Einstein, Xi19 and Malacca) were around 1 t/ha greater than those of older varieties (eg Mercia and Avalon). The optimum nitrogen rate was some 17 kg N/ha higher for the newer than it was for the older varieties and 29 kg

N/ha higher than the relevant RB209 recommendation. Although changes in the nitrogen cost to grain price ratio need to be taken into account, these results cast some doubt on current nitrogen recommendations for breadmaking wheat. A mechanism needs to be found for continuous adjustment to nitrogen recommendations for breadmaking wheat to take account of both varietal developments and changes in the nitrogen cost to grain price ratio. Commercial organisations, for example Velcourt and Masstock, conduct annual variety x nitrogen rate field trials. It may be that a mechanism could be agreed for accessing data from these trials whilst preserving commercial interests.

The need for current protein specifications for breadmaking wheat (usually minimum 13%) should be reviewed. Developments in varieties, in breadmaking techniques or in market requirements might allow the use of lower protein grain and smaller nitrogen applications. Any potential opportunities should be identified through discussions with the baking industry.

3.3.2 Malting barley

Around 1.7 million tonnes of barley grain, with a value of £200 million, is used annually for malting. Nitrogen for malting barley also is an old research subject that re-surfaced with the increased demand for lager and consequently for grain nitrogen concentrations of 1.60 – 1.85%.

Uptake and partitioning of nitrogen by malting barley crops were investigated early in the HGCA research programme (Project Report Nos. 47, 70, 94, 119). Delaying drilling of spring varieties was found to increase grain nitrogen concentration by 0.005% N/day. The optimum rate of applied nitrogen decreased by around 2.25 kg N/ha/day as drilling was delayed (Project Report No. 179). Findings were issued to growers in Topic Sheet No. 20, 1998/99.

The rate of applied nitrogen usually is restricted in malting barley to ensure acceptable grain nitrogen concentration, especially where the grain is for ale production. For spring-sown crops, a single application at early crop emergence was found adequate (Project Report No. 367). At 150 kg N/ha applied to Optic and Cellar, no significant reduction in lodging from growth regulator application was found (Project Report No. 367). An increase in typical nitrogen application rate from around 110 kg N/ha for ale to around 150 kg N/ha for lager was justified but no other significant changes to agronomy were needed (Project Report No. 367). These findings were issued to growers in Topic Sheet No. 76, 2003/2004.

Existing data might be used to develop relationships between the rate of applied nitrogen as a proportion of that needed for optimum yield as feed barley and the probability of achieving different malting qualities. The shape of this relationship and the extent to which it is affected by agronomic factors might be used for improving guidance to growers. An exercise like this is anticipated in HGCA project no. 3335 that deals with bioethanol from wheat.

3.3.3 Biofuels

There is increasing interest in cereals (wheat and triticale) for bioethanol production and oilseed rape for biodiesel. Various studies have demonstrated positive energy balances. In the Energy Act 2004, the UK introduced a Renewable Transport Fuels

Obligation (RTFO). This requires inclusion rates by volume for biofuels of 2.5% in 2008/9, 3.75% in 2009/10 and 5.0% in 2010/11. Analyses by the NFU (NFU 2006) indicated that a 5% inclusion rate would require 3 million tonnes of wheat (around 375,000 ha) and 2.7 million tonnes of rapeseed (around 840,000 ha). The total land requirement appears high but if co-products are taken into account (around 2.4 million tonnes of brewers grains and rape meal for animal feed), the net requirement falls to 900,000 ha. According to the NFU, this area could be available from mandatory set-aside and the area of wheat grown for export. Biofuel offers a significant and developing market for cereals and oilseed rape. Even if bioethanol wheat substituted for exports, the extra rapeseed required for biodiesel could amount to £400 million annually by 2010.

For bioethanol production, processing yield (alcohol yield per tonne of grain) decreases as grain protein concentration increases (Research Review No. 61, 2006). However, maximum alcohol yield per hectare may be achieved at a fertilizer nitrogen rate higher than that needed for optimum grain yield. Despite this, if no price premium is offered for low protein grain, then the optimum fertilizer nitrogen rate for bioethanol production is the same as that for optimum grain yield as the grower is paid per tonne of grain (Research Review No. 61, 2006). Unless price premiums become available, the grower is best advised to select a high yielding feed variety of wheat and to apply the amount of nitrogen normally recommended. An adjustment to nitrogen timing might be made, incorporating the usual third (May) application into the main (April) application. This would not affect yield and would help minimise grain protein concentration. Research on nitrogen timing for wheat for bioethanol is underway in the Extension to Project No. 3084. Preliminary advice has been given in Project Progress No. 14. The current ‘GREEN grain’ LINK project (Defra LK0959, Annual Project Report No. 2979, 2005) is investigating differences between varieties in nitrogen uptake and utilisation in wheat grown for bioethanol.

As suggested for malting barley, relationship between the rate of applied nitrogen as a proportion of that needed for feed yield and the probability of achieving a given grain protein concentration (using this as a predictor of alcohol processing yield) could be described using existing data from nitrogen response trials. This may be an outcome of the forthcoming HGCA project no. 3335.

Nitrogen supply does not appear to affect the quality of rapeseed for biodiesel production. Unless evidence is produced to the contrary, the same rates of application should be used for conventional and biodiesel purposes. However, the large increase in area of oilseed rape that could be required for biodiesel would emphasise the need for improved nitrogen economy in the crop.

Straw can be used as a biomass fuel. Environmental Power Resources Ltd operate the world’s largest straw-fuelled power station near Ely (www.eprl.co.uk). The availability of straw throughout the EU has been assessed by the EC Joint Research Centre (Edwards *et al*. 2005). It was concluded that there was scope within the EU for some 67 new power plants similar in size to that now operated near Ely. East Anglia was identified as one area where a significant amount of straw might be available for burning and electricity generation.

HGCA is involved in ongoing research into grain for bioethanol. Proposals here (section 3.4) for research to improve the nitrogen economy of oilseed rape would benefit biodiesel production.

3.3.4 Prediction of grain quality

Early prediction of grain quality would be useful, especially for breadmaking wheat where late nitrogen application might be adjusted. A fraction of grain proteins, high molecular weight glutenin sub-units (HMW-G), has been evaluated as predictors of grain quality at harvest, first in Hereward and later in other varieties (Project Report No. 219, 2000). No consistent relationships between HMW-G and grain protein concentration or loaf volume were found. However, grain protein could be predicted from Near Infra Red (NIR) spectral data of immature grains at GS75. In principle, this could be done in time for corrective foliar applications of nitrogen where found necessary.

Ideas were developed further in a Defra LINK project (LK0927, 2002 - 2006) with HGCA involvement (Project Report No. 401, 2006). It was concluded that NIR analysis of immature ears could form the basis for a crop monitoring system with targeted late foliar nitrogen applications.

The value of early grain protein prediction depends on acceptance of late foliar applied nitrogen as a suitable corrective action where needed. Such acceptance is not universal and one baker excludes the use of late foliar urea by suppliers.

3.4 Time of nitrogen application

Typically, three nitrogen top-dressings are applied in late February, early April and early May to winter wheat. The first application usually is around 40 kg N/ha and the second is the main application. Yield is not greatly influenced by changes in the allocation of nitrogen to these three applications. In Germany for instance, the first and third applications tend to be larger than the second. A few commercial unpublished comparisons of UK and German timings have shown no significant differences in grain yield. Two applications are more common in winter barley, with around 40 kg N/ha in February and the remainder in March. In spring-sown cereals, nitrogen may be applied as a single application either to the seedbed or at early emergence. For early sown crops, top-dressing at emergence may reduce the risk of nitrogen loss by leaching. Apart from this, no agronomic difference is likely between the timings. For cereals, further field research on spring nitrogen timing for yield does not seem a priority.

In England and Wales, it is generally accepted that application of nitrogen in autumn is not normally necessary for winter cereals. However, in Scotland application of autumn nitrogen to winter barley and winter wheat has been more common. A current SEERAD-funded project is being conducted by SAC to assess the yield benefits and nitrate leaching risk where autumn nitrogen is applied to winter barley (www.sac.ac.uk/research/projects/cropsoil/).

Current advice on timing of nitrogen applications for winter oilseed rape is less clear. Canopy management research has indicated that later nitrogen application than is now practiced could improve yield (Project Report No. OS49, 2001, Annual Project Report No. 3277, 2006 results). Some growers have reported benefit from nitrogen, additional to the normal recommendation, applied at flowering.

Improving the nitrogen economy of oilseed rape will become more pressing if, as expected, a significant market for biodiesel develops. Methods for improving nitrogen use efficiency by oilseed rape such as delayed, or additional late, nitrogen applications need evaluating. Possible interactions between nitrogen timing, green area index (GAI) development and variety in their effects on yield and optimum nitrogen rate need to be identified.
Further field research supported by desk study would be needed. Subsequently, grower guidance would be necessary.

3.5 Precision farming

The variable application of nitrogen within fields, a component of precision farming, has been developed largely by commercial organisations. For nitrogen, variable application is based on crop mapping for biomass, reflectivity or yield. The SoylSense and Loris systems of Soyl and Kemira GrowHow respectively involve imaging of the crop before nitrogen is applied to estimate biomass. Biomass and reflectivity at certain wavelengths are used in the Yara N-Sensor that can be linked to a fertilizer spreader. Yield mapping is installed in many combines.

The cost of soil sampling for mineral nitrogen probably precludes this method as a basis for variable application within fields (Project Report No. 134, 1996).

Whilst the hardware and software technology may be developed commercially, some crop aspects may be appropriate for HGCA involvement. For example, can variable nitrogen application produce more uniform grain quality and would this be a worthwhile improvement? For breadmaking or malting, is a grain batch with completely near uniform nitrogen concentration more valuable than a batch with the same average nitrogen concentration but significant internal variation?

