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Soil mineral nitrogen testing: Practice and interpretation

by

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Summary

Obtaining a reliable estimate of the Soil Nitrogen Supply (SNS) can be an important step in optimising nitrogen fertiliser doses, or quantifying potential losses to the environment. Where high or uncertain amounts of soil nitrogen are present, direct measurement of available Soil Mineral Nitrogen (SMN), as nitrate or ammonium, has been advised in preference to predictions based on previous crop, rainfall and soil type. However, a lack of confidence in test results, due to variation in the values indicated by analyses performed at different laboratories, and failure to meet expectations as to their accuracy as predictors of optimum nitrogen fertiliser dose, mean that this potentially useful tool could be under-used. The aim of this review was to examine how SMN analysis has evolved since its development, to identify possible causes of error and variation, and to re-define how best to utilise the technique.

Research in Germany in the 1970s found large differences between soils in the amount of SMN, even following the same previous crop. The highest accumulation typically occurred in early spring, with evidence that wheat was able to utilise this to at least 100cm depth. Soil nitrogen within rooting depth was found to contribute to crop requirement as effectively as applied nitrogen fertiliser.

Subsequent studies in the UK have identified significant seasonal variation in SMN, linked to soil type, previous crop, fertiliser use and weather, confirming direct measurement to be important. Current guidance is to test medium or heavy soils in autumn or spring, but for high rainfall areas or light soils to test in late winter or spring. Published research suggested that autumn sampling provides a better guide to optimum applied nitrogen dose. However, consultation revealed that spring sampling is considered by most to be preferable, as this removes the uncertainty of winter losses. The most appropriate time will depend on the purpose for which the information is being obtained, and the likely balance between net mineralisation (from crop residues or organic matter) and losses (due to leaching or denitrification). Errors in sampling or analysis were considered the most likely cause of very large differences that have been found when testing at different times in the spring.

Research has shown that SMN is present throughout the 0-90cm soil profile (or deeper), with at least half of the total at below 30cm depth. However, the proportions that are present in each layer can vary considerably. Consultation revealed that sampling to 60cm depth was considered essential, but views differed on the value of sampling to 90cm, even in the spring (as current guidelines suggest). SMN at 60-90cm depth has been found to be closely related to the amount present at 0-60cm, with prediction of optimum applied nitrogen doses not improved by directly measuring this. For manual sampling, a minimum of 10 replicate cores is recommended for homogenous sites. Areas known to have differing soil types or field histories should be sampled separately. The introduction of mechanical sampling has allowed a higher sampling intensity of 15-25 cores per 10ha field to be used. Careful mixing and sub-

sampling is necessary to ensure a representative sample for analysis. Most laboratories advise that, for SMN testing, samples are analysed as soon as possible. The samples should ideally be kept at the same temperature as they were in the ground, which may require refrigeration and transport in insulated containers. Freezing has been used for long storage, but samples must be analysed immediately upon thawing as increased mineralisation is possible. Research in the USA has suggested that air drying at room temperature is a more reliable method for preserving nitrate levels in low mineral N soils.

The standard procedure for analysis of available soil nitrogen is well documented, and consists of extraction with KCl, filtration of the extract, analysis by colorimetry, and conversion of nitrate and ammonium ppm to kg/ha based on bulk density of the soil. At each of these stages there is the potential for variation, but in particular bulk density could vary by +/-20%. Consultation revealed strong support for the re-introduction of ring testing or an accreditation scheme for SMN testing. It is widely acknowledged that mineralisation of organic matter can make a significant contribution to the SNS, and it is likely that this accounts for most of the variation in optimum applied nitrogen dose that cannot be explained by SMN status. Current guidelines suggest that net mineralisation should be small in mineral soils of low or average organic matter content, but research has not always supported this. Various methods, including incubation, modelling and chemical analysis, have been explored as a means of determining Potentially Available Nitrogen, but no single approach has universal support.

SMN testing is not recommended on peat soils (due to high net mineralisation), established grassland or in the first year after grassland is ploughed out, or within 3 months of organic manure applications. In these situations, knowledge of previous nitrogen fertiliser use, or the available nitrogen content of manures or other nitrogen-rich waste, may be a more useful guide. Previously, sampling on sandy or shallow soils has been considered less valuable than on nitrogen retentive medium or heavy soils, but recent milder and drier winters have questioned this. In Scotland, where light soils are more prevalent, and rainfall is higher, SMN testing is considered less reliable as a guide to optimum nitrogen fertiliser doses in spring, but is used to quantify soil reserves remaining post harvest to meet autumn needs.

The accuracy level for SMN tests was generally assumed to be within 10-20% (or 5-20 kg/ha) of the total, on 70-80% of occasions. Predictions of mineralisable nitrogen, or optimum nitrogen fertiliser doses based on SMN results, were felt likely to be much less accurate. There were differing views on how best to use SMN information, in particular the importance of results obtained for individual fields compared to overall trends year on year, or in like for like soil/crop situations.

Research suggests that a single measurement of SMN in late winter or early spring is a good indicator of the likely nitrogen capture by an unfertilised crop over the growing season, with effective recovery of 100%. However, there have been opposing conclusions as to the efficiency with which SMN will be

recovered compared to fertiliser nitrogen. In practice this is likely to depend on where the nitrogen is located in the soil profile, the effective rooting depth of the crop, and available moisture at that depth. Maximising the uptake of nitrogen present at depth is important, as this can provide a useful buffer during periods of summer drought, and if not taken up could be most at risk from loss by leaching.

Although the review revealed some widely differing views as to when and how best to determine soil mineral nitrogen, and how to interpret the information gained, it was concluded that:

- SMN results are a reasonable guide the amount of available nitrogen present in the soil at the time of testing, but differences of less than 10-20% (5-20 kg N/ha) should be ignored.
- For most mineral soils, testing once in late winter or spring provides a satisfactory guide to the likely soil nitrogen supply during the growing season, in the absence of applied fertiliser nitrogen.
- For soils with a high indigenous organic matter content, where significant quantities of nitrogen may be mineralised, testing in the autumn might give a better guide to the rolling soil supply.
- SMN testing has a valuable role in quantifying potential nitrogen losses, and in avoiding or identifying significant over-application of fertilisers. However it is only an approximate guide to optimum doses of applied nitrogen, and is likely to be more than 30 kg/ha out in 1 in 3 situations.
- The efficiency with which SMN is utilised relative to applied fertiliser nitrogen when both are present is crucial. A lack of certainty about this undermines the value of SMN measurements.
- Assuming that current fertiliser use is adjusted for crop and soil type, SMN testing is unlikely to give an economic benefit where it varies by no more than 30 kg N/ha in the majority of years, or where reserves are unlikely to exceed 100 kg N/ha.

