Project title:	Establishing Best Practice for determining Soil Nitrogen Supply (HGCA 3425) – Reporting and Technology Transfer (Post Warwick HRI)
Project number:	FV 345b
Project leader:	Dr Clive Rahn, PlantNutrition Consulting
Report:	Final report July 2012
Previous report:	
Key staff:	Dr Clive Rahn
Location of project:	Wellesbourne, Warwick
Industry Representative:	David Norman, Precision Agronomy Limited
Date project commenced:	1st October 2011
Date project completed (or expected completion date):	31 July 2012

DISCLAIMER

The results and conclusions in this report are based on an investigation conducted over a one-year period. The conditions under which the experiments were carried out and the results have been reported in detail and with accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results, especially if they are used as the basis for commercial product recommendations.

AUTHENTICATION

We declare that this work was done under our supervision according to the procedures described herein and that the report represents a true and accurate record of the results obtained.

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CONTENTS

GROWER SUMMARY

Headline

- Fields following Brassicas can contain large but variable reserves of nitrogen.
- Consider sampling Soil Mineral Nitrogen (SMN) in fields with high or uncertain amounts of residues such as in intensively cropped Brassica rotations or in fields where there is a past history of grass or regular inputs of organic manures.
- Interpretation of mineral N needs to be careful especially with shallow rooted crops.

Background

A project investigating the best practice for predicting soil nitrogen supply managed by HGCA - has been running since November 2007 and aimed to achieve consensus across the industry on best practice for estimation of Soil N Supply (SNS).

Specifically:

- To consider stakeholder concerns
- To collate unpublished data on SNS measurement
- To conduct new measurement to develop best practice for interpretation of Soil mineral N (SMN) analysis
- To evaluate uncertainties in SMN measurements
- To understand the importance of over-winter crop N in the interpretation of SNS in Oil seed rape

With needs to maximise the efficiency in which nitrogen fertilisers are used, reduce nitrate leaching and to minimise the crops carbon footprint (N fertiliser commonly contributing 50-85% of the footprint) the application of nitrogen has to be managed.

Currently SNS Index is an integral part of decision making for fertiliser applications to all crops. SNS Index, defined in 6 categories from low (Index 0) to high (Index 6), is a measure of the quantity of available nitrogen to a growing crop. For mineral soils, the highest indices are after intensive cultivation of Brassicas on silt soils in the driest parts of the country and the lowest are on shallow or light soils following cereals in the wettest parts of the country.

Crops grown on soils with an SNS Index of 6 will generally require little fertiliser (Factsheet FV 17). Over-fertilisation could lead to poor storage of produce whilst under-fertilisation could result in loss of yield. It is therefore important that Index is assessed accurately. The tables in the Fertiliser Manual (RB209) are a guide but where large amounts of leafy crop residue or manures have regularly been incorporated measurement of SMN should be considered.

HDC funded 10 field sites within the overall scheme to test the value of SMN measurements on fields after Brassica crops. The results from these sites are reported here.

The interpretation of soil mineral N measurements for field vegetable crops is more complex than for cereals as they generally have a different cropping period, have variable rooting depths and can be in complex and intensive rotations with high and variable amounts of N from crop residues.

This project aimed to address

- which assessment methods to use
- when to take samples
- sampling depth
- sample handling and analysis
- interpretation of the results

All are equally relevant in rotations of arable and vegetable crops so the topic was ideally suited as a cross-sector project with HDC and HGCA funding.

Summary

This summary specifically relates to field vegetable crops. The summary for the full HGCA report is appended to this project report – Appendix 1.

Measurements of Soil mineral nitrogen were made at 10 cereal sites following Brassica vegetables. An area of wheat crop was kept unfertilised by nitrogen so that crop nitrogen uptake from the soil could be measured at harvest; this nil-N crop N uptake is taken as the best estimate of SNS.

The values of SNS measured following cauliflower were variable, and much lower than expected (SNS Index 2 rather than index 3/4 by the Fertiliser Manual (RB209) at three of

the sites, Table 1. This was explained by conservative amounts of N being applied to the previous crops. The levels of soil mineral N were very low after the cabbage crops suggesting low amounts of soil N and crop residues. Soil mineral N levels were very large after calabrese crops reflecting the large amounts of residue left behind (average measured SNS = 5).

These figures suggest that the assessments of SNS Index using the Fertiliser Manual (RB209) can be in error and measurements of soil mineral N would avoid errors in under or over fertilisation of subsequent crops.

Table 1. Assessments of SNS Index on silt soils by the Field Assessment method (FAM) using the Fertiliser Manual (RB209) and by direct measurement at HDC funded sites after Brassica vegetables.

Year	Previous crop and residue group	Rainfall category	Soil Type	FAM SNS	Spring SMN 0-90	SNS Index Measured
2009		Low	Deep silt	4/5	156	4
2009	Calabrese	Low	Deep silt	4/5	128	4
2010	High N Veg	Low	Deep silt	4	173	5
2010		Moderate	Deep silt	4	310	6
	Average				**192**	**5**
2009	Cabbage	Low	Deep silt	3	10	0
2010	Medium N Veg	Low	Deep silt	3	52	0
	Average				**31**	**0**
2009		Low	Deep silt	3/4	65	1
2009	Cauliflower	Low	Deep silt	3/4	71	1
2010	Med/High N Veg	Low	Medium	3/4	104	3
2010		Low	Deep silt	3/4	150	4
	Average				**97**	**2**

Value of high soil supply to subsequent crops

On retentive silt soils larger levels of soil mineral N in the spring and autumn are closely associated with larger yields and N uptakes of unfertilised cereal crops at harvest. Figure 1 shows the close relationship between Spring SNS and N harvested in unfertilised wheat crops at harvest. This confirms the assessments that useful levels of mineral N are left behind after Brassica crops.

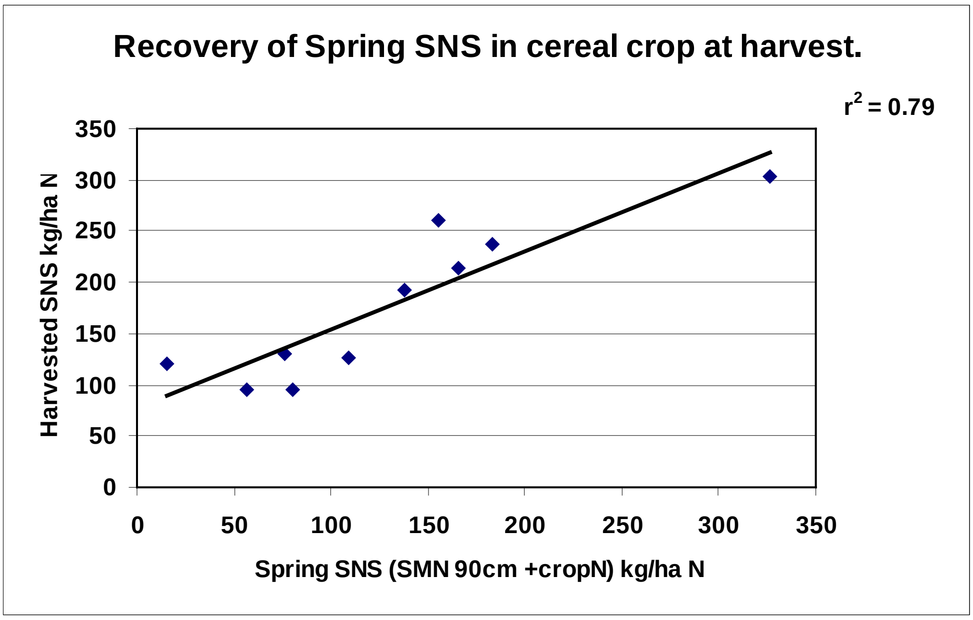

Figure 1. Close relationship between spring SNS and N harvested in unfertilised wheat crops.

Field vegetable crops can also make use of this nitrogen but there is an additional complication for field vegetables which have much shallower rooting than cereals. Crops such as salad onions will only be able to take up N from the top 30 - 45 cm of soil. In such cases SNS to 90 cm is irrelevant though its value has to be estimated to assess the appropriate SNS index in the Fertiliser Manual (RB209).

The appropriate fertiliser recommendation will be affected by the distribution of N within the profile. For field vegetable crops it is important to ensure that N is available to rooting depth especially with young or shallow rooted crops. Even for deep rooted crops like Brussels spouts sufficient N needs to be near the surface to promote early growth. Consider using the WELL_N computer decision support system as a tool in these situations.

In all situations good soil conditions are assumed – poor soil structure can restrict root growth which will reduce further the amount of N that can be taken up.

Appropriate sampling

Whilst measured values of SNS are valuable they have to be carefully measured. There is little room for poor sampling practices or delayed analysis.

Appropriate sampling equipment must be used. It is important to avoid cross-contamination of samples from different depths. Using a mechanised 1 metre long gouge auger (2.5 cm diameter) is a satisfactory and efficient method but care must be taken to avoid excessive soil compaction and contamination between soil layers. If each depth layer is to be sampled individually by hand, a series of screw or gouge augers should be used where the auger diameter becomes progressively narrower as the sampling depth increases. For most crops sampling soils to three depths 0-30, 30-60 and 60-90 cm is appropriate. Shallower sampling is acceptable for shallower rooted crops such as onions and lettuce but soil mineral N does need to be scaled to 90 cm to allow an index to be assigned, Table 2.

Table 2. Scaling up the SNS Index to take into account shallow rooting depth (assumes uniform distribution of N)

Crop	Rooting Depth	Mineral N To rooting depth[1]	Estimate of SMN Index to 90cm	Scaled SNS Index
Salad onions	30 cm	100	300	6
Crisp lettuce	45 cm	100	200	5
Cabbage	90 cm	100	100	2

[1] **From Appendix 10 of the Fertiliser Manual (RB209).**

At least 15 cores will be needed to represent a uniformly managed block of up to 20 ha. Five to 10 further sampling points may be necessary where SNS levels are expected to be very high or variable, after uneven amounts of leafy residues have been incorporated. It is very important that areas of the field with widely differing texture, cropping or fertilisation history are sampled separately.

Sampling in a W pattern (as opposed to more complex arrangements) is adequate to give representative samples. The 'W' design is the design recommended in the Fertiliser Manual (RB209). It requires the sampler to walk in a 'W' pattern across the field and extract soil cores at regular distance. The 'W' should cover as much of the field as is possible. Avoid sampling headlands or other obviously variable patches. Whilst walking in a "W" shape is adequate in most circumstances, the use of GPS techniques to both measure fields and generate sampling grids can be beneficial in large scale sampling campaigns, or for mapping purposes.

Appropriate sampling equipment must be used for assessing SNS. It is important to avoid cross-contamination of samples from different depths. Using a mechanised 1 metre long gouge auger (2.5 cm diameter) is a satisfactory and efficient method but care must be taken to avoid excessive soil compaction and contamination between soil layers.

If each depth layer is to be sampled individually by hand, a series of screw or gouge augers should be used where the auger diameter becomes progressively narrower as the sampling depth increases.

Sample handling and storage

If sub-sampling is required before the samples are sent to the laboratory it is important that the sub-sample obtained is representative. Take many small representative portions but avoid excessive mixing as this may stimulate mineralisation and over-estimation of the available nitrate-N.