3.6 Forms of fertilizer nitrogen

The main straight nitrogen fertilizers used in the UK are ammonium nitrate (prilled or granular), urea (prilled or granular) and urea ammonium nitrate (UAN, solution). Current recommendations, exemplified by Defra *RB209 Fertiliser Recommendations for Agricultural and Horticultural Crops*, are based on crop responses to nitrogen in ammonium nitrate. It has been known for several decades that urea can be less effective than ammonium nitrate as a nitrogen source due to loss of ammonia to the air after application (eg Cooke 1964, Chaney and Paulson 1988, Tomlinson 1970). UAN is a 50/50 mixture of ammonium nitrate and urea in solution and combines the properties of both sources (though in Defra project NT26 recovery of nitrogen applied as UAN was somewhat less than expected).

Recently, Defra has funded a major field and laboratory based research programme (NT26) on possible substitute products for ammonium nitrate. After considering all possibilities, it was concluded that only urea-based fertilizers offered a realistic alternative. However, the ammonia lost after urea application would have resulted in the UK being unable to meet its commitments on emissions. The research concluded that ammonium nitrate remained the most sustainable solid fertilizer option for farmers. Reports from this project give comprehensive coverage of the supply and use of ammonium nitrate and urea-based fertilizers, their behaviour and agronomic characteristics. There is a detailed report on the spreading properties of urea and others on crop responses to different nitrogen sources. Projects within NT26 are listed in Appendix 3 and all reports can be seen at the Defra web site: http://www2.defra.gov.uk/research/project_data/projects.asp?M=KWS&V=nt26&SUBMIT1=Search&SCOPE=0.

Calcium ammonium nitrate (CAN) is sometimes used in the UK for blending. In Germany and some other European countries, but rarely in the UK, it is used for direct application. CAN is manufactured by adding finely ground limestone to an ammonium nitrate melt. The nitrogen source is ammonium nitrate and there is no difference in agronomic effectiveness between CAN and ammonium nitrate.

Ammonium sulphate is the main sulphur source in nitrogen/sulphur fertilizers. A relatively small amount of ammonium sulphate, either in solid form or in by-product solutions is used as a straight fertilizer. As a nitrogen source, ammonium sulphate is as effective as ammonium nitrate but has a greater acidifying effect on the soil.

Some nitrogen is present in compound fertilizers as ammonium phosphates (DAP or MAP). As nitrogen sources, these materials are as effective as ammonium nitrate.

In view of the large amount of completed research, supplemented by the recent Defra NT26 project, new funding by HGCA for nitrogen source comparison seems unnecessary. Evaluation of UAN as a nitrogen source and the possible development of this product by addition of urease inhibitors or anti-scorch agents could be undertaken by the major suppliers.

3.7 Organic sources

Composted greenwaste and sewage sludge products are likely to be applied to land in increasing amounts. Composted greenwaste typically contains around 1.25 – 1.30% N in the dry-matter (Wallace 2005), most of which is in organic forms that become slowly available to crops. HGCA are involved in the five-year *Compost Use in Agriculture* project managed by Enviros that is due for completion in February 2007 (HGCA project no. 3155). If requirements of the Waste Management Licensing Regulations are removed from composts, the amounts of composts used in agriculture could increase substantially. Growers will need to be aware of the forthcoming *Quality Protocol* for composts developed by BREW, WRAP and the EA (details at www.wrap.org.uk) that covers selection and application of green waste composts.

Sewage sludge products typically contain 1.5 – 5.0% N in the dry-matter, again mainly in organic forms. Nitrogen release characteristics need definition, especially for the year after that of application.

The rates of release of nitrogen from these materials, and the extent to which this nitrogen is recovered by crops will vary widely depending on date of application, method of incorporation and soil and climatic conditions. Growers would benefit from guidance on the nitrogen value of composts and sludges.

3.8 Environmental impact

Nitrogen losses from soil to water and air represent costs to the farm and to the wider environment. At current fertilizer prices, loss of nitrogen typically is equivalent to £15 - £30/ha in cereal/oilseed rape rotations. Much of this loss is not recoverable as leaching and denitrification occur naturally and in the absence of any applied nitrogen. However, by adopting good agronomic practices, the grower can avoid excessive and unnecessary losses. Application of nitrogen fertilizers has been shown to have beneficial effects on various soil physical, chemical and biological properties (Defra project SP0504). However, application of nitrogen fertilizers tends to increase the rate of soil acidification and consequent lime requirement.

3.8.1 Nitrate leaching from soil

Nitrate in human diets was thought to be a contributory factor to methaemoglobinaemia in infants and to gastric cancer. The ‘Drinking Water Directive’ (80/778/EEC) of 1980 set a limit of 50 mg nitrate/litre in drinking water and this limit was extended to water sources in the ‘Nitrates Directive’ (91/676/EC) of 1991. Since 1980, the association between nitrate concentration in water and human health has been largely dismissed, at least in Europe, but the limits remain. Defra conducted a large research programme into nitrate leaching from soil, results of which were used for the Nitrate Vulnerable Zones Action Programmes within the UK and for the 7th edition of *RB209 Fertiliser Recommendations for Agricultural and Horticultural Crops* (now also available in computerised form as PLANET).

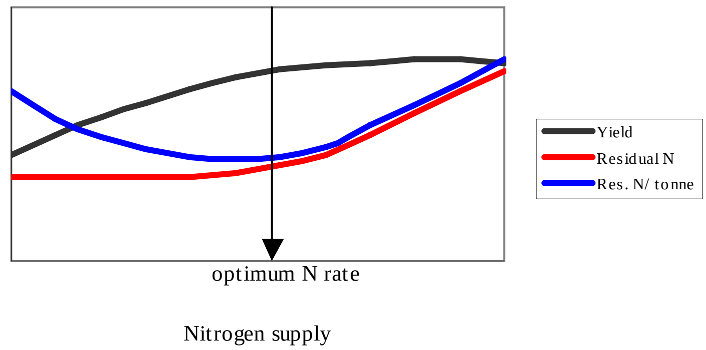
Requirements of the NVZ Action Programmes have been presented to growers in Defra *Guidelines for Farmers in NVZs* (England and Wales), Scottish Executive *Guidelines for Farmers in Nitrate Vulnerable Zones* (Scotland) and in Topic Sheet No. 63 (England).

Nitrate-nitrogen is mobile in the soil and will be lost with any drainage water. Most loss of nitrate to water occurs during winter and early spring so the overall objective is to minimise soil nitrate concentration at this time. This can be achieved by:

i. Using recognised nitrogen recommendation systems (RB209/PLANET is one but there are others, see Appendix 6);
ii. Measuring or estimating nitrogen contributions from mineralization, manures, crop residues and deposition and taking these into account;
iii. Ensuring green cover over winter where possible;
iv. Early drilling of autumn-sown crops where feasible;
v. Regular calibration and tray testing of fertilizer spreaders.

For autumn-sown cereals, it has been shown that nitrogen application up to the economic optimum has little effect on soil nitrate concentration after harvest (eg Chaney 1990, Richards *et al.* 1998). The amount of residual soil nitrate per tonne of grain produced tends to be at a minimum around the economically optimum nitrogen rate (Fig 3). In these crops, economic and environmental objectives largely coincide. There is less information on soil nitrate concentration after spring-sown cereals and oilseed rape. In rape, there are indications that nitrate concentration after harvest increases somewhat at nitrogen rates below the economic optimum.

Fig 3 Cereal yield, residual soil N after harvest and rate of fertilizer N applied



There will be a need for guidance to growers and advisers when the revised NVZ Action Programme rules are introduced in England/Wales and in Scotland, probably late in 2007.

3.8.2 Ammonia loss by volatilisation

Defra recently have funded a research programme, largely directed towards ammonia losses from livestock enterprises though some projects are relevant to cereals and oilseed rape (Appendix 3). Defra research was summarised in *Ammonia in the UK* (Defra 2002) and is incorporated in the computerised advisory tool MANNER. Other research on ammonia loss has been summarised (Holtan-Hartwig and Bockman 1994, ECETOC 1995). There are three issues associated with arable crops:

i. Application of manures
ii. Application of urea-based fertilizers
iii. Ammonia loss from crop surfaces

Application of manures can lead to significant ammonia losses depending on the method used and the period between application and incorporation. Up to 30% of total N in the manure might be lost during and after spreading (ECETOC 1995) and manure spreading accounts for some 33% of all ammonia emissions from agriculture (Defra 2006). However, ammonia loss can be greatly reduced by avoiding spraying slurry into the air on spreading and by various forms of rapid incorporation. For arable crops, shallow injection and band spreading via trailing hoses are advised. At least, applied manures should be incorporated as quickly as possible, preferably on the day of spreading.

It has long been known that ammonia can be lost following application of urea and this has been confirmed recently in Defra Project NT26. Application of fertilizers has been estimated to account for 11% of ammonia loss from agriculture in the UK (Defra 2006). ECETOC (1995) assumed an average 15% loss of the N applied in urea compared to 2% for ammonium nitrate. Corresponding values found in Defra project NT26 were 22% (range 2 – 43%) for urea and 3% (range –3 – 10%) for ammonium nitrate. These values are very similar to those reported more than forty years ago by Cooke (1964). Defra (2006) estimated that ammonia loss from agriculture could be reduced by 22% by switching from urea to ammonium nitrate.

Holtan-Hartwig and Bockman (1994) reviewed research on ammonia loss from crop surfaces, suggesting a typical 1.5 kg N/ha/year. This loss would increase if nitrogen application in fertilizers or manures exceeded recommended levels. Loss also could increase if the crop became severely stressed by disease or drought during grain filling.

In view of the large amount of research funded by Defra, ammonia emission is not a priority for HGCA.

3.8.3 Nitrous oxide loss by denitrification

Agricultural land is a major source of nitrous oxide, a potent and long-lived (>100 years) greenhouse gas. Research to 1994 was reviewed in detail by Granli and Bockman (1994). Since then, Defra have conducted a significant research programme, mainly directed at grassland and livestock enterprises.

Nitrous oxide is a product of microbial denitrification of nitrate in the soil. This is an anaerobic process and tends to occur during winter when soils are wet and where drainage is impeded. Loss can be minimised by ensuring as little nitrate as possible is present in the soil over winter. Normal good practice of matching nitrogen inputs to crop requirement and avoiding nitrogen applications in autumn wherever possible will help minimise losses. Defra research also indicated benefits from winter cover crops and irrigation.