In order to increase confidence in the reliability and interpretation of SMN test results, the following actions are recommended:

1. The introduction of a unified set of guidelines or best practice code for SMN testing, to include what and when to sample, what to analyse, and how to interpret the information.
2. The re-introduction of ring-testing, or implementation of an accreditation scheme, for SMN analysis, to eliminate laboratory procedural differences as a cause of variation.
3. The inclusion of a statement on all test results indicating the likely accuracy of the information, and their limitations as a guide to optimum doses of applied nitrogen fertiliser.
4. Careful matching of sampling depth and timing in relation to the information sought, the crop and establishment date, seasonal rainfall pattern, soil type and organic matter content.
5. Full account should be taken of the amount of nitrogen already in the crop at the time of SMN testing. The tendency towards milder winters and earlier drilling of wheat underline this need.

6. Further research is needed to better understand the interaction between, and relative recoveries of, fertiliser nitrogen and soil nitrogen present at different depths, within a single season.
7. There would be a benefit from further research to improve the ability to predict accurately release of nitrogen from soil organic matter, under field conditions and in a wide range of situations.

Introduction

Obtaining a reliable and meaningful estimate of the likely soil nitrogen supply (SNS) has become a key requirement for cereals and for many other crops. It is important for growers and agronomists, as it often represents a key part of the decision-making process for optimising nitrogen fertiliser doses. However it is also vital for both individuals and the farming industry as a whole, to quantify potential losses to the environment and to comply with NVZ Action Programme measures.

The simplest approach to achieving this is to make an estimate on the basis of field specific information such as the previous crop, winter rainfall and soil type. This 'field assessment method' forms an integral part of the fertiliser recommendation guidelines that are provided in MAFF Reference Book 209 (Anon. 2000). However, such an approach takes no account of differences in fertiliser use on the previous crop, the yield of that crop (and therefore nitrogen uptake) or other management practices that may influence the amount of nitrogen remaining in the soil. As a result, the SNS indicated for a given soil type and previous crop combination is sometimes at odds with that indicated by grower experience or optimum nitrogen dose.

The alternative to field assessment is direct measurement (by sampling and analysis) of soil mineral nitrogen (SMN), defined as the proportion of soil nitrogen that is directly available to plants as nitrate or ammonium, together with an estimate of mineralisable nitrogen and crop content. RB209 advises that direct measurement is the preferred approach where high or uncertain amounts of soil nitrogen are expected. Currently around 800,000 hectares of arable land receive organic manures or slurries each year, but there is an escalating need to dispose of other organic wastes with variable nitrogen contents, such that reliance on soil testing could increase. A recent report by one laboratory (Farmers Weekly, 23 December 2005) suggested that 10% of all samples they received in the 2005 growing season had a SNS of more than 170 kg N/ha (including potentially available nitrogen).

Whilst direct measurement of SMN is a useful tool, a lack of grower and agronomist confidence in the results means that it could be under-used at a time when there is an increasing need to accurately quantify soil nitrogen, and get nitrogen fertiliser doses correct. This may partly be due to unreasonable expectations, but also inconsistency in the values indicated by tests done at the same time on the same field, or on the sample even when sub-divided, when sent to different laboratories (Table 1):

Table 1. Soil mineral nitrogen test results from samples sent to different laboratories

Year	soil N (kg/ha)		
	Lab 1	Lab 2	Lab 3
2000	122	26	82
1999	54	52	163
1998	127	38	70
(TAG 1998-2000)			

(Samples taken in February from a field of continuous winter wheat on a clay loam soil)

Soil nitrogen analysis was first developed 30 years ago, and has been practised commercially for more than 15 years. The aim of this review is to examine how SMN testing has evolved since it was first introduced, to identify where opportunities may exist for error or misinterpretation that might explain the apparent lack of reliability and consistency, and to seek views on its current application and its usefulness to growers and agronomists in the field. Finally, recommendations are made as to how to overcome any concerns, and possible requirements for further research.

Project Overall Aim

To review the methods being used for testing soil nitrogen reserves, and to re-define best practice for carrying out the test and guidelines for interpretation of the results.

Specific Objectives

1. To review the current methods used for testing soil nitrogen reserves, including time of testing, sampling depth and intensity, sample handling and laboratory techniques.
2. To re-examine key research that has contributed to the development and validation of soil mineral nitrogen tests.
3. To determine whether current application of the test and interpretation of the results are appropriate, given the context within which this approach was developed.
4. To identify circumstances where soil nitrogen testing is currently being conducted or interpreted incorrectly, or factors that might explain some of the variation observed.

Approach Taken

The review that was conducted comprised two main elements.

1. Interested parties from the following sectors were consulted over a six month period:

Soil science and plant nutrition researchers

Fertiliser manufacturers

Laboratories involved in soil analysis

Independent fertiliser advisers

Companies involved in soil sampling

A list of individuals and organisations that contributed to this process is given under the acknowledgements.

The individuals who were consulted were provided in advance with an outline of the objectives of the review, and either face-to-face or telephone discussions took place, or written comments were received. Some of the key questions that were addressed are shown in Appendix A.

The amount of soil nitrogen test data that has been accumulated over the last 20 or more years is undoubtedly vast. It was beyond the scope of this project to review this data, and much of it is not within the public domain. However, the views expressed by participants in the consultation process were largely based on the individual datasets that they had accumulated, and it is therefore assumed that the conclusions of this exercise would be supported by the data that exists.

2. Published literature relating to soil nitrogen testing was identified, either by literature search or by recommendation during the consultation process. Although the number of papers and other publications that make reference to soil nitrogen testing is vast, the majority of these have included details of the procedure only as one of the assessment techniques used to provide data for crop nitrogen requirement studies. Rather less published literature was available that had studied soil nitrogen testing itself.

Development of Soil Mineral Nitrogen Testing

Jungk & Wehrmann (1978) helpfully defined the nitrogen sources of crop plants to be as follows:

1. Fertiliser nitrogen (which can be controlled) plus
 2. Nitrogen mineralised in the growing season (which can be estimated) plus
 3. Mineral nitrogen present at the start of the growing season (which can be measured)
- 2 and 3 together therefore represent the total nitrogen available from the soil

The experiments that they reported on the measurement of mineral nitrogen in the soil were in turn based on methods adopted from studies by other researchers working on sugar beet, barley and wheat in the early 1970s. They relied on measurement of the quantity of mineral nitrogen (ammonium and nitrate) in the whole rooted soil layer. A number of key questions were posed in the research work undertaken by Wehrmann, Scharpf and others in the mid 1970s, and reported in Jungk & Wehrmann (1978), which led to the development of the 'N_{min}' method.

- Are there differences in mineral nitrogen content between soils?