It is vital to keep the interval between sampling and analysis for SMN as short as possible. The effects of sample storage were tested in two seasons. The average increase in topsoil SMN was 1.5 kg/ha per day of storage at 2-4°C, compared to 2 kg/ha per day of storage at ambient temperatures. On average SMN in a 90 cm profile increases by ~5 kg/ha per day of delay, even when samples are kept refrigerated (2-4°C).

However this is not always the case. Figure 2 shows an example of the effect of interval between sampling and extraction on measured SMN for soil samples taken in spring 2009 from four fields stored at two temperatures, Ambient and chilled to between 2 and 4 degrees C. Abbreviations are site codes; TT= Terrington, EF= Lincs site, Mo = Morley, Be = Beccles, BX = Boxworth. This shows that the effects of storage can be variable. On the clayey arable site in Lincolnshire mineral N actually fell. The difference was attributed to its previous history of grass and occurrence of immobilisation or denitrification rather than mineralisation.

It is concluded that samples should be kept as cool as possible after sampling (ideally between 2 and 4 ^{0}C placing samples in a cool box) and stored for less than 3 days before analysis.

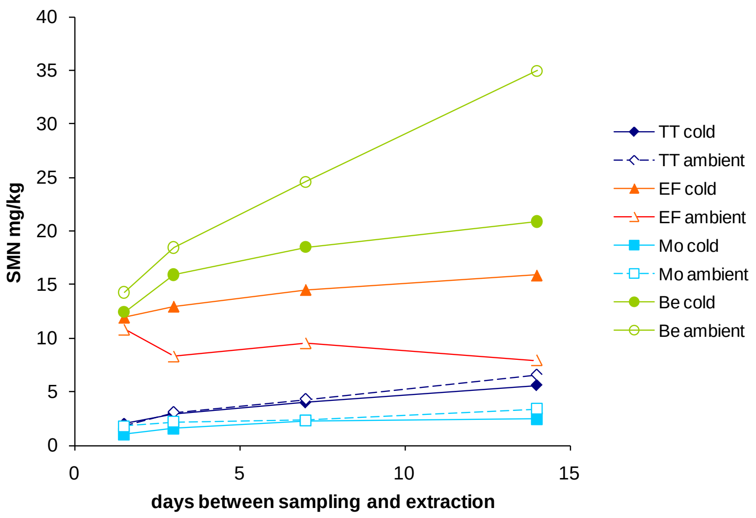

Figure 2. An example of the effect of interval between sampling and extraction on measured soil mineral N.

Financial Benefits

The main HGCA project identified that the financial benefits for cereal crops from measurement of soil mineral N could be largest on retentive silt soils and this was confirmed for the 10 sites sampled in the HDC project.

Savings in fertiliser were possible on sites following high residue crops such as calabrese. The amounts of residue nitrogen remaining after cauliflower crops were variable especially where conservative amounts of fertiliser had been applied.

Where field vegetable crops were likely to follow after cabbage and cauliflower crops measuring soil mineral N could avoid the risk of under fertilising and losses in yield. The benefits of soil samplings are obviously larger where the risk of under fertilising can be avoided. The cost savings are based on nitrogen fertiliser costing £1 per kg N and the price of cauliflower curds being set at £0.40 per curd. The response curve to N is taken for the first cauliflower crops in FV17.

Example 1 – Savings in fertiliser N

If a measurement of Soil Mineral N identifies a large reserve of available soil mineral N large savings of fertiliser are possible.

If 200 kg/ha N fertiliser is saved a possible £200/ha can be saved in fertiliser/ha.

Example 2 – Avoidance of error in fertiliser application

Where there is an overestimation of the residue contribution. For instance where conservative amounts of fertiliser N were applied to a previous crop, less residue N was incorporated than normal, and more overwinter rainfall than expected leached N out of the profile. Where a measurement of SNS Index might have been SNS Index 1 instead of 3 from tables in the Fertiliser Manual (RB209) – an extra 50 kg/ha N fertiliser would have been justified saving £400/ha in lost yield.

SNS Estimated	SNS Actual	N Fertiliser	Curds/ha	Output £/ha
3	1	210	31,000	12,190
3	3	210	32,000	12,590

Action Points for Growers

Which fields to sample

- The contribution from vegetable crop residues needs to be carefully determined - in some cases the SNS Index can be much lower than expected.
- Consider sampling Soil Mineral Nitrogen (SMN) in fields with high or uncertain amounts of residues such as in intensively cropped Brassica rotations or in fields where there is a past history of grass or regular inputs of organic manures.
- Measurements of SMN on peat and peaty soils can be unreliable.
- Choose the Field Assessment Method described in the Fertiliser Manual (RB 209) for soils where mineral N status is expected to be SNS Index 3 or less.

Time to take samples

For growing field vegetables, previous experience has shown:

- Take samples as close to planting date as possible after N has mineralised from previously incorporated residues. N release from winter incorporated residues (sprouts) can be slow.
- Introduce soil sampling for assessment of soil mineral N over a number of seasons so that experience can be gained in its use.
- Avoid sampling within two months after applications of nitrogen fertiliser or organic manures

Sampling and handling of samples

- For most crops sampling soils to three depths 0-30, 30-60 and 60-90 cm is appropriate.
- Sampling can be shallower for shallow rooted crops.
- Care needs to be taken to avoid contamination of samples from lower layers with soil from the surface.
- At least 15 sampling points are needed in a W pattern where previous crop management was uniform.
- Avoid excessive mixing when sub-sampling
- It is important that samples are chilled to between 2-4 ^{o}C as soon as possible after sampling and are analysed fresh within 72 hours.

Interpretation of results

- For most soils a conversion factor of 4 can be used to convert mg/kg to kg/ha for each 30 cm layer of soil.
- When sampling shallower than 90 cm depth, mineral N has to be scaled to 90 cm for assessment of SNS index.
- Consider using the WELL_N computer decision support system as a tool to interpret the results of the soil analysis when mineral N is not evenly distributed to 90 cm.
- If SMN measurements indicate that large changes in N use are required crops should be monitored for signs of deficiency or excess and the planned N strategy should be adjusted if necessary.
- Recommendations assume good growing conditions.

NB In Scotland Refer to Technical Note TN621 Fertiliser recommendations for vegetables, minority arable crops and bulbs (SAC 2009).

HDC factsheet 09/12 provides a summary of this project. It can be accessed through the HDC website www.hdc.org.uk.

SCIENCE SECTION

1. Introduction – estimation of Soil Nitrogen Supply for Field Vegetable crops

With needs to maximise the efficiency in which nitrogen fertilisers are used, reduce nitrate leaching and to minimise the crops' carbon footprint (N fertiliser commonly contributing 50-85% of the footprint) the application of nitrogen has to be managed.

Currently SNS Index is an integral part of decision making for fertiliser applications to all crops. SNS Index, defined in 6 categories from low (Index 0) to high (Index 6), is a measure of the quantity of available nitrogen to a growing crop. For mineral soils, the highest indices are after intensive cultivation of Brassicas on silt soils in the driest parts of the country and the lowest are on shallow or light soils following cereals in the wettest parts of the country.

Crops grown on soils with an SNS Index of 6 will generally require little fertiliser (Factsheet FV 17). Over-fertilisation could lead to poor storage of produce whilst under-fertilisation could result in loss of yield. It is therefore important that Index is assessed accurately. The tables in the Fertiliser Manual (RB209) are a guide but where large amounts of leafy crop residue or manures have regularly been incorporated measurement of SMN should be considered.

HDC funded 10 field sites within the overall scheme to test the value of SMN measurements on fields after Brassica crops. The results from these sites are reported here.

The interpretation of soil mineral N measurements for field vegetable crops is more complex than for cereals as they generally have a different cropping period, have variable rooting depths and can be in complex and intensive rotations with high amounts of N from crop residues. The steps that have to be taken into account are highlighted.

See also General Introduction in Appendix 1– (From - HGCA Project 3425)

2. Materials and methods

Details are provided here for the field work associated with the sites following field vegetable crops managed by ADAS. More details are available in the full HGCA report for work associated with the sample handling studies and analysis of data from all field sites following other crops managed by other project partners.

Task 1: Building consensus through stakeholder engagement

The project aimed to achieve some consensus across the industry on best practice for estimating SNS. To help achieve this a Steering Group met regularly through the project, chaired by Ian Richards and involving representatives from HGCA, ADAS, TAG, SAC, Rothamsted Research, NRM, Hill Court Farm Research, Eurofins, Scottish Agronomy, GrowHow, HDC (PlantNutrient Consulting) and PGRO. In addition, well attended Stakeholder meetings were held at the beginning and end of the project in 2008 (HGCA offices, London) and 2011 (PGRO, Peterborough). Attendees included Defra, government agencies (e.g. Environment Agency), industry bodies (e.g. NFU, AIC), distributors and manufacturers (e.g. Masstock, Hutchinsons, Frontier, Yara), agronomists, laboratories and soil sampling practitioners (e.g. SOYL, Envirofield) and farmers. Stakeholders were given the chance to contribute to the direction of the project at the start, and initial analyses of results were shared at the end of the project where contributions towards final conclusions were sought.

Task 2: Review of past data

Much work has been conducted on SMN methodology since 1980, in the UK and across the world. Not all of the relevant UK information has been fully published. An exercise was conducted at the start of the project to collate as much available past data as possible from all organisations. A dataset was created containing data from all past experiments where SMN had been measured in conjunction with measures of harvested SNS (grain yield and grain N% of unfertilised crop). Where N harvest index (NHI) information was not available this was assumed to be 0.75, so that total N yield could be estimated from grain N yield (TNY = GNY / NHI). The final dataset included over 550 experimental sites; it was used to assess the variabilities of measured SNS and harvested SNS, and the relationship between measured SNS and harvested SNS for a range of soil types and situations.

Task 3: Generating new data for evaluating SNS prediction

In addition to the data collated in Task 2, a new dataset was generated using a total of >180 cereal sites over 3 years where soil measurements were made in autumn and spring, and crop measures were made at harvest. The text here is largely reproduced from *Pages 97 – 102 of main HGCA Report.*

Ten of these arable sites were chosen following Brassica crops in East Anglia on deep silty soils, **Table 3**. The sites were managed by ADAS.

Table 3. Characteristics of sites after Brassica Crops, further details in Appendix.

Field ID	Harvest Year	Rotation[1]	Soil Type (RB209)	Previous crop	Fertiliser N to previous crop kg/ha	Residue class[3]
9H-121	2009	Intensive	Deep Silt	Calabrese	190	high N veg
9H-122	2009	Intensive	Deep Silt	Calabrese	150	high N veg
9H-123	2009	veg/arable	Deep Silt	Cabbage Processing	192	medium N veg
9H-124	2009	Intensive	Deep Silt	Cauliflower	120	med/high N veg
9H-125	2009	veg/arable	Deep Silt	Cauliflower	250	med/high N veg
10h-150	2010	veg/arable	Deep Silt	Cabbage	234	medium N veg
10h-151	2010	veg/arable	Deep Silt	Calabrese	230	high N veg
10h-152	2010	veg/arable	Medium	CauliflowerX2	240	med/high N veg
10h-153	2010	veg/arable	Deep Silt	Cauliflower	180	med/high N veg
10h-154	2010	Intensive	Deep Silt	Calabrese[2]	220	high N veg

Notes

1) Intensive – where mostly Brassica vegetable crops in the rotation.
2) Field 154 only 50% of calabrese crop harvested.
3) Residue class from Fertiliser Manual RB209 (2010).