Mitigation methods are well defined and there seems no immediate requirement for research funding by HGCA.

3.8.4 Soil acidification

The acidifying effect of nitrogen fertilizers, related to leaching of nitrate and nitrification of ammonium-nitrogen, has long been recognised. Defra has funded some research demonstrating and quantifying the effect of nitrogen fertilizers on acidification (Chambers and Garwood 1988, Goulding *et al*. 1998). Rothamsted Research developed the RothLime model that assists in decisions on liming by a range of materials and that can be downloaded free of charge from www.rothamsted.ac.uk/aen/rothlime/ . The latest version of RothLime includes a correction for acid rain and the lime recommendations are slightly higher than those in RB209.

4 Phosphorus

4.1 Background

In Great Britain, 2004/2005, around 106,000 t P_2O_5 were applied in fertilizers to wheat and barley and around 22,000 t to oilseed rape (BSFP 2006). The total purchase cost to growers was some £50 million.

Over the past decade, the proportion of cereal and oilseed rape area receiving fertilizer phosphorus and the average rates of application have generally declined (Table 2). The decline has been steady and continues (Johnston and Dawson 2005). In the absence of any phosphorus contribution from applied manures, it is likely that many crops are in negative phosphorus balance.

Table 2. Application of fertilizer phosphorus in Great Britain (BSFP 2006).

	Crop area receiving P_2O_5 (%)		Average field rate (kg P_2O_5/ha)		Overall rate (kg P_2O_5/ha)	
	1998	2005	1998	2005	1998	2005
Winter wheat	71	61	68	61	48	37
Winter barley	76	69	66	61	51	42
Spring barley	82	79	51	51	42	40
Oats	88	69	64	60	56	41
Winter oilseed rape	77	66	69	63	53	42
Spring oilseed rape	71	43	49	56	35	24

Typical phosphorus applications to, and removals by, cereal and oilseed rape crops are 40 – 80 kg P_2O_5/ha. However, annual losses from soil to surface water as little as 2 – 5 kg P_2O_5/ha can be associated with excessive eutrophication. Such losses, with a fertilizer value of less than £2/ha, are hardly significant to a grower. If phosphorus losses from soil to water are to be reduced, there may need to be grower incentives that are unrelated to the fertilizer value of the lost phosphorus or new regulatory controls.

Comprehensive reviews of the agronomic and environmental aspects of phosphorus use in agriculture have been published recently (Haygarth and Jarvis 1999, Johnston and Dawson 2005)

4.2 Amount of phosphorus to apply

4.2.1 Principle of recommendations

The principle for phosphorus fertilization of arable crops adopted in Defra RB209 is convergence on soil P index 2. This represents the soil available concentration where an application of phosphorus equivalent to that removed in the crop (the ‘maintenance’ amount) should ensure optimum yield. Where soil P index is less than 2, additional phosphorus is applied to ensure optimum yield and to raise the index to 2 over a number of years. On the other hand, where soil P index is greater than 2, less than the maintenance amount of phosphorus is recommended. This principle of convergence on an adequate soil concentration of available phosphorus is found in SAC and other recommendation systems. Successful use of these systems depends on regular soil analysis and on an ability to estimate crop removal of phosphorus.

It is unlikely that any significant change to the principle of phosphorus fertilization will be made when the replacement for RB209 is introduced. However, the assumption that soil index 2 is the appropriate target for all soils could be questioned. This index was selected as encompassing the critical soil available phosphorus concentration (usually taken as the concentration that supports 95% of maximum crop yield) found in a limited number of studies. Establishing critical phosphorus concentrations for a wider range of soil types could help refine recommendations, as suggested in HGCA Project Report No. OS58 (2002). There is evidence that the critical soil phosphorus concentration varies with soil physical conditions. The concentration tends to be lower on well structured soils presumably because roots are better able to exploit the phosphorus present.

The basis for phosphorus recommendations in England and Wales is the soil P index. In the current edition of RB209, index 2 is set as the target for arable crops but it is not clear that this index is most appropriate for all soil and crop conditions. Critical soil phosphorus concentrations to meet economic and environmental objectives need to be identified for a range of soils. Conditions that affect the critical concentration need to be identified.
New field research would be required but this would be routine in nature with a low risk of not obtaining necessary data.

4.2.2 Soil testing

The method for soil sampling for determination of P index has been established for many years. Arable soils are sampled to a depth of 15cm as this was felt to provide a representative index for the plough layer. Recent interest in various forms of minimum cultivation indicates that more guidance on soil sampling may be required. Phosphorus is immobile in the soil and virtually all of that applied to the surface will remain in the top few millimetres unless mixed with deeper layers by cultivation.

Soils usually are sampled either in autumn before seedbed fertilizer application or in early spring. It is generally thought that sampling time should be consistent for a particular field but there is little published information.

Usual advice is for fields to be sampled using the traditional 'W' pattern for sub-sample collection. Samples are bulked in the field to form a single sample that is submitted for analysis. This method is cheap (analytical cost of £7.50 is equivalent to 13p/ha/year for a 15 ha field sampled every four years) but useful information may be lost if the soil is not completely uniform across the field. The cost of full field mapping may be daunting but separate sampling of different parts of a field could be justified.

Additional soil sampling guidance for advisers and growers would be helpful. The only suitable booklet is now out of print (MAFF 1979).

4.2.3 Plant tissue testing

Plant tissue testing has been evaluated as an alternative to soil analysis. HGCA Project Report No.137 (1997) described critical concentrations (GS31 – 39) in the first leaf of wheat of 0.28 – 0.38% for total P and in whole shoot dry-matter of 0.05 – 0.07% for inorganic P. Findings were issued to growers in Topic Sheet No. 19, 1998/99. In later projects, (Project Report No. 224 in 2000 and 322 in 2003) the RQflex meter, a portable reflectometer manufactured by Merck, was evaluated for measuring sap inorganic P concentration in wheat at GS39 on-farm. In 2003, analytical cost was £2.50/sample excluding cost of labour and purchase price of the meter (£427). Generally, results of plant tissue testing agreed with those of soil testing. There are several difficulties with plant testing for phosphorus:

i. The test is diagnostic rather than predictive and results may be available too late to correct deficiency in the current crop (though development of effective foliar applications could overcome this);

ii. Plant testing is more expensive than soil testing if done in a laboratory (the laboratory soil test also covers potassium, magnesium and pH);
iii. Analysis on-farm is time-consuming and requires outlay on equipment.

In view of the research completed and the lack of grower uptake, further research probably is not justified at present.

4.2.4 Livestock manures

Quantifying phosphorus inputs is not a statutory requirement but it is good practice, necessary for fertilizer recommendation systems and an essential part of nutrient management plans for Environmental Stewardship. The amount of fertilizer phosphorus applied normally is known but there remains great uncertainty over the amount provided by any livestock manures. The difficulties in measuring or estimating reliably the average phosphorus concentration in manure and the rate of application affect grower confidence. This may be partly responsible for the small adjustment of fertilizer phosphorus application where manures also are applied to cereals or oilseed rape though a more realistic adjustment is made for potatoes (Table 3).

Introduction of a version of MANNER software that covers phosphorus as well as nitrogen will help increase awareness of the phosphorus value of manures. However, guidance would be helpful on sampling manures and on circumstances where using standard values would be more appropriate (see section 3.2.5).

Table 3 Application of fertiliser nitrogen and phosphorus to crops in Great Britain with and without applications of organic manures (BSFP 2006)

	Nitrogen (kg N/ha)		**Phosphorus (kg P_2O_5/ha)**	
	with manure	**no manure**	**with manure**	**no manure**
Winter wheat	177	199	31	38
Spring barley	87	112	38	42
Winter barley	120	150	42	43
Spring rape	158	149	25	24
Winter rape	180	209	27	44
Potatoes	*148*	*186*	*116*	*188*

4.3 Time of phosphorus application

For autumn-sown crops, fertilizer phosphorus may be applied to the seedbed or as a top-dressing to the crop in spring. At soil P indices of 2 or higher, no yield response is expected in the current crop and time of phosphorus application is not critical. However, at lower indices, some yield response is possible and application to the seedbed is preferable. Major fertilizer manufacturers offer suitable NPK products for spring application.

4.4 Forms of fertilizer phosphorus

Most of the fertilizer phosphorus applied to cereals and oilseed rape is in the form of triple superphosphate (single superphosphate is lower in concentration and little is now used) or ammonium phosphate (monoammonium phosphate or MAP and diammonium phosphate or DAP). These sources may be manufactured by the sulphuric acid route or, in the case of ammonium phosphates, by the nitrophosphate process. When made by the sulphuric acid route, the water-solubility of the phosphorus in the fertilizer is usually 90 – 95%. The remainder is in the form of dicalcium phosphate and iron phosphates that are available to the crop (Johnston and Richards 2003). When made by the nitrophosphate process, water-solubility typically is 70 – 85% but again the remaining phosphorus is available to crops. These differences in water-solubility have no agronomic significance for cereals and oilseed rape.

There have been claims that ammonium phosphates are more effective than superphosphate as phosphorus sources in calcareous soils. However there is little field evidence to support these claims. It is possible that ammonia evolution from ammonium phosphates applied to calcareous soil could damage seedlings though any effect is likely to be small where the fertilizer is broadcast (Fixen 1990).

Other 'water-insoluble' sources are sometimes used. These include the ash from poultry litter combustion, various rock phosphates, partially-acidulated rock phosphate and small amounts of LD-slag. Poultry litter ash has been marketed in the UK for some twelve years and its effectiveness as a phosphorus source has been established (though not published in the scientific literature). Although water-solubility is close to zero, the phosphorus in this material is largely available to the current crop. Rock phosphates, all with zero water-solubility, have been evaluated for direct application in both powder and granular forms. The rocks available in the UK, even the 'soft' rocks such as Gafsa, are ineffective as phosphorus sources where soil pH is higher than 6.0 – 6.5. They are more suited for grassland than for arable crops. SAC are leading a current LINK project that investigates the value of rock phosphates in organic farming (www.sac.ac.uk/research/projects/cropsoil/featured/plink/ Stockdale *et al.* 2006). Partially-acidulated phosphates are made by reacting rock phosphate with a small amount of acid so that the rock is partly converted to superphosphate. Agronomic properties are intermediate between those of superphosphate and rock phosphate. LD slag is produced by the steel-making process that superseded that used to produce basic slag as a by-product. Typically, LD slag contains around 2% P_2O_5 and is mainly a liming agent. Fisons conducted a large research programme on water-insoluble phosphorus sources (covering rock phosphates, LD slag, partially-acidulated rocks, ashes and mixtures of these materials in various physical forms) as supplies of basic slag were depleted in the 1970s. Results of this programme, largely unpublished, are now held by Yara UK.