Results from SMN tests on more than 1000 fields on loess soils in Hanover, Germany, in February 1977, showed values ranging from 18 to 283 kg N/ha following cereals, or 22 to 324 kg N/ha following sugar beet, within 0-90cm depth. Whilst previous crop had an influence, the variation within the same previous crop was so great that they concluded that nitrogen fertiliser could not be based on this alone. A further study (Wehrmann & Scharpf, 1986) of 1983 winter wheat fields in 1985 revealed an average of 64 kg N/ha, and a range of 20-567 kg/ha.

- At what depth is soil mineral nitrogen located?

Results revealed that SMN was mostly located below 40cm depth, and it was concluded that analysis of topsoil alone would be misleading for plants that were able to utilise soil nitrogen from greater depths.

- What is the right time to determine mineral nitrogen in the soil?

The work showed that in unfertilised wheat crops on a range of soils, SMN values tended to increase up until March due to mineralisation, and then decreased as uptake exceeded the mineralisation rate. Autumn testing was not examined. It was concluded that end of February / early March was the best time to analyse soil, as this was when the highest accumulation of mineral nitrogen occurred.

However it is worth noting that, in continental climates where soil often freezes for a considerable period over the winter, nitrate present in the autumn is most likely to be leached out when the soil

thaws in the spring. In contrast, in the more maritime climate of the UK leaching will also occur over the winter (Powlson, 1997).

- To what depth is mineral nitrogen utilised?

Soil nitrogen under wheat increased from 53 to 100 kg N/ha between January and March, but then decreased down to 60cm by April, 80cm by May and 100cm by June, whether nitrogen fertilised or unfertilised. In a fallow situation, mineral nitrogen continued to increase rather than decrease down to 40cm, with 44 kg N/ha net mineralisation between March and June.

- What is the optimum nitrogen fertiliser level based on soil analysis?

From observations on 16 field experiments looking at optimum fertiliser dose against increasing soil nitrogen it was concluded that the quantity of soil nitrogen in the rooted soil layer had the same effect as fertiliser applied in early spring, and therefore soil nitrogen should be fully taken into account.

This early work formed the basis for the current application of soil mineral nitrogen testing, although the key questions that were asked at that stage have since been the subject of various research studies, and there continues to be a divergence of views.

Underlying Variation in Soil Mineral Nitrogen

Chambers & Richardson (1993) reported that within the ADAS N index system that existed at that time, typical SMN reserves were 40-120 kg N/ha for Index 0 (e.g. following cereals or sugar beet), 120-200 kg/ha for Index 1 (following oilseed rape or potatoes), and in excess of 200 kg/ha for Index 2 (following long-term organic manure or ploughed-out grass). Harrison (1995) showed that variation in SMN could be as great or greater within soil/crop combinations as between combinations, particularly for clays, loams and silts, and it was observed that the N index system in use at that time was not a good predictor of SMN.

Changes in both the index system and nitrogen fertiliser use on individual crops have since occurred. However, comparisons made within trials conducted by The Arable Group have continued to show a divergence between SNS values based on the current field assessment method within RB209, and those obtained by direct measurement of SMN.

A review by Silgram & Chambers (unpublished) of SNS data collected from 100 field sites over a 10 year period has also revealed significant seasonal variation for different soil and crop combinations. For example, the SNS following oilseed rape varied by up to 40 kg N/ha between years. This variation was governed by factors such as soil type, previous crop, fertiliser use and weather. It was concluded that on-site measurements were important to aid effective utilisation of soil nitrogen reserves. SMN testing within set areas of 6 fields in the same arable rotation on a medium sandy loam soil in Norfolk and over a 12 year period has indicated that variation may shown a closer relationship with rainfall over several seasons compared to just one (Table 2).

Table 2. Seasonal variation in soil mineral nitrogen at Morley in Norfolk (mean of 6 fields)

Year	1 year		3 year rolling average	
	SMN (kg/ha) in 0-90cm depth	Rainfall (mm) in Oct-Feb	SMN (kg/ha) in 0-90cm depth	Rainfall (mm) in Oct-Feb
1994	44	413	-	-
1995	51	345	-	-
1996	62	187	52	315
1997	52	270	55	267
1998	53	363	56	273
1999	41	348	49	327
2000	50	252	48	321
2001	33	403	41	334
2002	33	272	39	309
2003	38	382	35	352
2004	32	316	34	323
2005	53	275	41	324

(Source TAG)

Review of Testing Methods

Time of Sampling

The current guidance given in RB209 is that on medium or heavy soils, sampling for SMN should take place in the autumn (following harvest of the previous crop) or spring (prior to the first application of nitrogen fertiliser in the current crop), but in high rainfall areas or on light soils sampling should take place in the late winter or early spring.

In their review of seasonal variation in soil nitrogen supply, Silgram & Chambers (unpublished) found that whilst long term autumn SNS following cereals was 20 kg N/ha more on heavy land than light land, this difference had increased to 36 kg N/ha in spring. Bhogal *et al.* (2000) observed that, on a sandy clay loam, there was a decline in SMN between the autumn and spring, especially following 'excess' nitrogen fertiliser applications. This was associated with an apparent movement of mineral nitrogen from the topsoil to the subsoil, with levels at 60-90cm remaining constant or increasing in most years. Sylvester-Bradley & Shepherd (1997) found that SMN in the autumn was less following sugar beet than following wheat, but due to greater net mineralisation over winter after beet (from the sugar beet tops) the soil N supply to the following wheat crop was similar. Hence autumn SMN analysis after beet could give misleading results.

Harrison (1995) showed, using regression models, that when 0-30 and 30-60cm depths were taken into account there was a tendency for autumn SMN to be a better guide to the optimum nitrogen dose (67% accurate to within +/- 30 kg/ha of applied N, compared to only 54% for spring SMN). However, using regression equations based on 0-30cm depth only, and this time assuming that SMN substituted 1:1 for applied fertilizer nitrogen, spring and autumn SMN were similar (71% autumn and 73% spring).

Most of those consulted during this review felt that sampling in the spring was always preferable, as the uncertainty of how much nitrogen would be lost due to leaching (or denitrification) over the winter months was then removed, and the assessment of the amount of nitrogen present in the soil (and therefore how much allowance should be made for this in the amount of fertiliser applied) was then as close as possible to the time of application. Some concern was expressed over sampling very early in the spring or in late winter (a month or more before first fertiliser nitrogen applications), and it was observed that there might be a tendency for samples to be being taken earlier in recent years.

Any change in SMN between the autumn and spring is likely to depend on the balance between mineralisation of organic nitrogen, and losses of mineral N by leaching or denitrification, which in turn will depend on soil type, excess rainfall and the soil organic matter content.