The effects of other vegetable residues were monitored in 2008 and 2009 at two sites. One following parsnips on a light sandy soil with a history of previous manure. The second site followed lettuce on an organic silt loam, with a history of both previous grass and organic manures.

At each site a representative area of the field was found where a 10m by 10m area was marked out, and from within which all measurements were taken from 9 sampling points within the area. This defined area was left unfertilised with N by the farmer. Spatial variability within such a small defined area was expected to be less than in a normal field situation, so soil sampling errors are likely to be less than in a commercial situation.

Signs were erected on the tramlines either side of the plot area saying “No N fertilisers” to mark the points where the fertiliser operator should turn off the spreader. A generous area was left around the field plot to ensure that no fertiliser got onto the plot area from adjacent tramlines, especially where spinning disc spreaders were used. In some instances a large tarpaulin was used to cover the plot area when fertiliser applications were made.

In addition to the main field plot where all soil measures were made, three additional areas surrounding the field plot were identified where additional crop samples were made at harvest of the commercially fertilised crop.

Soil sampling

Soil samples were taken in autumn (November or early December) and spring (late February or early March). Soil cores were taken from the 30cm soil horizons to 90cm depth from the 9 sampling points in the plot, each horizon being bulked from the 9 cores to give one sample from each horizon for analysis. Where possible samples were taken using Eijkelkamp “Stepwise” 30 mm soil corers for the top 30 cm and EJH Danish 22 mm and 19 mm corers for 30-60cm and 60-90cm depths respectively. Care was taken not to cross contaminate soil from one horizon to another, and to avoid any contamination from vegetation, removing the top 1cm of soil if necessary. In 2007/8 only top soil samples were taken on a 0-15cm and 15-30cm basis, 0-30cm samples were taken in 2008/9 and 2009/10.

Samples were dispatched to the labs in cool boxes with ice blocks as soon as possible after sampling. Sampling was timed to avoid sending samples on a Thursday or Friday so that samples were not in storage or transit over the weekend.

Assessments were taken of topsoil texture using flow chart from Appendix 1 of the Fertiliser Manual (RB209) for each horizon. In 2007/8 attempts were made to get an indicative measure of bulk density by weighing soil cores. With knowledge of corer volume an estimate of bulk density could be calculated. However, results were deemed too variable and untrustworthy to continue this in future years. Stone content of the topsoil was assessed by digging one spit with a spade and visually assessing stone size and abundance using reference charts from the Soil Survey Handbook (Hodgson 1976). An estimate of stone content of the deeper soil layers was made, using the **Table 4** below:

Table 4. Assessment of stone content in subsoil

Description	Stones %	Identification
Stoneless	0	No stones
Slightly stony	1-15	Occasional stones appearing in soil core
Moderately Stony	16-35	Stones felt when turning corer, stones or voids in sample common
Very Stony	36+	Corer penetration difficult, impossible in places.

Visual assessments were also made of the crop at the time of sampling including average plant density, average stage of tillering (i.e. Zadoks Growth stage or number of tillers per plant) and visual estimates of ground cover and green area index. Estimates of crop N were then made using the **Table 5** below:

Table 5. Assessment of crop N kg/ha

	Plant density (per m^2)			
Stage of tillering	*<80*	*80-140*	*150-250*	*>260*
seedling	*Consult study director about aborting site.*	0	0	0
up to 3 leaves		5	5	5
1-2 tillers		5	5	15
3-5 tillers		15	15	30
over 5 tillers		30	30	50

Shoots m^{-2}	*GAI*	*Crop N (Kg/ha)*
500	0.5	15
1000	1	30
1500	1.5	45

If crop N was deemed to be more than 25 kg/ha then 3 quadrats (0.25m^2) were taken from the plot area and samples weighed, dried to 100% DM, reweighed, bulked and dispatched to the lab for N analysis by Dumas.

Soil sample analysis

In 2007/08 analysis of soil samples was shared between 3 laboratories (Eurofins, NRM and HCFR). From 2008/9 onwards all soil samples were analysed by HCFR. All SMN samples were analysed for % dry matter, ammonium-N and nitrate-N concentration (mg/kg).

In addition topsoil samples in spring were also analysed for potentially mineralisable N (PMN) by anaerobic incubation, mineralisable N by Hot KCl extraction (2007/8 only), total N% by Dumas or Kjeldahl and SOM% by the RB247 Walkley Black Method. PMN values were converted to 'additionally available N' (AAN) by Hill Court Farm Research using the GrowHow method.

Harvest crop samples

Crop samples were taken from each site by hand before the crop was combined. Nine samples were taken from the 9 sampling points in the unfertilised area using a 0.25m^2 quadrat. All shoots in each quadrat were cut at ground level and kept separate. Three samples were also taken from each of the three areas identified in the surrounding commercial crop.

The fresh weight of each quadrat sample was measured and the number of shoots counted. A representative sub-sample of ten shoots was taken from each quadrat, the sample was weighed and then sent to ADAS Boxworth for processing, where samples were weighed again, sub-samples bulked into 3 samples, ears and straw were separated, oven dried and weighed, ears were threshed and grain dried and weighed to allow calculation of harvest index (grain dry weight/total dry weight).

After threshing chaff was recombined with straw for N analysis. In 2010 the 3 grain and 3 straw samples from each unfertilised and fertilised site were analysed separately to assess N uptake variability and measurement error. For later years it was deemed that variability in straw and grain N% between reps was sufficiently small for single determinations to be made on bulked samples in future years; variability was most influenced by grain yield. Grain and straw N% was determined by Dumas method by NRM laboratories.

Grain yield, grain N yield, straw yield, straw N yield and total N yield were calculated for the fertilised and unfertilised plots. Standard errors were also calculated from the variability in dry matter yield between the three subsamples. It should be noted that standard errors presented for N uptake do not include variability in N% measures as bulked samples were used in 2009 & 2010.

Estimating rainfall, drainage and N retention

The program IRRIGUIDE (Bailey & Spackman, 1996) was used to model leaching and N retention for each site. Over-winter rainfall for each site was calculated from Met Office weather data. IRRIGUIDE uses soil texture information in 30cm horizons to estimate when soils reach field capacity, hence the date when drainage begins, the amount of drainage and when drainage ends. Using rainfall data, the drainage between October and April, after autumn sampling and after spring sampling was calculated.

A simpler method for estimating N retention was also used at each site, using the approach adopted in HGCA wheat N management guidelines (Sylvester-Bradley 2009) reproduced in **Table 6**. For each site, two estimates of N retention following autumn sampling were made; one using generic rainfall from the generic rainfall map in RB209; the other using an in-year estimate of rainfall after sampling, where below 180mm was classed as (dry), 180 to 230 mm was moderate or above 230mm was wet. An attempt was also made to estimate retention following spring sampling, using estimates in **Table 7.**

Table 6. N retention (%) over winter for RB209 soil groups and over-winter rainfall classes (Sylvester-Bradley 2009).

Rainfall class	Deep silt	Deep clay	Medium	Shallow	Light sands
Dry	100%	95%	90%	70%	40%
Moderate	100%	90%	80%	50%	20%
Wet	80%	70%	60%	30%	10%

Table 7. N retention (%) after spring sampling for RB209 soil groups and rainfall classes.

Rainfall class	Deep silt	Deep clay	Medium	Shallow	Light sands
Dry	100%	100%	100%	80%	70%
Moderate	100%	95%	90%	70%	50%
Wet	95%	90%	85%	50%	40%

Data analysis

Relationships between various SNS predictors (SMN-derived and by the FAM) and harvested SNS were explored for the dataset as a whole, for different soil types and for different situations using a range of regression analyses in Excel and Genstat.

Task 4: Studies to assess uncertainties in sample handling, storage and analysis

Following the data review in Task 2, specific issues surrounding the measurement of SMN and the prediction of SNS were investigated. Two laboratory standardisation exercises were carried out in spring and autumn 2008. Soil samples of around 3 kg from 0-30cm cores were collected from 10 fields selected to represent a range of expected SNS levels. The samples were thoroughly mixed and six sub-samples of 500g were taken (each made up of 10 portions of 50g soil). Two of the six samples were sent to each laboratory in chilled packs for next day delivery. Temperature sensors were included in each batch of samples so that changes in temperature through transport could be assessed. Samples were analysed for SMN (soil DM%, nitrate-N & ammonium-N; mg/kg) and results compared.

Sample handling and storage exercises were carried out in spring 2009 and 2010. In each study soil samples were taken from four contrasting fields in each year. For the sample storage studies four separate ~3kg samples from 0-30cm were obtained by spade from each site. These were thoroughly mixed and sub-samples taken from each, to give samples for 8 (2009) or 10 (2010) storage treatments with 4 replicates. In 2009 samples were then stored at 2-4°C for <1.5 days or at room temperature for 7 days; or in 2010 samples were stored at 2-4°C for <1, 2, 4 or 7 days or at room temperature for 7 days. In 2009 one treatment also tested samples frozen for 14 days.

After storage, samples were extracted with KCl at ADAS Boxworth. Sample extracts were frozen and then sent to the laboratory (HCFR) for determination of nitrate-N and ammonium-N. For the sampling and sample handling exercises samples were generated from each of the 4 fields in each year by taking soil cores, either within a 10m x 10m area, or a wider 100m x 100m area.

From each of 4 replicates half of each sample was mixed thoroughly and subsampled carefully, the other half was not mixed and sub-samples were taken at random. In 2009, samples were stored at room temperature or 2-4°C for <1.5 or 7 days, in 2010 samples were stored at 2-4°C for <1.5 days before extraction at ADAS Boxworth.

All results were analysed by anova in Genstat to assess treatment differences.

Task 5: Studies of crop N in OSR

– See **Full HGCA report**.

Task 6: Cost: Benefit analyses to give Best Practice advice

Different criteria were used to assess the 'best' SNS predictor for a category of crop:

Accuracy:

The difference (bias) between the average prediction and average harvested SNS. Note that, because over-predicting harvested SNS (thus using sub-optimal fertiliser N and incurring yield losses) tends to be more costly than under-predicting harvested SNS; profit from use of any predictor is maximised if it has a small negative bias (zero to -20 kg/ha SNS).

Precision:

The extent to which a potential predictor accounted for each value of harvested SNS over a number of sites was assessed using

- the coefficient of determination (r^2) of the linear regression equation.
- the frequency with which a predictor gave 'right' or 'wrong' predictions, i.e. the proportion of times that the prediction was within +/- 20 kg/ha or more than +/- 50 kg outside of the harvested SNS.

The combined effects of imprecision and bias were assessed in two ways:

- Statistically: For any prediction, the coefficient of determination (r^2) for y = x shows how much of the variation in harvested SNS was explained by the actual values of any SNS predictor (without an intercept or slope).
- Economically: The effect on margin over N cost (‘profit foregone’) of using a particular SNS prediction at each site. For this we assumed N was applied according to the SNS prediction and then subtracted the margin over N cost if N had been applied according to actual harvested SNS; we used a typical yield response curve to fertiliser N (taken from HGCA Report 438), a grain price of £150/t, and an AN price of £300/t.

  Note that large errors in fertiliser N use are disproportionately costly compared to small errors, and average profit foregone (or the frequency of >£40/ha profit foregone) is affected by bias, especially if large (<-20 or >0 kg/ha SNS), as well as by imprecision. Prediction costs e.g. of SMN measurements, were not included in profit calculations.