Other phosphorus sources may become significant in future. Phosphorus removed from wastewater at sewage treatment works can be formed into struvites (ammonium magnesium phosphates) that can be used as fertilizers. They could become suitable phosphorus sources for cereals and oilseed rape (Johnston and Richards 2003). Composted greenwaste typically contains around 0.45 – 0.60% P_2O_5 in the dry-matter (Wallace 2005). Applied to meet the NVZ limit of 250 kg N/ha, compost would provide around 100 kg P_2O_5/ha. Sewage sludge products contain more phosphate (P_2O_5) than nitrogen, typically 2.0 – 4.5% P_2O_5 in the dry-matter.

Foliar application of phosphorus has been tested and sometimes is practised commercially. There have been reports in the USA that foliar application of mono-potassium phosphate could increase wheat yield where summer drought occurred (Benbella and Paulsen 1998).

The agronomic evaluation of unconventional phosphorus sources may best be the responsibility of the manufacturer or supplier. However, guidance to advisers and growers on the properties of phosphorus fertilizers would be helpful. For example, there is confusion over the terms ‘water-solubility’, ‘citrate solubility’ and ‘plant availability’.

4.5 Precision farming

Field mapping for soil phosphorus is available commercially. The difficulty is to combine successfully the conflicting needs for adequate sampling density and for acceptable cost. Typically, samples are taken from one point per hectare as this allows a cost that can be attractive to a grower. At a cost of around £0.4/kg P_2O_5, an average saving of around 15 kg P_2O_5/ha would be needed to cover the cost of sampling and analysis. This saving could be spread over 3 – 4 years as a soil phosphorus map would be unlikely to change significantly in any shorter period. The phosphorus saving needed would be less if potassium use also could be improved. It is possible also that a yield benefit also might occur in which case the economics become much more attractive. At current prices, around 50 – 60 kg additional wheat yield would be needed to cover costs.

Guidance is needed on optimum sampling densities and on the economic return obtainable from mapping.

4.6 Environmental impact

Two environmental issues have been associated with phosphorus: eutrophication of surface waters and cadmium enrichment of soils. The first is a direct consequence of phosphorus movement from soil to water. The second is related to phosphorus through the cadmium content of phosphate rocks and so of phosphorus fertilizers.

4.6.1 Eutrophication

Phosphorus is the controlling nutrient for algal growth in fresh surface waters where concentrations as low as 0.1 mg total P/litre are associated with excessive eutrophication. Losses of 1 – 2 kg P/ha/year, trivial to a grower, can have significant ecological effects. The Water Framework Directive requirement for ‘good ecological quality’ is likely to affect phosphorus use and loss mitigation. Loss of phosphorus to surface water is a particular problem in Northern Ireland where the Phosphorus (Use in Agriculture) Regulations (Northern Ireland) were introduced in 2006.

The behaviour of phosphorus in soils and mechanisms for transport from soil to water have been research subjects for some fifty years. Defra and BBSRC have funded much of this research in the past twenty years. Findings have been reviewed recently by Haygarth and Jarvis (1999) and by Johnston and Dawson (2005).

Losses occur in three ways:

i. Incidental loss where manure or fertilizer application is followed by heavy rainfall and consequent run-off;

ii. Erosion of soil particles entrained in water moving across the soil surface or into drains;

iii. Leaching where the concentration of soil available phosphorus is unusually high.

Of these mechanisms, loss by leaching has been shown to be minimal where soil available phosphorus concentration is not excessive. Defra research has shown that the extent of losses varies widely within and between catchments and through the year. Most loss tends to occur over winter when flow of water, and any entrained soil particles, is greatest. Risk factors associated with the different loss mechanisms have been identified and are incorporated in Cross Compliance requirements and in Environmental Stewardship management options.

Defra (2006) state that UK agriculture is in phosphorus surplus, that is, input exceeds output. However, while this applied to grassland, phosphorus balance in arable crops has become negative over the past decade (Johnston and Dawson 2005). This distinction between grassland and arable cropping in phosphorus balance may need to be made clear.

Most phosphorus loss occurs in discrete areas, particular fields where topography, soil properties or agronomic practices favour loss of soil or where manure is applied. The grower needs to be able to identify any fields at risk, to prevent risk developing in other fields and to devise corrective measures where they are needed. In addition to matching phosphorus application to crop need by regular soil analysis, use of recommendations and taking account of phosphorus in manures, growers should minimise soil loss by cultivating across slopes, avoid soil compaction and rutting and incorporate manures and fertilizers quickly after application (Johnston and Dawson 2005). The main need is for knowledge transfer to ensure both advisers and growers are aware of the problems phosphorus loss can cause and of the ways in which losses can be minimised.

Growers need greater awareness of the environmental issues associated with phosphorus and of the ways in which phosphorus can move from soils to water. Clear guidance is needed on identification of high-risk fields and farming practices and on practical mitigation methods.
No field research would be needed. The requirement is for clear guidance based on existing data.

4.6.2 Cadmium

Cadmium is a heavy metal that can accumulate in the human kidney eventually causing damage. Historically, the main source of cadmium affecting the human population has been metal smelting. As emissions have declined due to improved technology and regulations, attention has turned to other sources. Cadmium is added to soils where sewage sludge products, composts or phosphate fertilizers are applied. Cadmium is a constituent of the rock from which phosphate fertilizers are manufactured and a significant proportion passes into the final products. Some of the cadmium added to the soil in fertilizers or organic materials is taken up by crops and a part of that is translocated to harvested material. Availability of cadmium is affected by soil pH, tending to be low where pH is high. Uptake and translocation of cadmium differ between crop species and can differ between varieties within a species.

Maximum concentrations of cadmium in foodstuffs were set by EC Regulation 466/2001 of 2001. The limit for barley grain is 0.1 mg Cd/kg and in wheat grain 0.2 mg Cd/kg. Some EU states set maximum limits on cadmium concentration in fertilizers in the range 22 – 90 mg Cd/kg P_2O_5 (van Balken 2004). In the UK, the Sludge (Use in Agriculture) Regulations set limits for addition of cadmium to soils in sewage sludge products. Harmonised regulations for the EU have been discussed and member states positions (and a great deal of technical data) are summarised at http://europa.eu.int/comm/enterprise/chemicals/legislation/fertilizers/cadmium_en.htm

Cadmium and lead concentrations were measured in grain samples from the 1998 Cereals Quality Survey (Project Report No. 265, 2001). It was concluded that the cadmium concentration in barley grain would be unlikely ever to exceed the EC maximum limit. However, concentrations in wheat grain could approach or exceed the maximum limit under certain conditions. Liming, and possibly choice of a suitable variety, could help minimise concentrations in grain.

Growers have encountered problems when audited by some assurance schemes, notably Tesco's Natures Choice. Information on the non-nutrient and especially metals content of fertilizers has been requested but representative data for particular fertilizers often are not available. Heavy metals concentrations in manufactured fertilizers invariably are low but do vary with the sources of raw materials or intermediates. AIC produced an explanatory note (available at www.agindustries.org.uk) but growers might be better informed.

5 Longer-term issues

5.1 Variety screening and breeding for improved nutrient recovery and utilisation

Differences between varieties in recovery and utilisation of phosphorus (White *et al.* 2005) and nitrogen (Project Report No. 94, 1994) have been identified. Defra project AR0714 indicated that, in cereals and oilseeds, genetic reductions of 20% in fertilizer nitrogen requirement could be achieved in 15 – 20 years. The ongoing 'GREEN grain' LINK project (LK0959, 2004 – 2009) (Annual Project Report No. 2979, 2005) has identified varietal differences in nitrogen uptake and utilisation in wheat. Differences in nitrogen requirement between older and modern breadmaking wheat varieties have been identified (Project Report No. 400, Annual Project Report No. 3084). Varietal traits in oilseed rape associated with high yield at low nitrogen supply are being investigated in a LINK project (LK0964, 2005 – 2009) (Annual Project Report No. 3116, 2006).

The on-going Defra-funded WGIN (Wheat Genetic Improvement Network, www.wgin.org.uk) and OREGIN (Oilseed Rape Genetic Improvement Network, www.oregin.info) projects include evaluation of varieties for efficiency of nitrogen utilisation (WGIN) or minimum requirement for non-renewable inputs (OREGIN).

The current protocols for National List and Recommended List testing allow one rate of nitrogen (RB209 recommendation for the site, tailored as necessary for malting barley or breadmaking wheat). This technique will miss variety characteristics such as recovery of nitrogen from soil and fertilizer, and nitrogen requirement for grain protein concentration.

Routine inclusion of variety x nitrogen rate trials at several sites would provide much useful information for growers and would help avoid the kind of problem that arose with Xi19 and Malacca. A valuable database would develop to aid plant breeders in improving nitrogen recovery and partitioning. It could prove possible for HGCA to report nitrogen use efficiency as a varietal characteristic.

BBSRC (2004) has included ‘improving efficiency of resource use and minimising waste through lower input, including nutrient efficiency and lower residue systems’ as a priority for crop science research.

The genetic potential of crops for improved nitrogen uptake and utilisation should be better exploited. More routinely gathered information is needed on nitrogen use efficiency in different crop varieties. Variety testing for Recommended Lists should include field trials at more than one rate of applied nitrogen to provide relevant data.
An amendment to the current protocol for RL testing would be needed to include a number of field trials at more than one rate of applied nitrogen. Initially, this might be applied to winter wheat and winter oilseed rape.