The most appropriate time to sample might depend on the purpose for which the information is being obtained. Sampling in the autumn will give the best indication of the soil nitrogen that might immediately be available to an autumn sown crop (top 0-30cm of soil only), and will also indicate the amount of nitrogen that could potentially be lost through leaching by excess rainfall (or denitrification) over the winter months, especially on light or shallow soils. However the only immediate value to a grower would be where an autumn nitrogen application is being considered, otherwise it indicates only in hindsight how closely total nitrogen supply matched uptake by the previous crop.

Silgram & Chambers (unpublished) found that, following wheat, autumn SNS was strongly influenced by soil type and year, and was related to topsoil nitrogen content, but there was some effect of nitrogen applied to the previous crop. In turn, autumn SNS, along with total nitrogen content of the topsoil, were major factors in determining the spring SNS following cereals (or oilseed rape) on heavy land.

Sampling in the spring, once any losses over the winter have taken place, are more likely to provide a useful indicator of what is potentially available for uptake by the current crop, but does not necessarily provide a reliable guide to what is likely to remain in the soil after harvest (and therefore be at risk from losses the following winter). Silgram & Chambers (unpublished) did find that, following oilseed rape on heavy land, autumn SNS was influenced by the SNS in the previous spring, as well as the nitrogen fertiliser applied to the previous crop.

Observed differences are not restricted just to autumn versus spring. Substantial temporal variation in the spring has also been identified during sampling exercises (Table 3).

Table 3. Month to month variation in soil mineral nitrogen test results

Location	Soil Type	Previous Crop	soil N (0-90cm) kg/ha		
			January	February	March
Bedfordshire	deep clay loam	WOSR	116	110	17
Hampshire	chalkland soil	set-aside	46	94	147
(TAG, 2003)					
Northants	boulder clay	cont. WW	26	38	65
Lincolnshire	clay loam	WOSR	129	94	50
(TAG, 2002)					

(Winter wheat, no fertiliser applied, and no previous use of organic manures except Lincs 2002)

During the consultation it was suggested that fluctuation of 10-20 kg N/ha between months was normal, potentially more following a wet month, and that notable differences between months were likely to be observed 30-40% of the time. It was also suggested that occasional large differences between months were most likely to be due to sampling or laboratory / test errors.

Depth of Sampling

Chaney (1990), when sampling eight winter wheat sites post-harvest in 1987 and 1988, found that 50% of the total nitrate detected was in the top 0-30cm, 30% in the 30-60cm and 20% in 60-90cm.

Stokes *et al.* (1998) found that, for a range of previous crops and soil types at two locations, SMN was distributed throughout the 0-90cm soil profile, with more than half present below 30cm depth.

However, the less nitrogen applied to the previous crop, the less was present at depth (60-90cm). In individual fields the proportion of SMN present at different depths can vary considerably, as highlighted by data from 6 TAG sites on medium/heavy soils sampled in February 2005 (Table 4).

Table 4. Soil Mineral Nitrogen Present in February 2005

County	Soil Type	Previous Crop	Total SMN (kg N/ha)	% present at depth of		
				0-30	30-60	60-90 cm
Beds	clay loam	w beans	25.0	37	38	25
Beds	clay loam	w wheat	86.7	13	63	24
E Yorks	silty clay loam	combine peas	84.0	26	31	43
E Yorks	silty clay loam	combine peas	60.3	31	47	22
Essex	clay loam	turnip seed	56.8	15	45	40
Northants	clay	NR set-aside	96.1	71	19	10
Mean			68.2	32	41	27

The commercial service first launched by ADAS in 1991 was based on sampling in two or three 30cm depth layers, down to 60cm depth in the autumn (for medium or heavy soils), and to 90cm depth from late winter onwards. This provides the basis of the advice in RB209, with the following conditions:

1. For deep rooted crops an estimate of mineral nitrogen in the 60-90cm layer should be made if this is not sampled
2. For very shallow rooted crops, sampling to 30cm is all that is justified.
3. In addition, as the top 2cm of soil may be contaminated with vegetation, this is usually discarded.
4. If different soil layers are to be analysed separately, it is important to avoiding contamination between one depth and another, which requires particular care when sampling by hand.

There were differing views expressed on sampling depth during the consultation for this review. The majority of those consulted agreed that sampling to 60cm depth was necessary, but some questioned the value of sampling to 90cm depth even in the spring. One laboratory reported that many of the samples that they now received were to 30cm depth only, with very few 60-90cm samples. Another current commercial service relies on prediction of the SMN present in the subsoil below 30cm depth, based on a large number of reference sites that have been sampled previously to greater depth.

It was suggested that sampling at 60-90cm depth in January or February may give a misleading indication of what might be taken up by a crop whose roots might not reach that depth until April, especially on light soils or following very wet springs. This would be less of a concern for heavier land, drier springs or earlier established crops. It was also argued that samples taken to only 30cm depth immediately after prolonged heavy rain could give misleading results. Nitrogen may have moved deeper in the profile, but could still be available to the crop, or may be replenished in the upper layer by fresh mineralisation. There was a general consensus that there is a need to take careful account of seasonal rainfall and rooting depth of the crop to decide both the depth and time of sampling

Harrison (1995) showed that there was correlation between the amount of soil nitrogen present at different depths, both in the autumn and spring, with the greatest correlation between adjacent depths (in particular 30-60cm and 60-90cm). As a result, he found no loss of strength in the relationship between optimum nitrogen dose and SMN by excluding the 60-90cm values. Using regression models he found SMN at 0-30 and 30-60cm could be used to predict the optimum applied nitrogen dose for yield, but that the 30-60cm depth appeared to have more effect at reducing the dose than 0-30cm.

The value of separately testing individual sample depths has also been questioned, for situations where there is no particular interest where the soil nitrogen is within the profile (for crops whose roots will invariably reach 90cm, or deeper, on medium or heavy soils). The advice issued on SMN testing by the Foundation for Arable Research (FAR), the arable crop levy organisation in New Zealand, says exactly this. The cost saving could allow an increased sampling intensity, or repeat sampling at a later time. However, if the effectiveness of nitrogen uptake alters with depth (see later), analysing the full depth as one could give very misleading results.

Sampling Intensity

The existing guidelines given in RB209 recommend a minimum of ten replicate cores per field for soil nitrogen testing. For a homogeneous site, it is assumed that these would be taken in a systematic 'W' shaped pattern across the field, avoiding atypical areas (such as gateways or hollows). Field size is also not then important. Where areas of a field are known to differ in soil type, previous cropping or fertiliser/manure use, these have to be sampled separately. The cores must then be thoroughly mixed and carefully sub-sampled to obtain the required soil quantity for sending to the laboratory. Several of those consulted identified that this mixing and sub-sampling stage could be easier said than done, especially for poorly structured clays or subsoils.