3. Results

The summary results from the HGCA project are reproduced in Appendix 1. The full HGCA report contains all the data and its discussion. Only data specifically relevant to field vegetable crops is reported here.

3.1 Task 1: Building consensus through stakeholder engagement

Clive Rahn from PlantNutrition Consulting was a member of the steering group representing the interests of Field Vegetable Growers.

The steering Group met regularly through the project, chaired by Ian Richards and involving representatives from HGCA, ADAS, TAG, SAC, Rothamsted Research, NRM, Hill Court Farm Research, Eurofins, Scottish Agronomy, GrowHow, HDC and PGRO. In addition, well attended Stakeholder meetings were held at the beginning and end of the project in 2008 (HGCA offices, London) and 2011 (PGRO, Peterborough). Attendees included Defra, government agencies (e.g. Environment Agency), industry bodies (e.g. NFU, AIC), distributors and manufacturers (e.g. Masstock, Hutchinsons, Frontier, Yara), agronomists, laboratories and soil sampling practitioners (e.g. SOYL, Envirofield) and farmers. Stakeholders were given the chance to contribute to the direction of the project at the start, and initial analyses of results were shared at the end of the project where contributions towards final conclusions were sought.

Members of the steering group were involved in the pier review of the final HGCA report and a Topic sheet for arable growers.

3.2 Task 2: Review of past data

An analysis of a past dataset with >550 comparisons showed that measured SNS related to harvested SNS, but the relationships were not strong, probably due to large spatial and temporal variation in SNS. Some of this variation might be avoided by good practice, but probably not all. The relationship was strongest in the subset of data from uniform, N retentive soils where the spread in expected SNS was high.

3.3 Task 3: Generating New Data for evaluating SNS prediction

3.3.1 Measurements of Soil mineral N

HDC funded soil and crop measurements at 10 cereal sites following Brassica vegetables on N retentive soils. Measurements of soil mineral N were made late November/early December and mid February, **Table 8**

In the autumn mineral N levels to 90cm were much highest after calabrese, averaging 222 kg/ha N. than after cauliflower (126 kg/ha N) and were lowest after cabbage (47 kg/ha N). Nearly half of the mineral N was in the top 30cm.

The mineral N levels were unexpededly low after cabbage, and in 4 of the 5 fields after the cauliflower crops. This may be in part due to the gap between harvest in late October /early November and when the soils were sampled in the autumn being short. .

By the spring N levels after calabrese had dropped from 222 to 192 kg/ha N to 90cm. In spite of the late harvesting of the other Brassica crops there was no apparent evidence of any additional mineralisation as mineral N levels fell between November and February.

Table 8. Soil Mineral N levels on 10 sites following Brassica crops sampled by ADAS.

Year	Previous crop and residue group	Site ID	Rainfall category	Rotation Intensity	Autumn kg/ha N					Spring kg/ha N				
					0-30	**30-60**	**60-90**	**0-90**	**SNS**	**0-30**	**30-60**	**60-90**	**0-90**	**SNS**
2009	Calabrese High N Veg	9H-121	Low	Intensive	93	80	20	193	193	30	79	47	156	161
2009		9H-122	Low	Intensive	60	81	7	147	147	9	63	56	128	133
2010		10h-151	Low	veg/arable	105	79	15	199	204	31	64	78	173	178
2010		10h-154	Moderate	Intensive	180	118	50	348	353	31	124	155	310	315
2009	Cabbage Medium N Veg	9H-123	Low	veg/arable	16	7	37	59	59	5	4	1	10.0	15
2010		10h-150	Low	veg/arable	12	14	8	34	34	14	18	19	52	57
2009	Cauliflower Med/High N Veg	9H-124	Low	Intensive	30	53	16	98	98	18	30	18	65	80
2009		9H-125	Low	veg/arable	33	18	14	64	64	26	28	17	71	76
2010		10h-152	Low	veg/arable	69	15	7	91	91	42	36	25	104	109
2010		10h-153	Low	veg/arable	81	128	43	252	257	24	48	78	150	155

The values of soil mineral N remained much lower than expected following cauliflowers at three of the sites. The levels of soil mineral N were very low after the cabbage crops suggesting low amounts of soil N and crop residues. Soil mineral N levels remained large after calabrese crops reflecting the large amounts of residue left behind. The site with the highest mineral N was 10h-154 where only 50% of the marketable crop was removed leaving much larger residues.

However whilst large amounts of mineral N were present to 90 cm in the spring only 14% of the N following calabrese was in the 0-30 cm layer. The distribution of N would affect the availability to shallow rooted field vegetable crops.

The effects of other vegetable residues were monitored in 2008 and 2009 at two sites. One following parsnips on a light sandy soil with a history of previous manure use had an autumn mineral N to 90 cm of 155 kg/ha N, by the spring it had declined to only 55 kg/ha N. Another site following lettuce on an organic silt loam, with a history of both previous grass and organic manures had an autumn mineral N to 90 cm of 425 kg/ha N which reduced to 367 kg/ha N by the spring.

3.3.2 Sampling – variation in SMN over winter

Soil mineral N samples were taken at monthly intervals on field 10h-151 drilled with wheat which followed calabrese harvested in early September, **Figure 3**. Soil mineral N to 90 cm was 199 kg/ha in November rising to 270 kg/ha N in December. At the time spring SNS was determined in mid February mineral N levels had fallen to 173 kg/ha.

Soil mineral N levels fell beyond that point reaching only 48 kg/ha by mid April. This decrease was not explained by crop uptake which was only 35 kg/ha N at this time. This indicates leaching of N to below 90 cm, or immobilization. If N is lost by leaching it may still be within the reach of deeper cereal crops (as evidenced by the recovery of N at harvest) but beyond the range of shallower rooted vegetable crops.

Hence the recommendation that mineral N levels are measured as close to planting date as possible to account for any loss or accumulations of N.

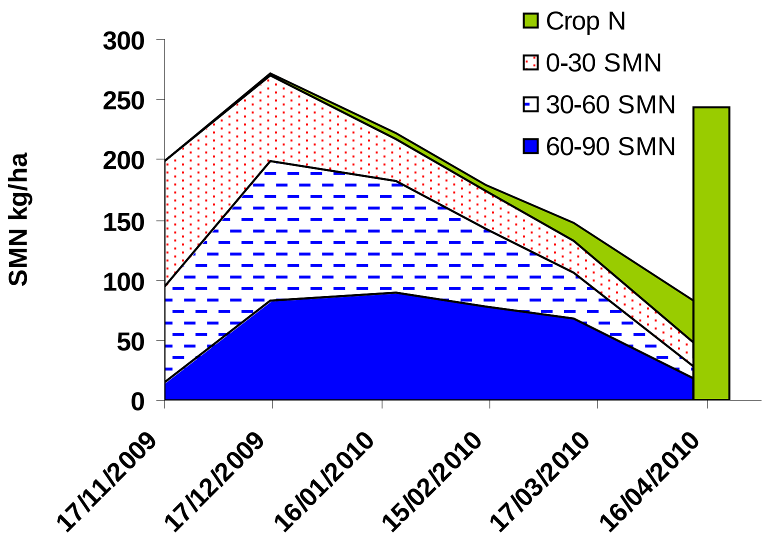

Figure 3. Monthly sampled mineral N levels at site 10h-151 after calabrese harvested in September**.**

3.3.3 Relationships in newly generated data

On retentive silt soils larger levels of soil mineral N in the spring and autumn are closely associated with larger yields and N uptakes of unfertilised cereal crops at harvest. **Figure 4** below shows the close relationship between Spring SNS and Harvested SNS, the Nil N crop uptake at harvest of the following cereal crops. This confirms the assessments that useful levels of mineral N are left behind after Brassica crops.

The relationships are slightly better from autumn rather than spring and better for 0-90 than 0-60 cm samples. Slopes are steeper for spring vs. autumn samples reflecting greater recovery of N in the soil in spring and the final crop uptake. The main HGCA report discussed the relevance of adjusting for different slopes and intercepts and concluded that the advantage of using them to adjust measured SNS to improve the prediction of SNS would be small except at the extremes.

Additionally it is surprising how little the relationships were affected by the diverse distribution of mineral N with depth. The recovery of N to 90 cm by shallow rooted field vegetable crops would be expected to be less and show more variability between sites.

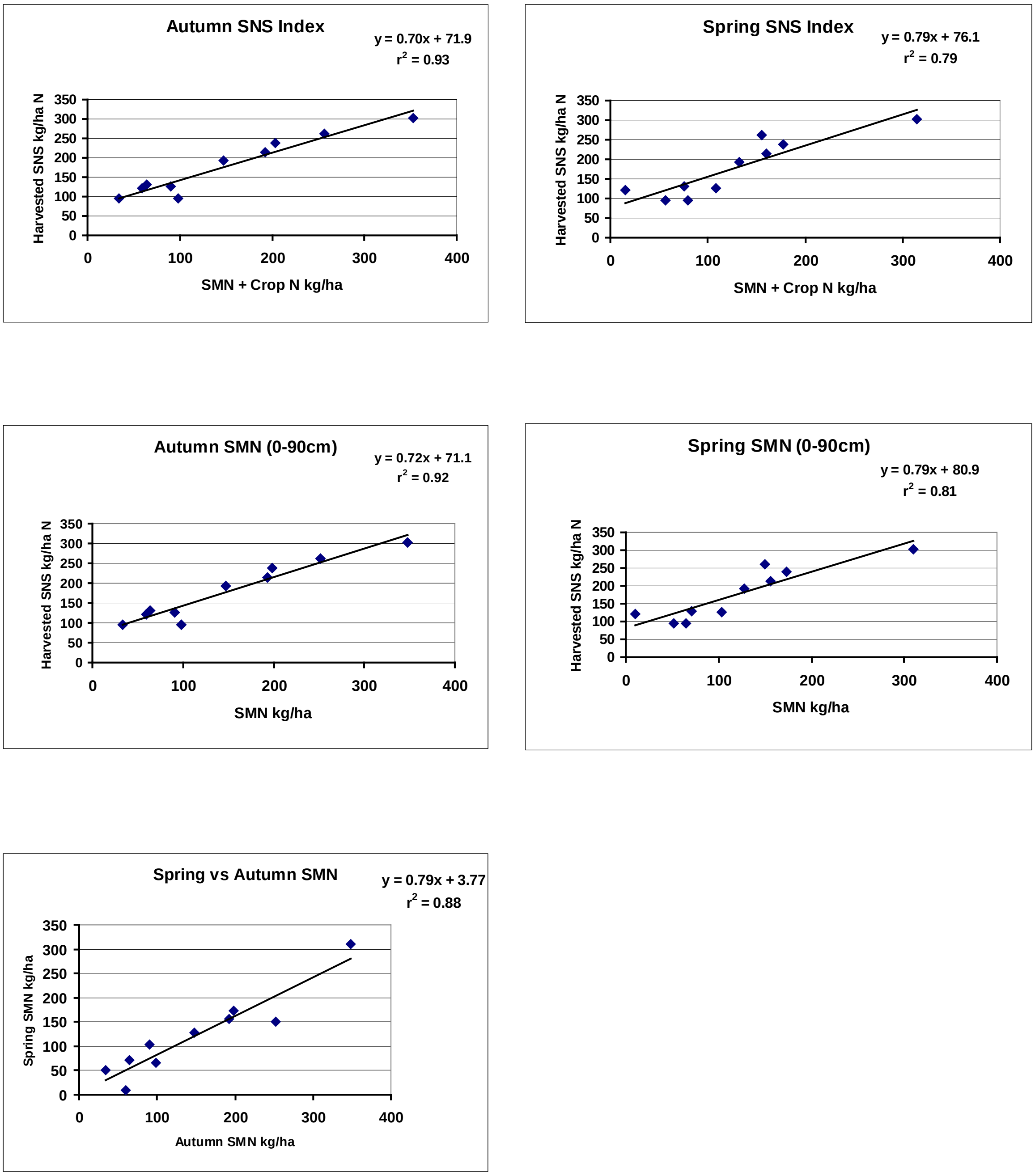

Figure 4. The close relationships between assessments of SNS by measurement and harvested SNS (N harvested in following unfertilised wheat crops at harvest).