5.2 Basis of recommendations

Some aspects of the scientific basis for current nitrogen recommendations could bear examination. For example the current Defra *RB209 Fertiliser Recommendations* takes no account of cereal yield for nitrogen though earlier editions included a yield correction. The assumptions concerning efficiency of recovery by crops of soil and of fertilizer nitrogen used for RB209 have been questioned. These assumptions currently are being assessed in HGCA project no. 3297. For phosphorus, the use of soil index 2 as the target for all arable crops on all soils could be an over-simplification.

The review and replacement of Defra RB209 Fertiliser Recommendations during 2007 and 2008 should meet immediate requirements.

5.3 Climate change

There is an ongoing Defra research programme on the likely impact of climate change. At present, there is high confidence in elevated atmospheric carbon dioxide concentration by 2050, loss of land to the sea and higher average annual temperatures (Defra 2006). Changes in rainfall are expected with drier summers and wetter winters. Greater storminess and more frequent weather extremes may occur.

Effects on crop yields, growth patterns and geographical distribution are inevitable. There will be consequent effects on nitrogen and phosphorus requirements and losses. However, it is presently thought that changes will be adaptive rather than sudden. Some current HGCA research on nitrogen and soil moisture (Project Report 159) is relevant.

Carbon accounting will be applied to crops, initially to those grown for biofuels but extending to all crops. The relationship to nitrogen and phosphorus is through the energy and carbon costs of fertilizer manufacture. Production of phosphorus fertilizers involves small costs but around 4.5 tonnes of CO_2 are emitted for every tonne of nitrogen in ammonium nitrate (Kongshaug 1998).

Some of the research proposed here will be relevant to climate change, notably improvement to the nitrogen economy of oilseed rape and to estimation or measurement of soil nitrogen supply.

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Appendix 1. HGCA research on nitrogen

Relevant HGCA reports and reviews

Project Report No. 14 (1989) Effects of various fertiliser-nitrogen regimes on the milling and baking qualities of home-grown bread-making wheats.

Project Report No. 46 (1992) The effect of fertiliser and soil nitrogen on the overall uptake of nitrogen in the plant and the grain nitrogen content of spring-sown malting barley.

Project Report No. 54 (1992) Nitrogen and fungicide interactions in breadmaking wheat.

Project Report No. OS8 (1994) The effects of site, season and sulphur and nitrogen fertiliser on yield and seed glucosinolates of winter oilseed rape.

Project Report No. 70 (1993) Effects of soil type and nitrogen on the quality of autumn-sown malting barley.

Project Report No. 73 (1993) Nitrogen prediction.

Project Report No. 86 (1994) Effects of nitrogen fertiliser on the protein quality of wheat for ruminants.

Project Report No. 94 (1994) Analysis and modelling of the effects of nitrogen on the growth, partitioning and quality of malting barley.

Project Report No. 109 (1995) Management of breadmaking wheat: effects of extra nitrogen on yield, grain and flour quality.

Project Report No. 119 (1995) Effects of site and nitrogen management on growth and grain quality for malting of winter barley.

Project Report No. 121 (1996) The influence of nitrogen fertilisers on the expression of functional proteins in wheat.

Project Report No. 134 (1996) Variation within fields of potentially available soil nitrogen using the hot KCl technique.

Project Report No. 26 (1998) Evaluation of the performance of commercial soil and plant testing laboratories for analysis of sulphur and nitrogen.

Project Report No. 159 (1998) An integrated approach to nitrogen nutrition for wheat.

Project Report No. 179 (1999) Effects of sowing and harvest dates, nitrogen, PGR and fungicide on yield and malting quality of spring barley.

Project Report No. 219 (2000) The early prediction of breadmaking quality of grain and its improvement through targeted late application of nitrogen fertilisers.

Project Report No. 221 (2000) The residual effects of strobilurin fungicides on soil nitrogen for the following crop.

Project Report No. OS44 (2000) Comparison of the performance of nine commercial laboratories for testing nitrogen and sulphur in plants and soil: a second study.

Project Report No. 250 (2001) Effect on yield and quality of strobilurin applications to spring malting barley.

Project Report No. 258 (2001) Decision support system to design whole farm rotations that optimise the use of available nitrogen in mixed arable and horticultural systems: on-farm testing.

Research Review No. 47 (2001) Foliar-applied nitrogen for grain protein and canopy management of wheat.

Project Report No. 280 (2002) Nitrogen management in second wheats following strobilurin fungicide programmes.

Project Report No. 303 (2003) Integrating manures, slurries and biosolids as nutrient sources in arable crop rotations.

Project Report No. 314 (2003) Effects of nitrogen, seed rate, fungicide and PGR on yield and standing power of spring oats.

Project Report No. 351 (2004) Root system management in winter wheat: practices to increase water and nitrogen use.

Project Report No. 359 (2005) Managing roots, nitrogen and fungicides to improve yield and quality of wheat.

Project Report No. 367 (2005) Nitrogen management in spring malting barley for optimum yield and quality.

Annual Project report No. 2660 (2004 results) Nitrogen management in spring malting barley for optimum yield and quality.

Annual Project Report No. 2979 (2006 results) Genetic reduction of energy use and emissions of nitrogen through cereal production: green grain.

Annual Project Report No. 3084 (2006 results) Optimising fertiliser nitrogen levels for modern cereal crops.

Project Report No. 400 (2006) Managing nitrogen applications to new Group 1 and 2 wheat varieties.

Project Report No. 401 (2006) Managing late N applications to meet wheat protein market requirements using pre-harvest near infrared (NIR) sensing (LK0927).

Project Report No. 402 (2006) Management of oilseed rape to balance root and canopy growth.

Research Review No. 58 (2006) Soil mineral nitrogen testing: practice and interpretation.

Research Review No. 61 (2006) Wheat as a feedstock for alcohol production.

Annual Project Report No. 3116 (2006 results) Breeding oilseed rape with a low requirement for nitrogen fertiliser (SAPPIO 00323, LINK 0979).

Annual Project Report No. 3277 (2006 results) Late nitrogen applications to improve yield of oilseed rape.

Relevant HGCA Topic Sheets and Project Progress

TS4 (1997) Nitrogen management for breadmaking wheats.

TS20 (1998/99) Growing spring malting barley.

TS28 (1999) Wheat as a dairy cow feed.

TS37 (2000) Effective winter oilseed rape canopies.

PP6 (2000) Using animal manures on arable crops.

TS40 (2000) Canopy management in winter wheat.

TS63 (2002/2003) Managing arable crops in NVZs in England.

TS63S (2003) Managing arable crops in NVZs in Scotland.

TS64 (2002/2003) Using manures and biosolids on cereal crops.

TS68 (2003) Nitrogen management of strobilurin treated winter wheat.

TS76 (2003/2004) Managing spring malting barley for consistent grain characteristics.

TS81 (2004/05) Managing spring malting barley to achieve 1.65 – 1.80 percent N grain.

PP14 (2006) Growing wheat for alcohol or biofuel production.

Appendix 2 HGCA research on phosphorus

Relevant HGCA reports and reviews

Project Report No. 137 (1997) Plant testing to determine the P and K status of wheat.

Research review No. 40 (1999) Phosphate and potash fertiliser recommendations for cereals: current issues and future needs.

Project Report No. 224 (2000) Development of on-farm plant tests for phosphate and potassium in wheat.

Project Report No. 265 (2001) Cadmium and lead in British wheat and barley: survey results and factors affecting their concentration in grain.

Project Report No. OS58 (2002) Plant and soil testing to assess the adequacy of phosphorus supply to winter oilseed rape.

Project Report No. 322 Field assessment of P and K plant testing for winter wheat.

Relevant HGCA Topic Sheets and Project Progress

Topic Sheet 19 (1998/99) Diagnosing P and K requirements of winter wheat

Project Progress 6 (2000) Using animal manures on arable crops.

Topic Sheet 70 (2003) Assessing within-field soil variability.

Appendix 3 Defra nitrogen projects relevant to cereals and oilseed rape

Nitrate leaching

KT0104	Technology transfer: effective nutrient use for arable crops
NT0101	Leaching from agricultural soil - management practices and measurement techniques (New code NT1 301)
NT0102	To use information from NT0101 to assess the effects of husbandry practices
NT0103	To provide support to IACR Brimstone Farm project
NT0104	Nitrogen cycling in arable soils (new codes NT1302/NT1901)
NT0107	To provide guidelines on systems which minimise nitrate leaching in clay soils (new code NT1 303)
NT0108	Interactions between soil structure and crop growth on leaching (Brimstone) (New code NT1304)
NT0109	To provide support to Brimstone Phase Ill (New code NT1305)
NT0110	Nitrate leaching - management practices in crop rotations (New codes NT1306/NT13010/NT10807/NT1808/NT1805)
NT0111	Timing N applications to avoid soil immobilisation (New code NT1309)
NT0113	To develop an approach for statistical analysis of data from NT0102/NT0201 To provide guidelines for improved nitrogen use on potatoes, oilseed rape & sugar beet (new code 1307)
NT0302	To assess the contribution to soil organic matter of leys, straw, FYM and the effects on crop yield
NT0303	To monitor nitrate leaching from organic farms (joint with ARP division)
NT040I	To prepare guidelines on the use of cover crops to minimise leaching. (new code NT1508)
NT0402	To study the use of cover crops in reducing N leaching
NT0501	To develop guidelines for estimating the effect of straw incorporation on N budgets (new code NT1505)
NT0502	To determine the immobilisation of N by incorporated straw and subsequent release
NT0702	To develop strategies for minimising fertiliser residues in greenhouse crops and associated nutrient surpluses
NT0704	To develop strategies for minimising fertiliser application rates compatible (New code NTI 507)
NT0801	To study nitrogen losses and transformations in arable land and to model these processes
NT0804	To improve understanding of the uptake of nitrates for the development of models of nutrient budgets
NT0805	To establish models of nutrient budgets & devise new methods of fertiliser application (New code NT1204)
NT0806	Leaching in cracking clay soils (New code NT1308)
NT0810	Review of mineralisation (arable crops)
NT0811	Review of mineralisation (agricultural systems)
NT0817	Soil sampler for mineral nitrogen
NT1101	Buffer zones
NT1201	Assessment of techniques for persuading farmers to adopt nitrate reducing practices
NT1202	A system for improved fertilizer recommendations for arable and