There appears to be general agreement that this minimum sample number had been determined as much by what was practical for manual sampling at depths down to 60 or 90cm, as to what was needed to provide a robust value within acceptable limits. It was not felt possible to define an optimum number of cores for every situation, as this would depend on the accuracy required and the level of variation present. The recent introduction of mechanical sampling, which typically allows a 0-90cm depth to be sampled within 30 seconds, means that a sampling intensity of 15-25 cores per 10ha field is now common, which should help to minimise the problem of unrepresentative cores provided that sampling points are chosen carefully.

Sample Handling, Storage and Speed of Processing

The advice in RB209 is that soil samples for SMN testing should be kept refrigerated and transported rapidly to the laboratory. This is often achieved in practice by packing with ice blocks in insulated containers, and sending by 'next day' courier in the first half of a working week. Consultation for this review surprisingly revealed differing views on the need to keep samples cool. However, most felt that samples should be refrigerated, and it was suggested they could be stored for up to 3 days in a fridge at 0-5°C. Freezing to -15°C was considered acceptable if samples had to be stored for more than 3 days, but samples needed to be tested quickly upon thawing, and concerns had previously been expressed by one UK laboratory that thawing after freezing increases mineralisation.

Recent work by Ma *et al.* (2005) in the USA has examined the effects of various methods of preserving samples (other than refrigeration) on the amount of inorganic N extracted by KCl. Over a two year period they examined soil samples from 0-20cm depth taken from eight locations representing different soil types. All of the preservation methods caused an increase in ammonium N, and to a lesser extent nitrate N, compared to immediate extraction and analysis of fresh samples. Air-drying at room temperature (22°C) produced the smallest increases in total inorganic nitrogen, and air drying in a greenhouse the highest. Freezing (to -15°C for two months) produced the highest increase in one season, and the lowest in another. They concluded that if preservation was necessary, air drying at room temperature was a reasonably reliable method, especially for nitrate N in low mineral nitrogen content soils.

A sensible compromise could therefore be to keep the soil samples at the same temperature as they were in the ground, such that if samples are sent to the laboratory immediately and tested the next day, refrigeration might not always be necessary.

Laboratory Procedures for Analysis of SMN

The standard procedure for the analysis of available soil nitrogen is described in MAFF Reference Book 427, The Analysis of Agricultural Materials (Anon., 1986). The principle stages are:

- Extraction with 2 Molar potassium chloride (KCl)
- Filtration of the extract
- Analyse for nitrate N and ammonium N by colorimetry
- Conversion of the nitrate and ammonium N concentrations to quantities per hectare using the bulk density of the soil

Within each of the stages there is the possibility of variation, and any errors in ppm could then be multiplied up by a large factor:

- Some laboratories use 1M rather than 2M KCl. It was considered by some that this might be important, and it was suggested that the results obtained from the two methods could be different.
- The soil solution ratio adopted, and how long it is shaken for
- The filter papers used (some contain nitrogen)
- The colour determination and standards used for the colorimetry
- The soil bulk density used. This is often standardised at 1.33 g/cm^3 , but could easily vary by +/- 20% compared to this. Peaty or stony soils present a particular problem.

However, during the consultation it was suggested that it should be possible for the analysis procedure itself to be accurate to within 1-2 kg N/ha for both ammonium and nitrate-N.

Many of those consulted during the review process suggested that confidence in the laboratory testing procedure itself could be improved by the introduction of a code of conduct or British Standard, or the re-introduction of formal sample exchange or ring testing. Some of the laboratories indicated that they already participated in some form of sample exchange. Whilst it was acknowledged that differences in procedures exist, it was observed that for a ring test the ability to get identical samples delivered to each laboratory in the same condition would be a problem. There was a suggestion that variation between laboratories was unlikely to be having a significant effect on results, nevertheless differences of the size highlighted by the TAG data shown earlier would be a concern.

Rapid Tests

Various attempts have been made to develop a rapid test for SMN that could be used in the field. For example, work done by Titchen & Scholefield (1992, 1995) found that a test using nitrate and ammonium test strips and a reflectometer was feasible and provided accurate results (within 5% of conventional laboratory based methods) within about an hour on grassland. They suggested that this type of test could be useful for making in-season adjustments to nitrogen applications. Ehsani *et al.* (1999) found that it was possible to sense SMN content in the soil using near infrared reflectance, provided that a site-specific calibration was carried out to filter out interfering effects. Hence this would only be of use for analysing within field variation in SMN, in an otherwise uniform site.

Estimation of Mineralisable Nitrogen

Although this review has focused on the determination of soil mineral nitrogen that is immediately available, it is widely acknowledged that the total reserve of organic nitrogen in the soil (whether from crop debris or indigenous organic matter) and its subsequent mineralisation can make a significant contribution to the amount of mineral nitrogen that subsequently becomes available to the crop. It has been estimated that SMN usually represents less than 1% of the total nitrogen present in the soil for fields in long-term arable cropping (Chambers *et al.*, 1991).

Chambers *et al.* (1991) observed that responses to fertiliser nitrogen decreased with increasing SMN, with no response at all above 250-300 kg/ha SMN (measured in the autumn). However, responses were variable between sites with similar levels, and this was attributed to differences in mineralisation later in the season. Harrison (1995) also concluded that factors other than variation in SMN alone were responsible for a substantial proportion of the variation in optimum nitrogen dose, and that this was most likely due to net mineralisation of organic matter and previous crop residues after SMN testing had taken place (estimated at up to 50-100 kg N/ha on high residue sites). Atmospheric deposition will (more predictably) add a further 35-40 kg N/ha (Goulding, 1990).

The nitrogen present in crop residues is likely to be released over a short period of time, depending on their C:N ratio, whereas nitrogen from soil organic matter would be cycled throughout the season. Conventional advice is that in mineral soils of low to average organic matter content, the net amount of mineralisation will be small. However, Shepherd & Sylvester-Bradley (1996) found that for wheat following oilseed rape, for soil organic matters within the range 2-8%, each 1% of organic matter contributed the equivalent of 25 kg N/ha. RB209 suggests that a soil with a topsoil organic matter

content of 10% may release 60-90 kg/ha more potentially available nitrogen than a soil with 3% organic matter (or 150-200 kg/ha more if the topsoil organic matter content is 20%).

Various methods have been explored to try to predict the amount of nitrogen that will become available during the season (known as potentially available nitrogen or PAN), including measurement of topsoil organic matter content, anaerobic incubation of soil samples in the laboratory, and computer modelling.

Wehrmann & Scharpf (1986) carried out investigations on 53 loess loam soils in Southern Lower Saxony with wheat. The aim was to forecast net mineralisation between the time of SMN analysis and the end of nitrogen uptake, by biological/chemical soil test methods and by calculation. No relationship was found between net mineralisation (determined from the increase in SMN on sheltered fallow plots or by plant analysis) and the laboratory values predicted by 11 different methods. Others have explored various incubation methods and found good correlations with the nitrogen release indicated in pot trials, but poor correlation with what appeared happened in the field (Richards, pers comm.), presumably due to the greater number of variables that affect mineralisation in the field. During the consultation it was suggested that estimates of PAN for peat or organic soils might be particularly unreliable, compared to what happens under field conditions.