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3.4 Task 4: Studies to assess uncertainties in sample handling, storage and analysis

See HGCA report sections 3.4 pages 62 to 89 for more details.

3.4.1 Sampling in the Field

Although not examined in this project, sampling intensity and pattern have been studied in a recently completed HGCA project. Full details can be found in the final report (Marchant, In Press), but the conclusions as they relate to SMN sampling are summarised here.

Optimal intensity of sampling for SMN increases with both field size and expected SNS (**Table 9**). More sampling is cost-effective on larger fields because of the potential for larger total yield and profit. More sampling is required when the expected SNS is large because this leads to large within-field variability of SMN. At one extreme, for a 60ha field with an expected SNS of 275 kg/ha, the most profitable sampling strategy was found to be around 25 cores. This is greater than the 15-20 cores recommended in RB209 (although the latter advises splitting fields of more than 10ha). However, a smaller number of soil cores was found to be optimal for fields of 20ha or less and with an expected SNS of up to 125 kg/ha, compared to the 15-20 recommended in RB209 (**Table 9**).

In practice, fields of up to 5ha or with an expected SNS of 25 kg/ha are unlikely to be sampled, so the optimal number of cores is likely to be between 8 and 12 for many situations, offering some potential for saving time compared to existing best practice advice.

Table 9. Optimal number of cores on 'W' when sampling SMN throughout the target area (from Marchant et al, in Press).

Target area	Expected SNS (kg/ha) 25	75	125	175	225	275
5 ha	3	4	4	5	6	6
10 ha	4	6	6	8	8	9
20 ha	5	8	8	10	10	13
30 ha	7	10	12	12	14	18
60 ha	10	14	15	18	23	23

Marchant *et al*. (In Press) compared the suitability of various different types of sample designs to estimate the mean concentration of soil nutrients within a management zone. The designs considered were:

1) The 'W' design recommended in RB209 (see description below),

2) A spatially stratified design,

3) A design that had been optimized for prediction of the mean concentration by geostatistical methods, and

4) A design which stratified the sampling according a yield map from the previous season.

Marchant et al. (In Press) concluded that, taking all factors into account, the 'W' design was the most efficient. They noted that, because RB209 fertiliser recommendations do not require very precise estimates of soil-nutrient concentrations, there are only small monetary implications of the additional errors from the 'W' design. If in the future more sensitive fertiliser recommendations are implemented, say if nutrient leaching had to be predicted accurately, then it might prove necessary to re-explore the implementation of optimized sample designs.

3.4.2 Sub Sampling

Table 10 shows the effect of thorough mixing of the soil prior to sub-sampling on the average SMN level for the four fields sampled in each year. In spring 2009, thorough mixing of the soil sample resulted in a significantly higher amount of nitrate-N (and therefore SMN) being measured. In 2010 however there was no effect of mixing on the amount of SMN measured. This was probably related to the temperatures when soils mixed, it being warmer in 2009.

Table 10. Effect of sample mixing on SMN values in spring 2009 and 2010: mean of four sites (and two storage durations/temperatures in 2009).

Treatment Regime	Average SMN mg/kg			
	Ammonium	Nitrate	2009 Total	2010 Total
Thorough	1.14	6.70	7.84	7.29
No Mixing	1.18	5.30	6.48	7.54
Mixing d.f.	64	64	64	64
s.e.d.	0.380	0.387	0.673	0.548
F Prob.	NS	<0.001	0.048	NS

Sub-sampling studies showed that thorough mixing of soil could increase measured SMN. However, mixing also reduced the coefficient of variation (cv) from 36% to 30%. There thus needs to be a compromise between acquiring representative sub-samples and avoiding stimulation of N mineralisation by excessive mixing.

3.4.3 Laboratory Standardisation

Laboratory standardisation exercises (**Figure. 5**) showed (with a few exceptions) differences between and within laboratories to be relatively small, given the inherent sample variability. The 'ring-tests' initiated in this project are now being continued by the major laboratories on an annual basis.

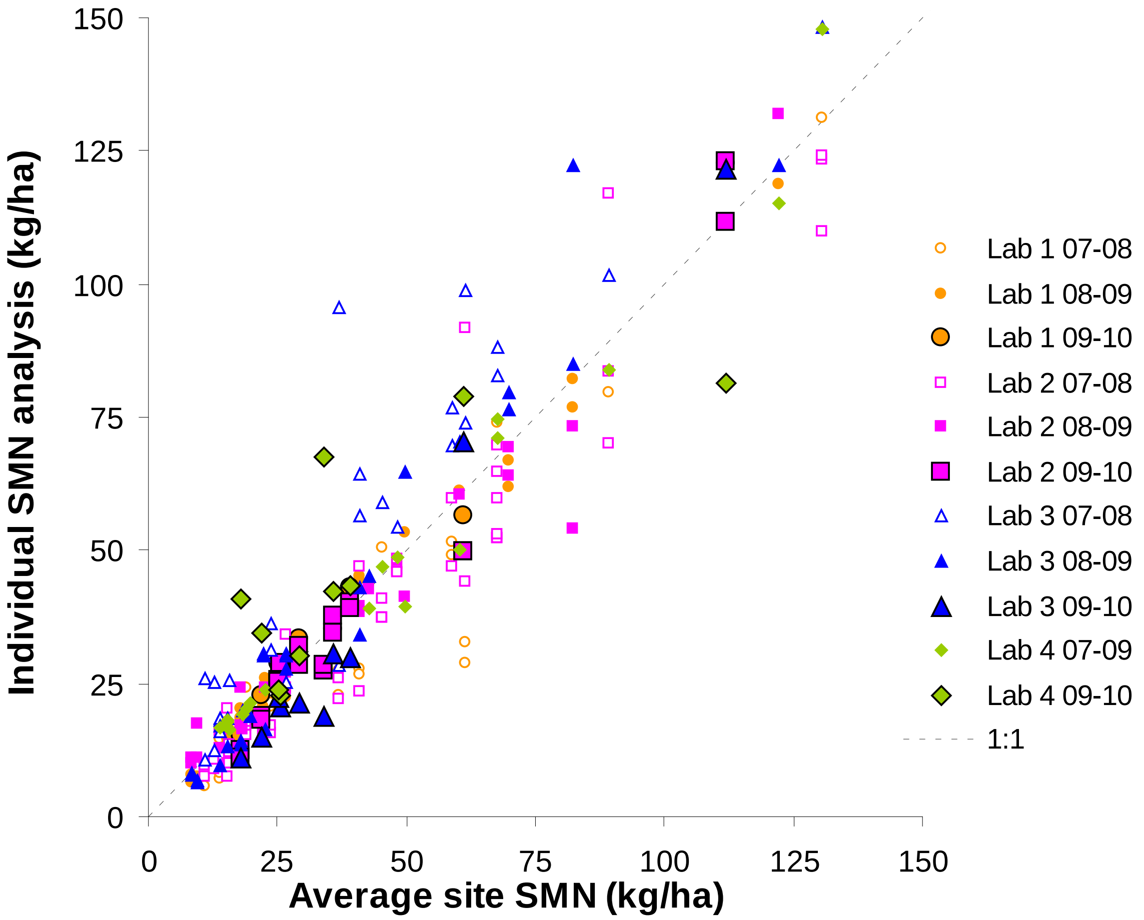

Figure 5. Range of SMN values (kg/ha) recorded by different laboratories for individual soil sub-samples from the same field sample, compared to the mean value for those sub-samples. Dotted line 1:1.

3.4.4 Sample storage before analysis

Sample storage studies (**Figure. 6**) showed SMN of refrigerated samples to increase steadily with delay in analysis after sampling. Subsoils changed less than topsoils. Average SMN 0-90cm increased by 2.5 kg/ha per day delay. Increases were larger and more variable at room temperature. In 2009 the effects with storage were variable. On the clayey arable site in Lincolnshire, mineral N actually fell.

It was concluded that samples should be cooled and stored for less than three days before analysis.

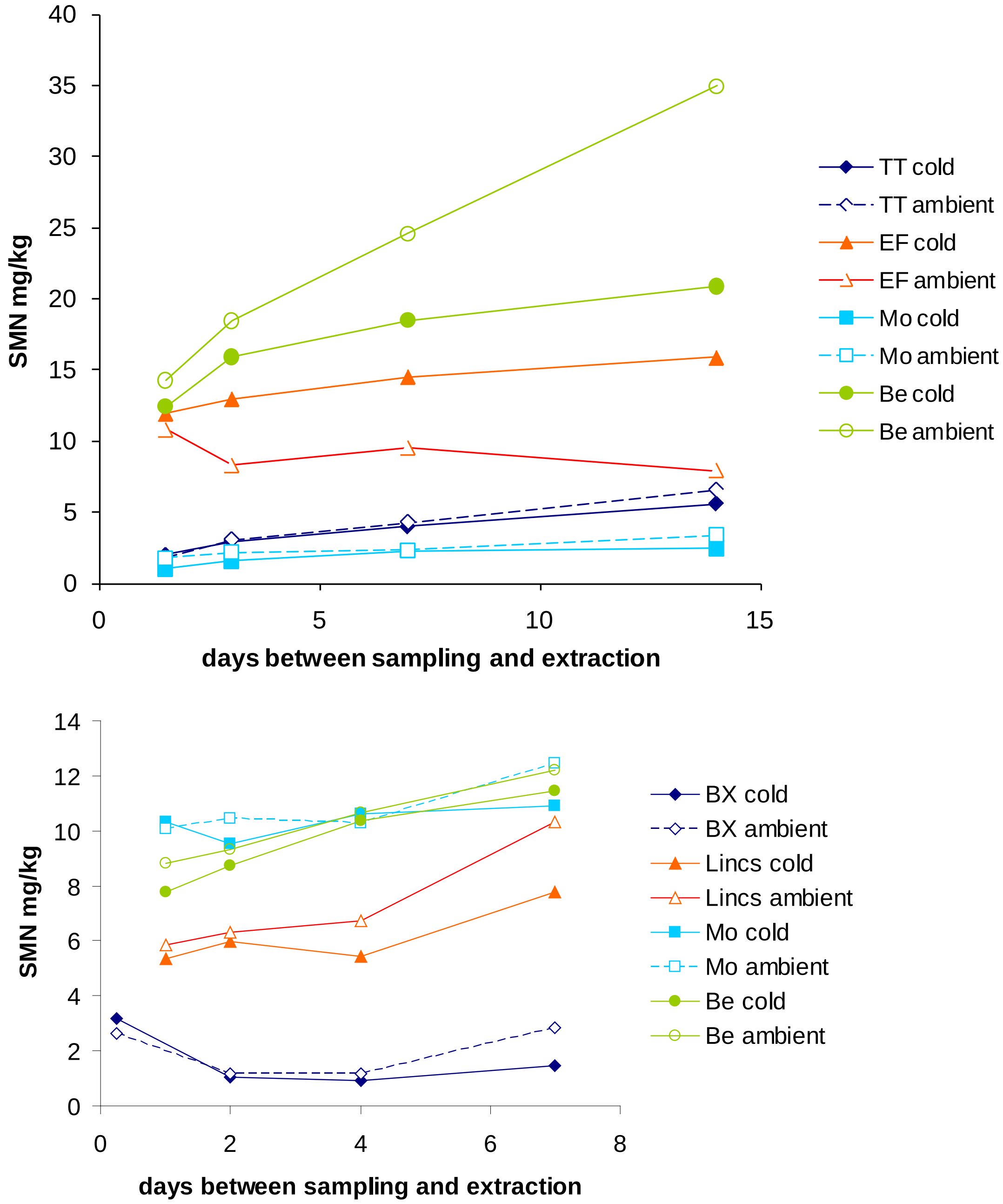

Figure 6. Effect of interval between sampling and extraction on measured SMN for soil samples taken from four fields and stored at two temperatures in 2009 (top) and 2010 (bottom). Abbreviations are site codes; TT= Terrington, EF= Lincs site, Mo = Morley, Be = Beccles, BX = Boxworth.