	horticultural crops
NT1203	Management practices, leaching and efficiency of nitrogen use (Previously NT0102)
NT1204	To devise new methods of fertiliser application to reduce nutrient use and pollution (previously NT0805)
NT1207	Growth and nitrogen recovery (previously NT0102)
NT1214	Studies of on-site crop residue management strategies to control N losses to the environment
NT1301	Nitrate leaching - method development: Chalk soils (previously NT0101)
NT1303	Soil drainage and leaching (previously NT0107)
NT1304	Interactions between soil structure and crop growth on leaching (Brimstone)(previously NT0108)
NT1305	To provide support to Brimstone phase III (previously NT0109)
NT1306	Effects of straw incorporation and cultivation (previously NT0110)
NT1307	To provide guidelines for improved nitrogen use on potatoes, oilseed rape and sugar beet (previously NT0201)
NT1308	Leaching in cracking clay soils (previously NT0806)
NT1309	Timing N applications to avoid soil immobilisation (previously NT0111)
NT1310	Effects of crop cover on aquifer recharge (previously NT0102)
NT1311	Medium-term effects of sub-optimal N applications
NT1312	N measurements on set-aside
NT1313	On-farm monitoring of nitrate leaching from organic rotations (previously NT0305)
NT1316	Nitrate leaching from ploughed-out five year set-aside
NT1318	Effect of cultivation on soil nitrogen mineralisation
NT1319	Losses of nitrogen as dissolved organic N
NT1503	Re-examination of existing data on N mineralisation and the construction of a database to analyse existing and new data
NT1504	N mineralisation in arable conditions
NT1505	N requirements of straw incorporation (previously NT0501)
NT1506	N requirements of straw incorporation (previously NT0502)
NT1508	Cover crops (previously NT0401)
NT1510	The measurement of mineralisation in field soils IACR/IGER part
NT1511	The measurement of mineralisation in field soils ADAS part
NT1512	The measurement of mineralisation in field soils. Reading part
NT1513	Use of CO_2 efflux measurements to validate and improve components of the SUNDIAL model
NT1514	Mechanisms of mineralisation in arable crops (previously NT0104)
NT1515	The effects of physical, chemical and microbiological factors on the release of N from crop residues
NT1518	The distribution of soluble organic nitrogen in arable soils.
NT1519	Modelling N mineralisation
NT1520	Indices of nitrate loss from arable soil
NT1521	Measuring the contribution of below-ground inputs to mineralisation
NT1523	Studies of microbial and chemical factors affecting nitrogen release from crop residues
NT1525	Refining the use of soil organic matter as an indicator of soil N
NT1526	The contribution of cover crops incorporated in different years to nitrogen mineralisation
NT1527	Writing up of work on effects of straw residues on N cycling

NT1803	The establishment of a new system study: nitrogen flows in mixed farming systems
NT1803	The establishment of a new system study: nitrogen flows in mixed farming systems
NT1804	To use information from NT0101 to assess the effects of husbandry practices on N loss from soil (Previously NT0102)
NT1805	Effects of crop rotation and management practice on nitrate leaching from a sandy soil (Previously NT0110)
NT1 807	Effects of crop rotation and husbandry and nitrogen rate on nitrogen leaching and gross margins in an arable rotation
NT1810	Nitrogen losses from whole farming systems: incorporation of additional measurements of N loss in existing studies.
NT1811	A desk study to extrapolate results from simple experiments on N losses to the system level; an arable system.
NT1817	Studies on nitrogen use and leaching in rotation and mono-culture cereal cropping (Previously NT0112)
NT1818	Nitrogen deposition from the atmosphere and its contribution to nitrate leaching
NT1822	Strategies to further reduce N leaching loss from LIFE
NT1823	Optimising efficiency of nitrogen use across whole farm rotations: mitigation for arable and ley-arable systems
NT1830	Effects of crop yield. Management and N fertiliser rate on nitrate leaching, yield and soil N status - Oasby and Ropsley
NT1830	Effects of crop yield. Management and N fertiliser rate on nitrate leaching, yield and soil N status - Qasby and Ropsley
NT1840	Nutrient balancing for farm systems: Technology transfer to the industry
NT1852	Sustainable drainage-scoping study to determine effects of drainage status on hydrology, agricultural management & nutrient movement.
NT1853	The Coates Farm Study II: Nitrogen flows in a changing mixed farming system
NT1853	The Coates Farm Study II: Nitrogen flows in a changing mixed farming system
NT1901	Minimising total losses of nitrogen from agriculture (Previously NT0104)
NT1907	Measurement of full N cycle: arable soils
NT1916	Leaching of soluble organic N
NT2101	N & C mineralisation of soil organic matter and crop residues
NT2208	Contribution to the nitrate conference
NT2210	Contribution to the nitrate conference
NT2212	Special issue of Soil Use and Management - Tackling nitrate from agriculture
NT2213	Publication of MAFF nitrate conference papers in Soil Use and Management journal
NT2301	Analysis of the seasonal variation in soil mineral N dataset
NT2302	Utilising N in cover crops
NT2304	Improvement of N capture and N use efficiency from foliar applied urea through manipulation of urease gene expression
NT2305	Developing wheat genotypes with reduced nitrogen requirement by manipulation to decrease Rubisco content
NT2308	Long-term effects of nitrogen fertilisers on the fertility of arable soils
NT2310	Long term effects of on-site strategies to control losses of crop residue

	nitrogen to the environment
NT2501	Development of prototype soil nitrogen supply calculator
NT2502	An evaluation of Well_N and 7th edition of RB209 in providing advice for good fertiliser practice in NVZ areas
NT2504	Desk study to evaluate the practical benefits and constraints of fertiliser placement
OC9002	Studies on nitrogen use and leaching in rotational and monoculture cereal cropping
OC9114	Denitrification of riparian buffer zones
OC9412	Genetic manipulation of the nitrogen efficiency of wheat
SP0202	To assess inputs of nutrients and acidity from the atmosphere and leaching
SRO121	The calibration and evaluation of capacitance sensors for the measurement of soil water fluxes

Loss of ammonia to air

AM0101	National Ammonia reduction strategy evaluation system (NARSES)
AM0102	Modelling and measurement of ammonia emissions from ammonia mitigation pilot farms.
AM0104	Desk study to quantify relationships between incorporation techniques & their work-rate on reducing NH_3 emissions
AM0107	Production of a Defra booklet - Bringing down ammonia emissions. Progress in research and development
AM0l08	Updating the ammonia emissions inventory for the UK for 1999
AM0113	Updating the inventory of ammonia emissions from UK agriculture for the years 2000 and 2001
AM0119	In depth review of the outputs of DEFRA as programme of research on measurement and control of ammonia emissions from agriculture
AM0120	National evaluation of the impact of improved manure management for reducing ammonia emissions on nitrate leaching
AM0121	Ammonia R&D review
AM0123	A collation and analysis of current ammonia research
AM0126	Further evaluation of ammonia mitigation options
AM0130	Scoping the use of process modelling for use in the assessment of ammonia mitigation options
CC0252	Contribution to NERC GANE programme (NERIT/S/2000/001 95) ES0114 Integrating slurry management strategies to minimise nitrogen losses - application rates and method (Slurry - NR)
ES0l15	Optimising slurry application timings to minimise nitrogen losses:OPTI-N
ES0l16	Field work to validate the manure incorporation volatilisation system (MAVIS)
NT0105	To quantify ammonia emissions from arable agriculture and provide guidelines on minimisation
NT01401	Open Competition: Use of injectors and low trajectory spreaders
NT2104	Contribution to NERC GANE programme
NT905	Ammonia fluxes over arable land
WA0203	Quantify losses of pollutants after application of wastes to land and understand controlling mechanisms

WA0604	To measure the influence of livestock waste application on gaseous emissions from land and to identify likely controls
WA0613	Distribution, deposition and environmental impacts of ammonia emitted by agriculture
WA0616	Control of atmospheric ammonia emissions
WA0617	Effect of rainfall on ammonia emissions from injected slurry
WA0623	Control of atmospheric ammonia emissions

Loss of nitrous oxide to the air

AM0127	Updating the inventories of ammonia, nitrous oxide and methane from UK agriculture for the years 2002-05
CC0207	Greenhouse gas absorption and emission in arable soils
CC0224	The effects of cultivation and residue incorporation on nitrous oxide emissions from arable soils
CC0226	Review of carbon substrates which stimulate denitrification and N20 emission in agricultural soils
CC0227	A review of factors influencing N_2O and N_2 emissions from agricultural soils to identify abatement strategies for N_2O
CC0229	Cost curve assessment of mitigation options in greenhouse gas emissions from agriculture
CC0232	Diurnal variation in nitrous oxide fluxes and impact on agricultural emission factors
CC0233	Nitrous oxide emissions from agricultural soils, and the potential for their reduction
CC0237	Evaluating the ‘boundary line’ method for predicting N_2O emission (and denitrification) from manures applied to soil
CC0238	N_2O and denitrification measurements on nutrient demo farms (add on to NT2001)
CC0241	Long-term measurement of N_2O emission from manures
CC0243	Application and development of a UK nitrous oxide emission model
CC0246	The effect of FYM storage conditions on land application practices on N_2O emissions
CC0248	Emission factors for N_2O from soils
CC0251	New methods to quantify agricultural nitrous oxide emissions (MANE)
CC0256	N_2O losses following application of organic (sewage sludge & animal manure) and inorganic fertilisers to winter wheat
CC0259	Review of Defra research programme on greenhouse gas emission and control
CC0262	Mitigation of greenhouse gas emissions from agriculture: Socioeconomic impacts (CTE018)
CC0272	Synopsis and review of relevant projects to assess mitigation options for nitrous oxide and methane to inform the Climate Change Programme.
NT1903	Denitrification in the unsaturated zone (New code NTI 903)
NT1915	Additional work for NT1907: Measurement of full N cycles: arable soils
OC9114	Denitrification of riparian buffer zones
OC9601	Research to produce an inventory of nitrous oxide emissions derived from agriculture
SP0518	The interaction of minimal cultivation regime and N fertiliser rate on soil C and N cycling: Ropsley