One company currently includes determination of PAN as part of their soil nitrogen testing service, which is based on incubation for 7 days at 40°C, followed by normal extraction with KCl. A modification of the standard analysis for SMN, using hot KCl, was developed by Gianello & Bremner (1986). Here, the nitrate fraction extracted approximates to mineral nitrogen present at the time of sampling, but the increased ammonium fraction includes an amount that represents the more labile fraction of the soil organic matter. McTaggart & Smith (1993) found that this gave good correlation with uptake of soil nitrogen by spring barley provided that the previous crop was a cereal. Other attempts have also been made to develop a chemical test that might correlate to incubation (Menasseri *et al.*, 1994).

Application and Interpretation

Which Fields to Sample

There are two ways in which the information from SMN testing might be used: as a guide to potential losses from the soil, or as a guide to the fertiliser nitrogen requirement of the crop. RB209 states (and previously concluded by Chambers *et al*, 1991) that, as a guide to fertiliser use, measurement of SMN will be of most value where high or uncertain soil nitrogen residues are expected. Examples include:

- Where organic manures are regularly used (but not within 2-3 months of their application)
- Following crops that leave large amounts of leafy, nitrogen-rich crop debris
- Where long leys or permanent pasture are ploughed out (but not in the first year after ploughing)
- Where there are indications of excessive nitrogen availability (e.g. lodging)

In more stable or predictable situations, such as all-arable rotations with no use of organic manures, use of the field assessment method (described earlier) is advised.

SMN analysis is not recommended on peat soils (on the basis that nitrogen released by mineralisation of organic matter is the major component of the SNS and is difficult to predict), or on established grassland. RB209 also indicates that sampling on nitrogen retentive, medium or heavy soils is more worthwhile than on sandy or shallow soils that are prone to leaching. Goodlass *et al*. (1996) found that on heavier soil types, previous crop affected both SMN and nitrogen requirement of the following crop, but on shallow and sandy soils, there was less variation in the spring SMN, and these soils showed no effect of previous crop on nitrogen requirement. However, there has been some suggestion that recent milder and drier winters have led to higher SMN levels in light soils than in heavier soils, possibly as a result of increased early mineralisation (e.g. Farmers Weekly, 23 December 05).

Webb & Sylvester-Bradley (1994) concluded that, whilst the uncertain (but potentially large) size of SMN residues after ploughing out grass had important implications, a single measurement of SMN was not an adequate basis for determining fertiliser nitrogen requirements for following crops due to variability, and that sampling three times was necessary to identify systematic variation. They found that knowing the fertiliser regime applied to the grass was just as good as an indicator of soil supply.

In Scotland, SMN testing is not generally recommended (Sinclair, pers comm.), other than in the second year following grass, as it is considered that SMN has limited predictive ability for optimising nitrogen doses. This might partly be due to the tendency for light soils to be more prevalent, higher rainfall, and higher organic matter (and ammonium levels) in the soil than in England. Instead SAC

nitrogen fertiliser recommendations are based on current crop and intended market, likely nitrogen residues (soil type and previous crop), rainfall over the winter and between fertiliser applications, and current/previous manure use.

Wehrmann & Scharpf (1986) examined the limitations of the N_{min} method that was developed in Germany. A high reliability in forecasting nitrogen fertiliser requirements was found if nitrogen supply was affected only by leaching, denitrification, mineralisation or immobilisation in the usual manner. The factors and conditions influencing this (largely through their effects on leaching and net mineralisation) were summarised as follows:

Increased reliability

rapid, early rooting
soils with high WHC and deep rooting
moderate rainfall
low organic manuring
low temperatures
uniform rotation

Decreased reliability

time between soil analysis and rooting
shallow or sandy soils
high rainfall
high or changing organic manuring
high temperatures
variable rotation

Note that two of the situations associated with low reliability (high or changing manuring, and variable rotation) are those in which RB209 suggests SMN testing will be of most value.

Some have suggested that following the use of organic manures sites should also not be sampled in the first year. As an alternative, Chambers & Smith (1992) found that SMN measurements following application of pig and cattle slurry and FYM were significantly related to the amount of ammonium nitrogen supplied by the manures (provided slurry was rapidly incorporated). Following poultry manure SMN was related to the amounts of ammonium and uric acid nitrogen. They concluded that analysing individual organic manures is a valuable technique for predicting crop available nitrogen. The recommendations issued by SAC suggest that analysis of crop residues for N and C content may also be helpful for high or variable residue crops, such as leafy vegetable and fodder crops.

Although rarely advised as a guide to nitrogen fertiliser use in Scotland, it is still acknowledged that SMN testing can be important to identify reserves remaining in the soil after harvest of the previous crop. The NVZ guidance note for inorganic N applications during the closed period, issued by SEERAD in July 2005, states that ‘agronomic justifications for autumn nitrogen applications should be supported by SMN analysis’, and that ‘samples should be taken after harvest of the previous crop, and samples taken prior to cessation of the previous crop’s growth will not be acceptable’.

Accuracy and Reliability of Results

Most of those consulted said that in their opinion the results of SMN tests were likely to be accurate within 10-20% of the total (so typically between 5 and 20 kg N/ha) on 70-80% of occasions. It was considered that much of the variation was likely to be due to sampling rather than analysis. It was felt that estimates of mineralisable nitrogen were likely to be much less accurate. It was accepted that there was sometimes variation in the results of SMN testing that could not be explained, and that the only realistic target was to ensure that the values reported were accurate for the day that the test was done. Many commented that they thought that the lack of accurate weather forecasting was a much greater limitation to the ability to predict SNS than the ability to determine available SMN.

Harrison (1995) concluded that, using best fit regression models, it was possible to predict the optimum nitrogen fertiliser dose for yield from SMN data within +/- 30 kg/ha of applied N in 54% (using spring SMN) or 67% (using autumn SMN) of cases. However, this assumed that some account was taken of differences between sites (in particular soil type and organic nitrogen reserves), which might alter the intercept of the relationship between SMN and optimum nitrogen fertiliser dose. Even allowing for the latter, this is a much lower level of confidence than that suggested for the actual measurement of SMN.

However, a recent review (unpublished) of over 40 winter wheat nitrogen response trials conducted by The Arable Group on a range of mineral soil types between 2000 and 2005 has revealed no correlation between optimum nitrogen fertiliser dose and SMN (measured to 60 or 90cm depth in early spring), for SMN values between 10 and 100 kg N/ha. A subsequent re-examination of the data from Harrison (1995) leads to the same conclusion for autumn SMN, if values in excess of 150 kg N/ha are excluded.