3.5 Task 5: Studies of crop N in OSR

See the summary of the results in **Appendix 1** and details in the **HGCA report.**

3.6 Task 6: Cost-benefit analysis to give best practice advice

Table 11 below shows the cost benefit analysis for cereals after Brassicas only which differs from **Table 55** in full HGCA report as it excludes lower residue lettuce and parsnip crops. It demonstrates a strong benefit to the use of measurements to asses SNS index, the best performance overall being provided by measurements of SNS to 90cm in autumn or spring. Including adjustments for AAN, leaching, slope and intercept deliver no better precision in assessment of SNS errors or profit forgone.

TABLE 11. Comparison of approaches for SNS prediction on 10 sites following Brassica vegetables on silt soils 2008-2010. # Negative r^2 values indicate the extent to which predictor values gave worse deviations than a constant i.e. the mean. ‘Best’ predictors are developed through ‘Best’ predictors are developed through section 3.7 and defined in section 3.7.8 in full HGCA Report.

	Coefficient of determination		SNS errors (kg/ha)				Profit foregone		
Approach	R2 linear regression	R2 y=x	Mean error (accuracy)	Precision	% within 20kg/ha	% outside 50 kg/ha	Average £/ha	% <£10/ha	% >£40/ha
Constant 100 kg/ha	0	0	78	2	20%	50%	54.86	50%	50%
RB 209 FAM	0.24	-0.25	44	17	40%	50%	34.16	40%	30%
RB 209 FAM including manure	0.24	-0.25	44	17	40%	50%	34.16	40%	30%
Autumn SNS 0-90	0.93	0.62	32	1	40%	30%	12.76	50%	0%
Autumn SNS 0-60	0.92	0.38	48	0	20%	30%	21.29	20%	10%
Spring SNS 0-90	0.79	0.27	47	4	20%	50%	23.54	20%	20%
Autumn SNS 0-90 (max 200)	0.84	0.38	48	1	40%	50%	19.26	30%	10%
Spring SNS 0-90 (max200)	0.79	0.07	60	0	20%	60%	27.60	20%	30%
Spring SNS 0-90 +AAN (max 200)	0.72	0.45	36	6	20%	30%	16.78	50%	20%
Spring SNS 0-60 +AAN(max 200)	0.44	0.05	43	12	30%	50%	27.89	40%	30%
Autumn SNS (leach adj)	0.83	0.20	56	1	20%	70%	24.47	20%	10%
Spring SNS (leach adj)	0.81	0.06	61	0	10%	60%	27.92	20%	30%
Autumn SNS 0-90 int & slope	0.93	0.30	52	1	10%	60%	21.52	30%	10%
Spring SNS 0-90 int & slope	0.77	0.43	38	4	30%	30%	17.27	60%	20%
Autumn 'Best'	0.83	0.47	40	5	10%	30%	16.44	50%	10%
Spring 'Best'	0.75	0.59	25	9	40%	30%	12.68	60%	10%

Financial savings in fertiliser costs were possible on sites following high residue crops such as calabrese. The amounts of residue nitrogen remaining after cauliflower crops were variable especially where conservative amounts of fertiliser had been applied.

Where field vegetable crops were likely to follow after cabbage and cauliflower crops measuring soil mineral N could avoid the risk of under fertilising and losses in yield. The benefits of soil samplings are obviously larger where the risk of under fertilising can be avoided. The cost savings are based on nitrogen fertiliser costing £1 per kg N and the price of cauliflower curds being set at £0.40 per curd. The response curve to N is taken for the first crops in FV17 project.

Example 1 – Savings in fertiliser N

If a measurement of Soil Mineral N identifies a large reserve of available soil mineral N large savings of fertiliser are possible.

If 200 kg/ha N fertiliser is saved a possible £200/ha can be saved in fertiliser/ha.

Example 2 – Avoidance of error in fertiliser application

Where there is an overestimation of the residue contribution. For instance where conservative amounts of fertiliser N were applied to a previous crop, less residue N was incorporated than normal, and more overwinter rainfall than expected leached N out of the profile. Where a measurement of SNS Index might have been SNS Index 1 instead of 3 from tables in the Fertiliser Manual (RB209) – an extra 50 kg/ha N fertiliser would have been justified saving £400/ha in lost yield (**Table 12**).

Table 12. Financial effect of incorrect assessment of Soil N status.

SNS Estimated	SNS Actual	N Fertiliser	Curds/ha	Output £/ha
3	1	210	31,000	12,190
3	3	210	32,000	12,590

4. Discussion and conclusions

Research in project HGCA 3425 was conducted mainly with deeper rooted cereals crops in mind. Field vegetables are much more varied in terms of their rooting, cropping period and complexity of rotation. This section highlights some of these differences and makes appropriate comments.

4.1 Defining Soil N Supply for field vegetable crops

In the Fertiliser Manual (RB209) SNS for arable crops is defined as:

> *"The amount of nitrogen (kg/ha) in the soil (apart from that applied for the crop in manufactured fertilisers and manures) that becomes available for uptake by the crop in the growing season, taking account of nitrogen losses"*

This includes the mineral N content of the soil to 90cm plus the crop N content at the time of its measurement and an estimate of subsequent N mineralisation from soil organic matter.

For field vegetable crops sampling is normally carried out prior to planting so there is no crop N content to take account of. For arable crops an allowance is made for subsequent mineralisation of N from soil organic matter during the growing period. This allowance needs to be modified to take account of variable growing periods of field vegetable crops. The mineralisation component of SNS is taken into account in the recommendation tables in the Fertiliser Manual (RB209). The estimates vary from 22 kg/ha for short season crops such as lettuce to over 100 kg/ha for crops such as Brussels sprouts, see Appendix 10 in the Fertiliser Manual (RB209).

For practical purposes SNS for field vegetable crops is taken as the soil mineral N level to 90cm at planting. **See Appendix 2** for a conversion table

A further allowance needs to be made as many vegetable crops do not root to 90cm – **see section 4.4.1**.

In Scotland residue levels are defined as Nitrogen residue groups – see **Appendix 2** and SAC (2009) Technical Note TN621 Fertiliser recommendations for vegetables, minority arable crops and bulbs August 2009

4.2 Which assessment method to use

The main HGCA report concludes that the largest benefits from soil mineral N determinations are on silty soils where large amounts of nitrogen rich vegetable crop residues are incorporated – these are situations where SNS index above 4 are expected. The HGCA report does register some caution where SNS is above 160 kg/ha but in the data after brassicas there are clear relationships beyond that limit – **Figure 4**. So mineral N sampling has been found to be beneficial. Research reported in project FV17 has already shown the value of such measurements of soil mineral N in rotations of Brassica crops.

FAM can be used on other soils where lower amounts of soil mineral N are expected. Assessment of FAM depends on accurate assessment of soil type, organic matter content, previous crop residue and over winter rainfall.

Assessments of SNS in vegetable cropping rotations can be difficult The data from ADAS was used to test the assessment of SNS Index by FAM based on previous Brassica cropping, **Table 13**.

The values of SNS measured following cauliflower were variable, and much lower than expected (SNS Index 2 rather than index 3/4 by FAM) at three of the sites. This was explained by conservative amounts of N being applied to the previous crops. The levels of soil mineral N were very low after the cabbage crops suggesting low amounts of soil N and crop residues. Soil mineral N levels were very large after calabrese crops reflecting the large amounts of residue left behind (average measured SNS = 5).

Table 13. Assessments of SNS Index by Field Assessment method (FAM) as described in the Fertiliser Manual (RB209) and measurement at HDC funded sites after vegetables.

Year	Previous crop	Rainfall category	Soil Type	FAM SNS	Spring SMN kg/ha 0-90cm	SNS index measured
2009		Low	Deep silt	4/5	156	4
2009	Calabrese	Low	Deep silt	4/5	128	4
2010	High N Veg	Low	Deep silt	4	173	5
2010		Moderate	Deep silt	4	310	6
	Average				**192**	**5**
2009	Cabbage	Low	Deep silt	3	10	0
2010	Medium N Veg	Low	Deep silt	3	52	0
	Average				**31**	**0**
2009	Cauliflower	Low	Deep silt	3/4	65	1
2009	Med/High N	Low	Deep silt	3/4	71	1
2010	Veg	Low	Medium	3/4	104	3
2010		Low	Deep silt	3/4	150	4
	Average				**97**	**2**

These figures suggest that the assessments of SNS Index by the FAM can be in error and measurements of soil mineral N would avoid errors in under or over fertilisation of the following crops.

On retentive silt soils it may also be useful to check mineral N levels following wet winters. Whilst SNS is still high, little mineral N might be readily available to young or shallow rooted crops. N rates may need to be adjusted to take account of N moved out of the rooted zone.

On very light soils following very wet winters it may also be useful to check SMN. If SMN is very low (< 50 kg/ha) further N may be justified for shallow rooted crops such as onions.

Where crops are planted in succession in the same year it may be worthwhile sampling at planting of second crops (see FV17 Report).

If SNS Index is expected to be 3 or less use the Field Assessment Method unless there is a special reason.

Measurements of SMN on peat and peaty soils can be highly variable and difficult to interpret without local knowledge.

In Scotland use Technical Note TN621 Fertiliser recommendations for vegetables, minority arable crops and bulbs (SAC 2009).

4.3 Assessing SNS level by measurement method

Where it has been identified that the assessment of SNS by measurement is beneficial it is worth introducing the technique to the farm over a number of seasons so that experience can be gained in its use.

4.3.1 When to Sample

For growing cereals refer to the HGCA Report and Topic sheet – taking care to make allowances for the high and variable residues from vegetable crops.

For growing field vegetables previous experience (FV17) has shown that it is best to take samples as close to planting date as possible after N has mineralised from previously incorporated residues. (Measurements on sites after Brussels sprouts can have low soil mineral N until April /May because it takes time for N to mineralise from the leafy residues).

Applications of fertiliser and manure can stimulate rapid fluctuations in mineral N, so avoid sampling within two months after the applications of nitrogen fertiliser or organic manures.