WA0637	Denitrification and nitrous oxide emissions following new slurry application techniques for reducing ammonia losses
WA0706	Ammonia and nitrous oxide emissions from the utilisation of slurry and FYM from beef cattle

Project NT26

NT2601	Alternative nitrogen-containing fertiliser materials
NT2602	A scoping study to assess the feasibility of increasing the efficiency of use of nitrogen-containing fertilisers
NT2603	The behaviour of some different fertiliser-N materials: initial field experiments
NT2604	Ammonia emissions from nitrogen fertilisers: wind tunnel construction
NT2605	The behaviour of some different fertiliser-N materials: main experiments
NT2606	Ammonia emissions from nitrogen fertilisers: wind tunnel construction (support to project NT2605)
NT2610	Spreading accuracy of solid urea fertilizers

Soil acidification

SP0202	To assess inputs of nutrients and acidity from the atmosphere and leaching
SP0203	To improve model of lime loss from arable and grassland soils

Genetic improvement related to nitrogen

AR0703	The Defra oilseed rape improvement network – OREGIN
AR0709	The Defra wheat genetic improvement network – WGIN
AR0714	A study of the scope for application of crop genomics and breeding to increase nitrogen economy within cereal and rapeseed based food chains
LK0959	Genetic reduction of energy use and emissions of nitrogen in cereal production – GREEN grain
LK0964	Novel resources for oilseed rape breeding. Improving harvest index (ORB-LINK)

Appendix 4 Defra projects related to manures

ES0106	Brimstone-NPS: Integrated land use & manure management systems to control diffuse nutrient loss from drained clay soils
ES0114	Integrating slurry management strategies to minimise nitrogen losses - application rates and method (Slurry - NR)
ES0115	Optimising slurry application timings to minimise nitrogen losses: OPTI-N
ES0116	Field work to validate the manure incorporation volatilisation system (MAVIS)
KT0105	Manure Nutrient Evaluation Routine (MANNER - NPK)
KT0106	MANNER - Policy support model (MANNER-PSM)
KT01013	Nutrient management decision support system (PLANET)
LK0904	Integrating organic amendments as nutrient sources in arable crop rotations
NT0309	N losses from organic manures (new code NTI 405)
NT0311	Nitrogen losses from drained clay soils receiving organic manures (new code NT1406)
NT0604	Provide guidance of efficient use of cattle slurry & FYM as nutrient sources (new code NT1404)
NTI401	Open Competition: Use of injectors and low trajectory spreaders
NT1402	To improve guidelines on waste management practices which will minimise the risk... (NT0301)
NT1405	N loss from organic manures (previously NT0309)
NT1406	Nitrogen losses from drained clay soils receiving organic manures
NT1408	Development of user-friendly systems for on-farm estimation of the available nitrogen content in solid manures/slurries.
NT1410	Nitrate leaching risk from livestock manures (Previously NT0310)
NT1412	Improved prediction of nitrogen availability and losses following land application of organic manures
NT1414	Development and evaluation of a rapid test strip method for determining the N supplying power of slurries.
NT1415	Improved precision of manure and slurry application
NT1421	Economic evaluation of improved manure application technique (for AU NT20)
NT1422	Critical drainage and nitrate leaching losses from manures applied to freely draining soils (for AU NT20)
NT1423	Good MANNERs (MANure Nitrogen Evaluation Routines): development of an improved manure N decision support system.
NTl501	Fate of nitrogen from organic manures
NT1528	Mineralisation of organic N from farm manure applications (extension to NT1501)
NT1808	Effect of organic manures on medium term N cycling and nitrate leaching (Previously NT0110)
NT1831	The effect of organic manures on medium term N cycling and nitrate leaching - second phase
NT1835	The effects of manure application to land on N loss pathways to air and water
NT1849	Co-operative agreements in agriculture
NT2001	Integration of animal manures in crop and livestock farming systems: nutrient demonstration farms
NT2002	Effect of manure spreading imprecision on crop yield.

NT2004	Minimising nitrogen losses in drainage water following slurry applications to drained clay soils (add-on to NT1028)
NT2006	Manure analysis database (MANDE)
NT2008	Nitrogen value of solid manures - effects of contrasting manure management practices
NT2009	Developing improved sampling guidelines for liquid and solid manures
NT2010	Environmental impacts of solid and liquid manure systems
NT2106	Mineralisation of organic nitrogen from farm manure applications (extension to NT 1528)
NT2508	Rapid reduced cost analysis of manures by near-infrared spectroscopy
OC8906	Nitrogen leaching risk from livestock manures
OC9220	Surface layer water pollution by livestock waste
OC9402	Improve precision of manure application
WA0506	Review of appropriate techniques to measure slurry nutrient status
WA0508	Manure nitrogen model
WA0646	Fate of N following land application of solid and liquid pig manures
WA0726	Application of NIR spectroscopy to rapid, cost effective prediction of manure and slurry composition

Appendix 5 Defra phosphorus projects relevant to cereals and oilseed rape

ES0l10	Lowland Catchment Research (LOCAR)
NTl002	Sheet erosion and phosphate loss
NT1003	Phosphate loss from agriculture
NT1004	Phosphorus loss from agriculture
NT1006	Co-ordination of phosphate R&D
NT1007	Mobility of phosphorus in arable soils
NT1008	Phosphorus leaching from phosphorus rich soils
NT1009	Analytical techniques for phosphorus in water
NT10I0	Analytical techniques for phosphorus in water
NT1011	P losses from organic manures
NT1012	Phosphate loss from cracking clay soils
NT1013	Phosphorus loss in surface run-off from different land uses
NT1014	Erosion and phosphorus loss estimation from NSI sites
NT1015	Phosphorus mobility in arable soils (continuation of NTI 007)
NT1018	Strategies to control phosphorus loss from agricultural land: a review
NT1020	Additional measurements of P loss from Rosemaund and Trent catchments
NT1021	Additional measurements of P loss from Gleadthorpe lysimeters
NT1022	Compilation of an inventory of coefficients of P loss from agricultural land
NT1023	Phosphorus co-ordination project
NT1024	Phosphorus inputs to large river systems: Quantifying the diffuse export coefficients for the river Swale catch ments
NT1025	Identification of high risk soils for sediment - associated P loss in subsurface flow and an assessment of its???
NT1026	Brimstone phase IV: Reducing phosphorus losses from arable soils
NT1027	Measurements of phosphorus loss at the farm and catchment scale
NT1028	Measurements of phosphorus loss from manures
NT1029	Leaching of P in lysimeters
NT1030	Review of phosphorus retention at the field and catchment scale
NT1031	Brimstone Farm: Systems to minimise the loss of nutrients especially P, to drainage water from a structured clay soils
NT1033	Field and farm scale investigation of the mobilisation and retention of sediment and phosphate
NT1036	Quantification of national P loss from agriculture to water
NT1037	Measurement of P stored in stream biomass and bed sediment at Rosemaund and Trent
NT1040	What causes the P change-point to differs much between soils
NT1042	Indicators of P transfers from agricultural land and classification of NSI soil P data
NT1044	Diffuse phosphorus transfer in the Hampshire Avon catchment: A scoping study on two tributaries
NT1046	Assessment of P leaching losses from arable land
NT1314	Leaching of nutrients other than nitrogen from an arable sandy soil: long-term lysimeter data and paper writing
PE0l01	Co-ordination role for the Defra -RMED phosphorus research programme
PE0105	Towards a national consensus on indicators of P loss to water from agriculture
PE0106	An environmental soil test to determine potential for sediment & P

	transfer in run-off from agricultural land (DESPRAL)
PE0109	Using the Psalm model to interpret the phosphate change-point and its relation with iron in the soil
PE0111	Towards understanding factors controlling transfer of phosphorus within and from agricultural fields
PE0l14	Assessment of the implications of NVZ designations for P loss from agriculture to surface waters
PE01016	Linking agricultural land use and practices with a high risk of phosphorus loss to chemical and ecological impacts in rivers
PE0l18	Co-ordination role for the Defra -RMED phosphorus research programme
PE0201	Impacts of targeted mitigation options on phosphorus loss at the field and catchment scale
PE0203	Cost curve assessment of phosphorus mitigation options relevant to UK agriculture
PE0205	Strategic placement and design of buffering features for sediment and P in the landscape
SP0505	Soil phosphorus and heavy metal contents on the nutrient demonstration farms

Appendix 6 Advisory systems and aids for nitrogen application

Various advisory systems and aids to decision making are used in the UK and other European countries. There are four main types:

i. Tables of recommendations for different soil, climate and crop conditions (eg. RB209, SAC Guidelines)
ii. Crop models of varying complexity that take account of field-specific conditions (eg. N Plan, Well_N™)
iii. Measurement based systems involving chemical analyses of soil, crop or sap (eg. Nmin, SAP) or non-destructive crop measurements (eg canopy management, N Tester, N Sensor)
iv. Certificated advisers (eg. FACTS)

Use of the different systems is not exclusive. For example, measurements of soil mineral nitrogen may be used directly as a guide to nitrogen requirement or may be input to a table or model based system. Certificated advisers may reach a decision alone or may use any of the other systems.

Each European country has its own preferred advisory systems. For example, in Italy and Greece, competent advisers are relied on. Measurement of soil mineral nitrogen is used in Austria, Denmark, Finland, Germany, Netherlands and the UK though the way in which results are used differs between countries. The JUBIL method developed at INRA in France involves measurement of nitrate concentration in plant sap. A similar system is available in the UK from Omex. INRA also developed the AZOBIL and STICS models that provide fertilizer recommendations based on estimates of crop nitrogen requirement and contributions of nitrogen from soil, manures and crop residues.

The main systems currently used in the UK for cereals and oilseed rape outlined below. SUNDIAL is included though it is not yet available commercially to growers.

Table-based systems

DEFRA Booklet RB209 Fertiliser Recommendations/PLANET: For England, Wales and Northern Ireland, this is a required source of information on fertilizer recommendations – not just tables but explanations of the principles of crop nutrition and a great deal of reference material. RB209 is complementary to the more sophisticated recommendation systems and covers nutrients other than nitrogen. RB209 is available in interactive format for PCs as PLANET.
Further information at www.defra.gov.uk and www.planet4farmers.co.uk. Available from: The Stationery Office, The Publications Centre, PO Box 29, Norwich, NR3 1GN tel 0870 6005522 (RB209) or from www.planet4farmers.co.uk (PLANET).