How to Use SMN Information

The consultation revealed a dichotomy between those who believe individual results are important to the grower, and those who believe only the overall trend is important. Concern was expressed that results from different sampling programmes in the same season sometimes gave opposite indications as to whether the overall trend in SMN was up or down. Where a grower is relying on tests from his own farm, it was suggested that a history of sampling was more useful than a one-off test, and that extrapolating results from one year into another was of little value due to changes between seasons. There was also the suggestion that a national data base, or series of reference sites, could be useful for individuals to compare against. In France, it is common for growers to use an average value for SMN measured in multiple fields. Extension services calculate and publish these based on soil type, previous crop and the use of organic manures (Laurent, pers comm.).

Stokes *et al.* (1998) found that spring SMN accounted for 75% of the variation in crop N uptake between February and harvest in unfertilised crops. Sylvester-Bradley *et al.* (2001) reported that this work and that of others showed that SMN measured at one time (in February) is a good indicator of likely nitrogen capture over time, and concluded that SMN alone was sufficiently predictive because the most variable component of mineralisation (residues resulting from previous fertiliser use and previous crop) was realised before SMN was measured.

It could be argued that, in a stable rotation, the most reliable guide to whether nitrogen fertiliser doses are appropriate to requirement (and therefore how much there might be left that is at risk from losses) would be provided by sampling after harvest of the previous crop. If, year on year, sampling indicates relatively large amounts of SMN, then this would indicate applications to be in excess of requirement.

There are many indications that applications in excess of crop requirement are contributing to a build up of soil fertility (via organic matter or crop residues) that will subsequently provide part of the nitrogen supply to subsequent crops. Chaney (1990) showed that the amount of SMN remaining in the autumn or spring after harvest of the previous crop was dependent on the amount of fertiliser nitrogen applied over and above crop requirement (or the optimum rate for yield), not on the previous crop itself or the absolute amount of nitrogen applied. Shepherd & Sylvester-Bradley (1996) found that typically autumn SMN increased by an average of 15 kg N/ha for every 100 kg/ha applied to oilseed rape up to the economic optimum, but with larger increases in SMN above the economic optimum. Bhogal *et al.* (2000) also observed that post-harvest SMN increased with increasing nitrogen fertiliser application to the previous crop, but in this case it occurred at 20-40 kg N/ha less than the optimum fertiliser dose. Glendining *et al.* (1992) had previously reported that this might only occur where dry soil conditions or other factors had limited the uptake of nitrogen.

Recovery of SMN

It is widely acknowledged that crops do not recover all of the fertiliser nitrogen that they receive. Bloom *et al.* (1998) found apparent recoveries ranging from 43-88% in 70 experiments on winter wheat. RB209 suggests that average recovery in the grain and straw is about 60% on most soils (70% on light sands, but only 55% on shallow soils). Powlson (1997) reported that under UK conditions around 15-25% of the nitrogen applied to cereals in the spring is often lost during the growing season. MacDonald *et al.* (1989) examined the contribution of unused nitrogen fertiliser post harvest to nitrate leaching. They, and others, have shown that less than 10% of the nitrogen leached in any one year comes directly from the fertiliser applied in that year. Most is from mineralised soil organic matter,

built up from crop residues (and therefore indirectly from fertiliser nitrogen). King *et al.* (2001) suggested that temporary immobilisation (due to turnover of fine roots in the topsoil) during rapid growth could account for much of the apparent loss of applied fertiliser nitrogen.

Stokes *et al.* (1998) found that recovery of SMN in unfertilised crops was at least 100% (with on average an extra 30 kg N/ha taken up), but rightly pointed out that this does not mean that the exact same SMN measured in February was subsequently recovered in crop growth, but that there was a tight balance between mineralisation and immobilisation.

Harrison (1995) observed that, if it is assumed that soil nitrogen substitutes 1:1 for fertiliser nitrogen, the optimum nitrogen dose was best predicted by soil nitrogen in only the top 0-30cm depth. However, more of the variation in optimum dose was explained by not assuming a 1:1 relationship, and by including the 30-60cm depth. He concluded that it was likely that this was because the soil nitrogen below 30cm depth was more prone to losses, and taken up less readily by plant roots. This might apply particularly to soil nitrogen observed at 90cm depth in either the autumn or early spring. By the time that root systems are well developed at depth, in most practical situations fertiliser nitrogen will already have been applied and crops will be less reliant on scavenging for soil nitrogen at depth.

However, others have argued (and RB209 indicates this) that soil nitrogen may be taken up with greater efficiency than applied nitrogen due to being more evenly distributed down the soil profile. One reason for this might be that fertiliser nitrogen will mainly be present in the top 0-30cm of soil where the soil microbes (that are likely to lock-up or denitrify nitrate) are found. Further down there will be less microbes and less transformation (Barraclough, pers comm.). Stokes *et al.* (1998) found that 25% of the SMN recovered by unfertilised crops was taken up after flowering, and that uptake was least effective at this time where most of the SMN was close to the soil surface.

Kuhlmann *et al.* (1989) examined the utilisation by wheat of SMN from the subsoil at depths down to 200cm. They found that subsoil mineral N content varied widely with farming practice, but that winter wheat roots could take up nitrogen from depths down to 150cm. Averaged over 22 sites, 33% of the total nitrogen uptake was from the subsoil (range 9-75%), with 25% from 30-90cm and 8% from 90-150cm. Decreasing the nitrogen supply to the topsoil increased uptake from the subsoil. Uptake from the subsoil was not dependent on water uptake as nitrate was readily transported to absorbing roots by diffusion. Rooting densities below 120cm were insufficient to extract much nitrogen until after flowering, but this could be important during grain fill if topsoil nitrogen is made unavailable by summer drought. If not taken up, this same nitrogen could be at risk from loss by leaching.