4.3.2 How to sample

Appropriate sampling equipment must be used for assessing SNS in both arable and horticultural rotations. It is important to avoid cross-contamination of samples from different depths. Using a mechanised 1 metre long gouge auger (2.5 cm diameter) is a satisfactory and efficient method but care must be taken to avoid excessive soil compaction and contamination between soil layers. If each depth layer is to be sampled individually by hand, a series of screw or gouge augers should be used where the auger diameter becomes progressively narrower as the sampling depth increases. For most cereals sampling soils to three depths 0-30, 30-60 and 60-90cm is appropriate. For vegetable crops sampling to 90cm is not always necessary – see section 4.4.1.

At least 15 cores will be needed to represent a uniformly managed block of up to 20 ha. In intensive rotations of field vegetable crops 5 to 10 further sampling points may be necessary where SNS levels are expected to be very high or variable, after uneven amounts of leafy residues have been incorporated (see **Table 9**). It is very important that areas of the field with widely differing texture or cropping history are sampled separately.

Sampling in a W pattern (as opposed to more complex arrangements) is adequate to give representative samples. The 'W' design is the design recommended in the Fertiliser Manual (RB209). It requires the sampler to walk in a 'W' pattern across the field and extract soil cores at regular distance. The 'W' should cover as much of the field as is possible. Avoid sampling headlands or other obviously variable patches. Whilst walking in a "W" shape is adequate in most circumstances, the use of GPS techniques to both measure fields and generate sampling grids can be beneficial in large scale sampling campaigns, or for mapping purposes.

4.3.3 Sample handling and analysis

There are several stages in the sampling, handling and analysis process that have the potential to introduce uncertainties into SMN measurement.

When sampling cores the soil from each sampling point is bulked for each depth. If sub-sampling is required before the sample is sent to the laboratory it is important that the sub-sample obtained is representative. Take many small representative portions, avoid excessive mixing as this may stimulate mineralisation and lead to over-estimation of the available nitrate-N.

It is vital to keep the interval between sampling and analysis for SMN as short as possible. **(Figure 6)** Samples should be cooled in the field and transported to the laboratory at 2-4°C, for analysis within three days of sampling.

For any sets of samples that are to be compared it is important that the delay from sampling to analysis is standardised It is suggested that standard delays of ~24, ~48 or ~72 hours could be adopted. Long term (one week or more) storage of soil samples is not appropriate for SMN testing. Freezing is not suitable for commercial SMN testing.

All samples from the same batch should go to one laboratory as small differences in handling and analysis will make a difference.

The HGCA report recommends annual ring testing to ensure that any systematic differences between analytical laboratories are identified and corrected.

4.4 Interpretation of Results

4.4.1 Dealing with the interpretation of Soil Mineral N for shallow rooted crops.

SNS Index is based on measurements of SMN to 90 cm so mineral N values to a lesser depth have to be scaled up to what they would be to 90 cm as shown in the **Table 14** below. For field vegetables as samples are taken before planting there is no need to make allowances for crop N content. The contribution of N from the mineralisation of soil organic matter is taken into account in the recommendation tables.

Table 14. Scaling up the SNS Index to take into account shallow rooting depth (assumes uniform distribution of N)

Crop	**Rooting Depth**	**Mineral N To rooting depth[1]**	**Estimate of SMN kg/ha to 90cm**	**Scaled SNS Index**
Salad onions	30 cm	100	300	6
Crisp lettuce	45 cm	100	200	5
Cabbage	90 cm	100	100	2

[1] **From Appendix 10 of the Fertiliser Manual (RB209).**

If mineral N content to 45cm depth for a crisp lettuce crop is 100kg/ha N. The scaled up value to 90cm would be 200kg/ha N equivalent to SNS index 5. This can be used to determine the crop N requirement of the lettuce from tables in the Fertiliser Manual (RB209) or by calculation – see an example in the information box below.

Estimation of fertiliser requirement

Data is taken from Appendix 9 and 10 in the Fertiliser Manual (RB209) to estimate crop nitrogen requirement **(CRN)**

$$CRN = \frac{Nuptake - (MineralisedN + SoilMinN_{90} \times RootDepth/90)}{Fertiliser\,\mathrm{Re}\,\mathrm{cov}\,ery}$$

N uptake is the amount of nitrogen taken up by an optimally fertilised crop.

Mineralised N – is based on estimates of N released from soil organic matter during the growing season.

SoilMinN – based on a measured value to 90 cm.

RootDepth – based on rooting depth of crop cm.

Fertiliser Recovery = 0.6 (Based on a fertiliser recovery of 60%).

Example for Crisp Lettuce

Data from Appendix 10

N uptake – 165 kg/ha N .

Mineralised N – 22 kg/ha N.

SoilMinN – !00 kg/ha sampled to 45 cm depth. 200 kg/ha to 90 cm.

RootDepth – 45 cm

$$CRN = \frac{165 - (22 + 200 \times 45/90)}{0.6}$$

Crop Nitrogen Requirement = 72 kg/ha N.

Information Box – Example of assessment of the crop nitrogen requirement of Crisp Lettuce based on a mineral N measurement to 45cm.

4.4.2 Example of interpretation of SMN values using the WELL_N Model.

Even if SNS Index is high, if limited N is available in the topsoil, fertiliser may still be required. WELL_N can be used to interpret such results. In this example SNS Index is the same for both soils but the distribution of mineral N by depth is completely different leading to different fertiliser requirements for a Brussels sprout crop following cauliflowers. **Table 15**

Table 15. Interpreting SMN values using the Well_N model.

SNS(Index)	**Field 1** **6**	**Field 2** **6**
	kg/ha N	
0-30cm	150	25
30 – 60cm	100	100
60-90cm	25	150
0-90cm	**275**	**275**
RB209 (2010) recommendation	0	0
WELL_N recommendation	25	125

Additionally using WELL_N to interpret mineral N data also helps to overcome errors due to:-

- Further mineralisation from incorporated residues not accounted for at the time of sampling
- Further mineralisation of N from SOM since sampling.
- Affect of drainage from time of sampling until time of planting

4.4.2 Dealing with Soil properties

The main HGCA report concluded the following

- o A standard bulk density (1.33 kg/l) is adequate to predict harvested SNS; bulk densities specific to soil type & depth give little improvement in predictions.
- o No evidence has been found to show value in adjusting for stone content. If adjustments are made, care is needed to ensure that stone contents are not over-estimated.

Results normally come back from the laboratory as mg/kg $NO3^-$ and $NH4^+$ on a dry soil basis. These need to be adjusted for the dry bulk density of the soil and be converted to kg/ha before they can be interpreted in the SNS tables in the Fertiliser Manual (RB209). In the absence of properly conducted assessments of soil bulk density the mineral N (nitrate and ammonium) figures expressed as mg/kg on a dry basis for a 30cm thick layer can be converted to kg/ha for that depth by multiplying by 4.

4.4.3 Dealing with adjustments for mineralisation contribution of N from Soil organic matter

Across the new dataset, see **summary table 2** in **appendix 1**, mineralisation measures improved predictive power in spring, but not in autumn. Total soil N% and SOM% give useful information regarding mineralisation potential. The implied relationship within RB209 of 10kg/ha N being mineralised for each 1% increase in SOM% above 4% provides a sensible basis for judging mineralisation, but further calibration is required to provide robust predictions of likely additional mineralisation. GrowHow calibrated AAN measures gave improved prediction of harvested SNS, and reduced the value of slope and intercept adjustments.

For field vegetables mineralisation is dealt with quite differently to that for arable crops. Any adjustments for potential mineralisation will need to be scaled for the duration of the growing season. There may also be times when the N mineralised may not be fully recovered, resulting from a combination of shallow rooting and leaching of mineralised N out of the root zone. This complexity is almost impossible to predict without the use of computer models.

The WELL_N model can be used to interpret soil mineral N measurements with potential to overcome problems associated with :-

- Uneven distribution of N with depth
- Further mineralisation from incorporated residues not accounted for at the time of sampling
- Further mineralisation of N from SOM since sampling.
- Affect of drainage from time of sampling until time of planting

For the sites following Brassica, **Table 10** shows that most of the variance in the estimate of Harvested SNS is accounted for by soil mineral N to 90cm. The addition of AAN or any other soil property does not significantly add to the value of the prediction. When SNS levels are already high SNS 5 or above an estimate of mineralisation is going to be of little significance.

4.4.4 Large changes in N use

Projects such as FV17 and the high values of mineral N found after calabrese crops may lead to large changes in the recommendations for later crops. Where this is the case it is worth adopting the changes cautiously.

It is important that

- Crops are regularly monitored for signs of deficiency or excess.
- That relevant account is taken of distribution of N with depth
- The crop roots can actually grow as expected – good soil conditions are expected.

5. Knowledge and Technology Transfer

Meetings

Many meetings were held during the life of the project which are listed below.

- Two stakeholder workshops – May 12 2008 @ HGCA London.
- Jan 27 2011 @ PGRO Peterborough
- ADAS Open days at Boxworth, Rosemaund & High Mowthorpe 2008, 2009, 2010, 2011, 2012
- Cereals 2009, 2010, 2011, 2012
- VCA Agronomist Conference November 2010
- HGCA Agronomist conference November 2011

Articles

Several articles were written including

- **Knowing your Nitrogen Levels** - HDC NEWS April 2010
- **In the know about N** - HDC NEWS May 2012

Factsheets

Two grower information sheets were contributed to as part of this project:

- **Estimating Soil Nitrogen Supply (SNS)** Summer 2012 HGCA - Topic Sheet 115
- **Soil Nitrogen Supply for field Vegetables**. HDC Factsheet 09/12

6. Future research and information transfer requirements

Information transfer

A campaign of information transfer is needed to field vegetable growers to ensure that they are aware of the key conclusions of the project.

- Brassica growers would be the main target especially as they are most likely to benefit from the advantages of measuring soil mineral nitrogen. They also need to be made aware of the appropriate procedures to be followed to achieve that benefit.
- All vegetable growers benefit from the revised recommendations in the Fertiliser Manual especially those growing shallow rooted crops. Educating the industry to the factors influencing efficient use of soil and fertiliser nitrogen by shallow rooted field vegetable crops would be beneficial.

Research

Survey

The HGCA project has confirmed the benefits of the assessment of SNS index on deep silty soils in intensive Brassica rotations. In many cases this is not just in situations where SNS index is high but also where SNS is uncertain. These results have certainly shown unexpectedly low residues of N after some cauliflower and cabbage crops. However this sampling was only conducted on a limited number of farms and more general monitoring with better collection of supporting agronomic data would help in formulating better definition of the SNS indices after field vegetable crops in future versions of the Fertiliser Manual (RB209).

Measurements of SMN could be made in a larger number of fields over a number of seasons ahead of main planting time. The study could be augmented by a summary of analysis results (with permission) from commercial laboratories.

Profiling Study

The development and validation of a more holistic approach is proposed by ADAS to managing N fertiliser decision-making on the farm, which acknowledges farm to farm differences separately from within-farm aspects of farming systems. One of the farming systems that could be tested is one growing brassicas with cereal break crops.

ADAS suggests that a ‘Farm N profiling’ approach should be tested that would integrate a wide range of information sources, including farmer experience as well as soil and crop assessments, to build a picture of how current N use on a farm relates to optimal N management. This could identify and resolve the farm to farm differences that are seldom explicit in multi-site experimentation but which some allied research projects have shown to be important. Thus, future work should address prediction of crop N requirements holistically, by assessing all its components together (harvested SNS, crop N demand, and fertiliser N efficiency), not just SNS (as here). This work should examine variation in crop N requirements at different levels separately: farm to farm, between rotational positions, between years, between fields and within fields; and it should develop and evaluate targeted approaches for predicting and managing each level of variability.