SAC recommendations: SAC produce fertilizer recommendations for Scotland that are available in the *Guidelines for Farmers in Nitrate Vulnerable Zones* distributed by SEERAD. As in RB209, recommendations take account of soil type, previous cropping, any manures applied and winter rainfall.
Further information at www.scotland.gov.uk.

Model-based systems

SUNDIAL: The SUNDIAL dynamic model was developed at Rothamsted Research to simulate nitrogen pathways through the soil and plant. Inputs include soil type, climatic data, cropping history, sowing date and expected yield. SUNDIAL is not a crop growth model, hence the need for expected yield as an input, but simulates nitrogen movement and transformations. Amounts of nitrogen in various pools in the soil, lost by leaching, volatilisation or denitrification and taken up by the crop are updated weekly within the model. SUNDIAL is used as a research tool and has been developed as a fertilizer recommendation system (SUNDIAL-FRS) for most annual arable and some horticultural crops.
Further information at www.rothamsted.ac.uk/aen/sundial/sundial.htm.

eNhance: Terra Nitrogens eNhance uses a target yield and, in the case of cereals, grain protein specification to determine total nitrogen requirement of the crop. Estimated contributions of nitrogen from mineralization and manures are then subtracted to leave a residual amount that is supplied by fertilizers. Soil Nitrogen Supply index can be entered if available, otherwise tabulated values are used. Terra maintain around thirteen sites on differing soils where soil mineral nitrogen levels are monitored during late winter and early spring. These provide data that can be used in estimating soil mineral nitrogen for eNhance. eNhance is intended for use by, or with, a FACTS certificated adviser. The system is available free of charge to those who register at the Terra web site and data can be stored for later retrieval.
Further information at www.teranitrogen.co.uk. Available from Terra Nitrogen (UK) Ltd., Florence House, Radcliffe Crescent, Thornaby, Stockton on Tees, TS16 6BS.

N Calculator: The Kemira Grow-How N Calculator uses estimated yield, soil type, sowing date, variety and fungicide programme to estimate the total nitrogen requirement of the crop. Nitrogen supply from non-fertilizer sources is then entered as the results of an N Min analysis (see below). Alternatively, an estimate of this supply is supplied from a table showing previous crop and soil type. Fertilizer nitrogen requirement is then the difference between total requirement and supply from non-fertilizer sources. N Calculator is available free of charge at the Kemira Grow-How web site.
Further information at www.kemira-growhow.com/uk. Available from: Kemira Agro UK Ltd, Ince, Cheshire, CH2 4LB. tel 0151 3572777.

N Plan: Hydro Agris N Plan is based on a model of soil N supply, crop growth and response to N that in turn derived from a long programme of field experimentation. The model, introduced in 1980 and updated and developed annually since, is most comprehensive for winter wheat and winter barley but covers oilseed rape, potatoes and spring barley. For wheat and winter barley, N Plan provides estimates of potential yield based on site characteristics. Inputs required comprise soil texture, rooting depth, previous cropping, seedbed cultivation method and fertilizer, spring tiller count (for wheat) and details of any manures applied. A comprehensive help function provides guidance on inputs. In addition to the recommendation for fertilizer N, a cab guide can be printed to help in field operations and record keeping. N Plan is available free of charge on CD and via the internet.
Further information at www.yara.co.uk. Available from: Yara UK Ltd, Immingham, N Lincolnshire, DN40 2NS.

WELL_N™: This model uses data gathered before and during the growth of a crop to give nitrogen fertiliser recommendations. The model, developed by HRI from the research model N_ABLE, was introduced in 1994. An optimum recommendation for

fertiliser requirement is given based on yield. Optimum nitrogen fertiliser defined as the level where a further 10kg/ha of nitrogen fertiliser increases yield by less than 1%.The WELL_N™ model provides estimates of the fresh and dry crop yield, nitrogen content of crop and its residues. It also provides estimates of leaching since the start of the run and soil mineral N states at harvest, for different N fertiliser rates. This additional information enables alternate strategies of fertiliser application to be formulated. WELL_N™ and RB209 recommendations were compared in Defra project NT2502.
Further information at www.warwickhri.ac.uk. Available from: Warwick HRI, Wellesbourne, Warwick, CV35 9EF tel 024 76574455.

Measurement-based systems

Kemira N-Min: This is a system for measuring the amount of N that is available to the crop, and that which is expected to become available, by taking and analysing soil samples. Samples, at least 15 per field, are taken by the user and submitted to the laboratory by a pre-arranged courier in freezer kits that are supplied. Results are returned, usually within 10 days, to show information on soil N supply and an N-Calculator to establish fertilizer N requirement. Soil pH, P, K and Mg status are also recorded. The N Calculator can be used independently of N Min.
Further information at www.kemira-growhow.com/uk. Available from: Kemira Agro UK Ltd, Ince, Cheshire, CH2 4LB. tel 0151 3572777.

Deep N and Soil N Service: These two services are very similar and are both based on soil sampling to 90cm to measure available N. Sampling is by the service provider and employs the Geonor mechanised soil sampler taking 20 cores per field. Cores are bulked to give one representative sample which can be divided into three layers if required. For autumn sown crops, the sampler operator has a chart to estimate the amount of N already taken up by the crop.
Further information at www.envirofield.co.uk. Available from: Yara UK Ltd, Immingham, N Lincolnshire, DN40 2NS (Deep N) or Envirofield tel 01284 850473 or 07775 558920 fax 01284 851028 (Soil N Service).

Sap testing: Analysis of nutrient levels found in sap of crops at defined growth stages. Presents a current snapshot of nutrient status rather than an historic one, allowing nutrient management through the growing season. Oldest actively growing leaf and petiole is sampled from at least 20 plants. Sampling should take place early morning (before 10am) to allow correct interpretation. In addition to N, other major, minor and micro nutrients are measured. Sample is submitted to Omex for analysis.
Further information at www.omex.com. Available from: Omex Agriculture Ltd, Bardney Airfield, Tupholme, Lincs, LN3 5TP. tel Gidon Bahiri 01553 760011 or mobile 07850 475018.

Canopy management: Research funded by HGCA on canopy management in wheat and oilseed rape is used in various ways to aid nitrogen decisions. SOYL Ltd offer SOYLsense, a crop mapping service that provides LAI and nitrogen requirement maps in wheat.
Further information at www.soyl.co.uk/soylsense/index.html. Available from SOYL Ltd, Red Shute Mill Business Centre, Hermitage, Newbury, Berkshire, RG18 9QL, tel. 01635 204190.

N Tester: Yaras N Tester is intended to be used in conjunction with N Plan to refine the late (GS33 on) N applications to cereals. It comprises a hand-held meter which is closed onto a leaf to take a measurement. 30 leaves must be measured to help ensure a representative reading for a field. The method is based on relationships derived between chlorophyll (which the meter detects) and plant N status and requirement. The N Tester is normally leased for a year during which a dedicated phone line is used to obtain the N recommendation (this takes into account variety). Use of the N Tester on other crops is under development.
Further information at www.yara.co.uk. Available from: Yara UK Ltd, Immingham, N Lincolnshire, DN40 2NS.

N Sensor: Yaras N Sensor is a tractor mounted and used to vary the rate of fertilizer N applied within the field to take account of variation in crop N requirement. The system is based on relationships between different components of the reflected light spectrum and crop N status and requirement. Four sensors detect light reflected from the crop and another detects incoming radiation from the sky. This arrangement allows changes in the reflected spectrum due to sun angle and clouds to be taken into account. A recently developed version of the N Sensor has an inbuilt light source to overcome problems of ambient light and to allow 24 hour operation. Further information at www.yara.co.uk. Available from: Yara UK Ltd, Immingham, N Lincolnshire, DN40 2NS.

Agros Nitrogen Meter: Measures plant-available N (ammonium-N) in slurry/manure and sludges. Equipment comprises a plastic container with meter, measuring tube, reagent jar and measuring scoop. A hygrometer is included for measuring phosphorous and dry matter. The kit is contained in a plastic case and includes enough reagent for about 30 tests. Measurement is takes a few minutes. First, the scale is selected, depending on the type of manure to be measured. The manure sample, water and a chemical reagent are then added, using supplied measures, which should be full to the brim. After the lid has been placed in position, the contents are stirred for 4 to 8 minutes. The result for plant available N is then read directly on the scale - no conversion tables are necessary. The divergence from laboratory methods is normally under 5%.
Available from: Qualex, 51 Dauntsey, Chippenham, Wiltshire, SW15 4HN, tel 01249 890317, fax 01249 892323 e-mail robert@j.painting.freeserve.co.uk or from Rekord Sales (GB) Ltd, Manor Road, Mancetter, Atherstone, Warwickshire, CV9 1RJ. Tel 01827 712424.

Quontofix Nitrogen Meter: Measures ammonium-N (quickly available N) content in slurry and manures. Equipment comprises slurry and reagent containers, water reservoir and calibrated tube and measurement devices. The base of the instrument is filled with water by pouring through a calibrated tube, until black zero mark is reached. 100ml of slurry is then poured into the jug provided and thence into a larger vessel. A further 200ml of water is added and the container stoppered
150ml of reagent is then introduced. The container is shaken at one and two minutes when the reading can be taken. The quantity of N is expressed in terms of available ammonium-N in kg per m3.
Available from B.M.Sykes, Cwmwyntell, Letterston, Haverfordwest, Pembrokeshire, SA62 5TJ. telephone/fax: 01348 840420.

Certificated advisers

FACTS (Fertiliser Advisers Certification and Training Scheme) was established in the UK in 1993. Entry to the scheme is by examination, usually following a formal training course. Those passing the examination can join the BASIS Professional Register (demonstrating continuing competence through cpd points) or the Annual Scheme that provides an information service and technical newsletters. Most newly qualified FACTS advisers join both. There are around 2000 FACTS advisers, the number increasing over recent years.
Further information at www.factsinfo.org.uk and at www.basis-reg.com.