Conclusions and Recommendations

It was evident from both the consultation process and the review of relevant literature that there are differing views as to when and how best to determine soil mineral nitrogen, and how to interpret the information gained. Most of the key elements have been re-examined in published research since the original development and validation of the procedure 30 years ago. Not surprisingly though, this research has not provided all the answers, and there has often been a proportion of variation that either could not be explained or predicted. Based on the views expressed and the research findings, the main conclusions from this review would have to be as follows:

- There is a good probability that, if properly conducted, the results obtained from SMN testing are a reasonable guide to the amount of available nitrogen present in the soil at the time of sampling. However, the accuracy is likely to be only within 10-20% (5-20 kg N/ha). Differences observed between sites or seasons of this magnitude are therefore of little significance.
- For mineral soils of relatively low organic matter content, testing the soil on only one occasion can provide a satisfactory guide to the likely soil nitrogen supply during the growing season, in the absence of applied fertiliser nitrogen. This should still be the case where there are large amounts of crop residue, provided that these have had time to mineralise prior to soil testing (which is likely to mean sampling in the late winter or spring).
- For soils with a high indigenous organic matter content, where significant quantities of nitrogen may be mineralised steadily throughout the growing season, this must be taken into account. In the absence of a reliable means of predicting this, a better guide to the rolling SNS might be obtained by sampling post harvest or in the autumn, as a baseline for the following spring.
- SMN testing has a very valuable role to play in quantifying the potential for losses of nitrogen to the environment, and in avoiding or identifying significant over-use of fertilisers. However, it is only an approximate guide to optimum doses of applied nitrogen. The implication from Harrison (1995) is that in at least 1 out of every 3 situations, the optimum nitrogen fertiliser dose indicated by SMN testing is likely to be more than 30 kg/ha out. If site factors such as soil type, soil organic matter and crop rooting depth are not taken into account, the error could be much greater. It is likely that many growers and agronomists are assuming a much higher level of accuracy.
- The efficiency with which SMN is utilised relative to applied fertiliser nitrogen when both are present is crucial. A lack of certainty about this undermines the value of SMN measurements.

- Assuming that current fertiliser use is adjusted as appropriate for the crop and soil type, testing SMN is unlikely to give a consistent economic benefit in situations where it varies by no more than +/-30 kg N/ha in the majority of years, or where reserves are unlikely to exceed 100 kg N/ha.

In order to increase confidence in the reliability and interpretation of SMN test results, the following action points are worthy of further consideration:

1. The Industry would benefit from an agreed, unified set of guidelines, or code, as to best practice for sampling, analysing and interpreting the results of soil nitrogen testing. This review has highlighted some significant differences of opinion, which need to be reconciled
2. There is a strong desire amongst users for the re-introduction of ring-testing for soil nitrogen analysis, or implementation of an accreditation scheme, in order to eliminate laboratory procedural differences as a cause of variation. Whilst this could only be achieved with the full support of the laboratories concerned, and there are likely to be practical difficulties and cost implications, it is fundamental to maintaining confidence in the ability to obtain meaningful results.
3. There is a need for the inclusion of a ‘warning’ statement on soil nitrogen analysis results indicating the likely accuracy of the information, and the limitations that these might have in the prediction of optimum nitrogen fertiliser dose. Growers and agronomists can then moderate any adjustments they might make to their fertiliser strategies, where the information appears to conflict with expectation or previous experience.

This is made even more important by the way in which adjustments in nitrogen fertiliser dose are recommended, when using the current SNS Index system in RB209. For example, the adjustment for winter wheat grown on most mineral soils between SNS indices 1 and 3 is from 220 kg N/ha down to 150 kg N/ha, a difference of 70 kg N/ha. However, an increase in SNS index from 1 to 3 could be prompted by as little as a 21 kg N/ha difference in the amount of SMN found, which it has been suggested here might be little more than the size of the error in the test results.

Even where SMN testing indicates that the SNS should be sufficient for the crop’s needs, not all of this will be available immediately to a crop. For example, some additional fertiliser nitrogen may be needed to support early growth (during tillering and initial canopy expansion), where the majority of the SMN is present below 60cm depth. It might be helpful to provide further guidance on this (based on the proportion available over time) with the soil tests results.

4. It is important to match sampling depth and timing to the information that is required, the crop and establishment date, the seasonal rainfall pattern and the soil type and organic matter content. For example, knowledge of SMN reserves at 60-90cm depth may be more important for deep rooted crops that may be at risk from drought later, or where an assessment is needed of the potential for losses from leaching prone soils.
5. At the same time, it is vital to take account of the nitrogen already taken up by the crop. This could account for seasonal differences of as much as +/-25% in the SMN measured in spring in a typical wheat crop (based on the comparison of a 'backward' crop with around 500 shoots/m² against a 'forward' crop with around 1500 shoots/m², equating to a difference of about 30 kg N/ha, and an average SMN of 60 kg N/ha). The tendency towards milder winters and earlier drilling of wheat underline the need to consider the impact that this might have, especially on available nitrogen within the 0-30 and 30-60cm soil depths.
6. Whilst it is possible to predict how much SMN is present at depth from the amount measured in the upper soil layers, there appear to be differing views on the effectiveness with which crops are able to utilise SMN at different depths (particularly deep subsoil), compared to applied fertiliser nitrogen. It must be assumed that, when present at the same depth, nitrate or ammonium derived from fertiliser nitrogen will be utilised with the same efficiency as that from SMN. However, this does not mean that SMN would not be used with greater efficiency in the absence of any applied fertiliser nitrogen, nor that nitrogen from either source (SMN or leached applied nitrogen) would be utilised with the same efficiency at 60-90cm depth as at 0-30cm depth. Further research to better understand the balance and interaction between soil and fertiliser nitrogen within a single season, and to examine how to maximise the uptake of nitrogen present at depth (thereby reducing potential leaching losses), would be of benefit.
7. The release of nitrogen from soil organic matter is fundamental. Whilst in many arable soils the contribution from organic matter may be relatively small, in situations where SMN is likely to be at its highest (where arguably it is most important to measure it) release from organic matter is likely to be a significant component of the soil nitrogen supply. The importance of this is not restricted to just 'organic' soils: any attempt to build up soil fertility or improve soil structure through increased soil organic matter will impact upon this. The lack of conclusive published evidence that this can be predicted accurately in a wide enough range of field situations is a concern, and suggests that further research is needed.

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Appendix A

Typical Questions Posed to Participants in the Consultation Process

- How was the original soil mineral nitrogen test developed and validated?
- Has anything changed since that time that could affect validity of the results e.g. field factors, sampling procedures, sample handling, laboratory techniques, basis of interpretation?
- What are the main factors that determine when soil N testing should be carried out?
- Would testing on several occasions give a more meaningful value than just once?
- How much can soil mineral nitrogen measurements change, in the absence of significant leaching/denitrification losses?
- What is the likely 'error' around soil mineral nitrogen measurements (based on 10 sub-samples per field)?
- Where is the greatest margin for error, measuring what is currently available or predicting what might become available?
- Is the margin for error dependent on the circumstances in which the test is being used e.g. high after organic manures, low in continuous cereals?
- Are there fundamental differences between the various soil nitrogen testing services offered, which means that one or other may be more or less accurate or more or less appropriate in a given situation?
- Are soil nitrogen test results being misinterpreted?
- Where nitrogen response curve trials indicate that the soil supply has been more, or less, than that indicated by soil N testing, what is the most likely reason for this?
- Are there any circumstances where soil nitrogen testing could give misleading results and should not be used?