Mineralisation of n from soil organic matter.

There are three main aspects of further work –

- To improve the reliability of the estimates of mineralisation in Appendix 10 of the Fertiliser Manual (RB209) for individual crops.
- To investigate how measurements of soil mineral N can be interpreted on organic and peaty soils.
- To improve estimates of SNS index for late planted field vegetable crops (RB209 designed for autumn or early spring planted crops)

Modelling

Modelling techniques have led to the successful development and release of the WELL_N model – whilst this model is still useful there are areas where it’s performance could be improved.

Models such as EU-Rotate_N (Rahn et al 2010) have been developed to simulate the turnover of nitrogen in field vegetable rotations with a view to reducing nitrogen losses whilst retaining economic output.

Further research could be carried out to develop each of these models but this would need significant investment to restore the modelling capabilities formerly available at HRI.

7. Glossary

Abbreviations Used

AAN	Additionally Available Nitrogen (by GrowHow method)
AN	Ammonium nitrate
CV	Coefficient of variation
DM	Dry matter
FAM	Field assessment method
GAI	Green area index
GNY	Grain nitrogen yield (kg/ha)
ha	Hectare
harvested SNS	Crop N uptake at harvest of unfertilised crop (our definitive measure of SNS)
HCFR	Hill Court Farm Research
Hot KCl	Measure of mineralisation using hot KCl extraction
KCl	Potassium chloride (reagent used in SMN analysis)
N	Nitrogen
NHI	Nitrogen harvest index
Nmin	SNS prediction service offered by GrowHow
PMN	Potentially mineralisable nitrogen
r2	Coefficient of determination
S.E.	Standard error
SMN	Soil Mineral Nitrogen
SNS	Soil Nitrogen Supply (SMN + Crop N)
t	Metric tonne
TNY	Total nitrogen yield (kg/ha)

8. Acknowledgements

Many organisations participated in the completion of the parent HGCA funded project including ADAS, TAG, SAC, Rothamsted Research, NRM, Hill Court Farm Research, Eurofins, Scottish Agronomy, GrowHow, HDC (PlantNutrient Consulting) and PGRO. Attendees at the stakeholder meetings included Defra, government agencies (e.g. Environment Agency), industry bodies (e.g. NFU, AIC), distributors and manufacturers (e.g. Masstock, Hutchinsons, Frontier, Yara), agronomists, laboratories and soil sampling practitioners (e.g. SOYL, Envirofield) and farmers.

The first part of this project was completed whilst I was part of the Warwick Crop Centre of Warwick University.

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10. Appendices

APPENDIX 1 – Project Summary reproduced from full HGCA Report

Introduction

Aim and objectives

The use of soil mineral nitrogen (SMN) testing in estimating soil nitrogen supply (SNS) has been the subject of uncertainty in the industry and in recent HGCA reports. This project was set up to address the concerns, provide best practice advice and build confidence in the estimation of SNS.

Overall aim:

To achieve consensus across the industry on best practice for estimation of SNS.

Specific objectives:

1. To collate and consider stakeholder concerns about estimation of SNS and (at the end of the project) to present stakeholders with evidence for best practice.
2. To collate unpublished data on measurements of SMN and prioritise uncertainties.
3. To establish best practice for interpretation of SMN analysis, including sampling depth and assessments of potentially mineralisable N (PMN).
4. To evaluate uncertainties in SMN results, including field sampling methods, sample handling and transfer, and laboratory processing and analysis.
5. To determine the most appropriate method for interpreting over-winter assessments of crop N in oilseed rape.
6. To compare and evaluate approaches for the prediction of SNS both from soil measurements and field assessment methods (FAMs), then to provide guidance on where and when SMN analyses are best used to inform on-farm SNS estimation.

As well as the initial HGCA funding for this project additional funding from GrowHow, HDC and PGRO allowed a larger dataset of SNS measures to be generated, addressing a wider range of situations, with potential for higher levels of SNS to be explored, especially for sites following vegetable crops and pulses.

Background

Of the judgements that farmers make when deciding how much fertiliser N to apply, one of the most important is the amount of N that will be available to the crop from the soil: the SNS. Variability in SNS between different fields, situations and years can be large. Values for a given situation can be judged by a FAM (e.g. as in RB209 or SAC-TN625), but this necessarily gives averages of a wide range of possible values. For the past 20 years the 'gold standard' for predicting SNS in most situations has been regarded by many as SMN testing, yet sampling and analytical techniques for the SMN method still vary, and little guidance exists to inform best practice. In recent years some have even questioned its value altogether. In HGCA Research Review 58 Knight et al. (2006) identified various issues that surround the SMN method. These included estimating crop N, best sampling time, depth and intensity; sample storage, transport and processing; and analysis and interpretation. Whilst much work has been undertaken on these issues in the past, this has not always entered the public domain (e.g. Silgram 1997; Silgram & Goodlass 2006). HGCA Research Review 58 highlighted the need for a set of guidelines of best practice for the SMN method, and possible accreditation of practitioners. In addition, practices that could reduce the cost of the SMN method (e.g. using shallower sampling depths) or improve its predictive performance (e.g. estimating potentially available N by incubation or by considering total N%; Bhogal et al. 1999) need to be evaluated.

Subsequently, HGCA Research Review 63 (Richards, 2007) recommended that "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, N mineralised during spring and N taken up by the crop over winter need to be clarified. Guidance is then needed on the appropriate choice of method for different circumstances taking account of cost and the degree of accuracy required."

This project sought to address these recommendations in full. Key uncertainties in direct measurement of SMN were identified and recommendations for best practice were developed. On-farm strategies for using direct SNS measurements were then compared with the FAM in The Fertiliser Manual (2010; hereafter referred to as RB209), and best strategies evaluated for different field and farm types.

The expense of SMN sampling means that its use is most likely to be worthwhile where potential fertiliser savings are large i.e. where expected SNS is large or uncertain. There is, however, a need to identify more exactly where and when the SMN method is of greatest benefit, and how results can be used to improve N planning across the whole farm. In addition, rigorous and transparent information is required by the industry to ensure confidence in all of the approaches available to estimate SNS.

This project, involving a broad consortium, drew on previous published and unpublished data and reports, publications, expertise and on-going projects as well as providing new data. It used a robust framework to identify best practice for predicting SNS, using *crop N uptake near harvest without applied N* ('harvested SNS') as the definitive measure of SNS. A cost-benefit analysis of best-practice identified where and when the use of soil measurement should prove worthwhile in farm situations.

Materials and methods

This project was composed of six tasks to meet the six objectives outlined above.

Task 1: Building consensus through stakeholder engagement

The project aimed to achieve some consensus across the industry on best practice for estimating SNS. To help achieve this a Steering Group met regularly through the project, chaired by Ian Richards and involving representatives from HGCA, ADAS, TAG, SAC, Rothamsted Research, NRM, Hill Court Farm Research, Eurofins, Scottish Agronomy, GrowHow, HDC and PGRO. In addition, well-attended Stakeholder meetings were held at the beginning and end of the project in 2008 (HGCA offices, London) and 2011 (PGRO, Peterborough). Attendees included Defra, government agencies (e.g. Environment Agency), industry bodies (e.g. NFU, AIC), distributors and manufacturers (e.g. Masstock, Hutchinsons, Frontier, Yara), agronomists, laboratories and soil sampling practitioners (e.g. SOYL, Envirofield) and farmers. Stakeholders were given the chance to contribute to the direction of the project at the outset and initial analyses of results were shared at the end of the project where contributions towards final conclusions were sought.

Task 2: Review of past data

Much work has been conducted on SMN methodology since 1980, in the UK and across the world. Not all of the relevant UK information has been fully published. An exercise was conducted at the start of this project to collate as much available past data as possible from all organisations. A dataset was created containing data from all past experiments where SMN had been measured in conjunction with measures of harvested SNS (grain yield and grain N% of unfertilised crop). Where N harvest index (NHI) information was not available this was assumed to be 0.75, so that total N yield could be estimated from grain N yield (TNY = GNY / NHI). The final dataset included over 550 experimental sites; it was used to assess the variability of measured SNS and harvested SNS and the relationship between measured SNS and harvested SNS for a range of soil types and situations.

Task 3: Generating new data for evaluating SNS prediction

In addition to the data collated in Task 2, a new dataset was generated using a total of >180 cereal sites over three years where soil measurements were made in autumn and spring, and crop measures were made at harvest. At each site one 10 metre by 10 metre area was identified for soil and crop sampling, to which no N fertiliser was applied. SMN was measured to 90 cm (or to maximum soil depth where soils were shallow) in 30 cm horizons by bulking nine cores at each date. Crop N at sampling was estimated by visual assessments of growth stage and plant population, as well as ground cover and GAI, and by quadrat samples if crop N was judged to be greater than 30 kg/ha. SMN was measured in autumn (November) and spring (February). In spring additional measures were made on the 0-30 cm samples of soil organic matter (SOM), total soil N%, mineralisation by hot KCl extraction (in 2008 only), and potentially mineralisable N (PMN) by anaerobic incubation. PMN values were converted to ‘additionally available N’ (AAN) by Hill Court Farm Research using the GrowHow method. Field and soil information was obtained for each field including previous cropping, rainfall area, manure history, grass history, soil texture, soil series and stone content. This information was used to determine FAM estimates of SNS index. IRRIGUIDE was used to estimate rainfall and drainage for each site, for the over-winter period as a whole and following autumn and spring sampling. Estimates of N retained after sampling were made using assumptions of soil group and over-winter rainfall category from the approach advocated in the HGCA nitrogen for winter wheat management guidelines.

At harvest, nine 0.25 m^2 quadrats were taken from the unfertilised area, and separately from the surrounding commercially fertilised crop, to allow determination of grain yield, grain protein, straw N%, N harvest index and total N uptake.

Relationships between various SNS predictors (SMN-derived and by the FAM) and harvested SNS were explored for the dataset as a whole, for different soil types and for different situations using a range of regression analyses in Excel and Genstat.

Task 4: Studies to assess uncertainties in sample handling, storage and analysis

Following the data review in Task 2, specific issues surrounding the measurement of SMN and the prediction of SNS were investigated. Two laboratory standardisation exercises were carried out in spring and autumn 2008. Soil samples of around 3 kg from 0-30 cm cores were collected from ten fields selected to represent a range of expected SNS levels. The samples were thoroughly mixed and six sub-samples of 500g were taken (each made up of 10 portions of 50g soil). Two of the six samples were sent to each laboratory in chilled packs for next day delivery. Temperature sensors were included in each batch of samples so that changes in temperature through transport could be assessed. Samples were analysed for SMN (soil DM%, nitrate-N and ammonium-N; mg/kg) and results compared.

Sample handling and storage exercises were carried out in spring 2009 and 2010. In each study, soil samples were taken from four contrasting fields in each year. For the sample storage studies four separate ~3kg samples from 0-30 cm were obtained by spade from each site. These were thoroughly mixed and sub-samples taken from each, to give samples for eight (2009) or ten (2010) storage treatments with four replicates. In 2009, samples were then stored at 2-4°C for <1.5 days or at room temperature for 7 days; in 2010, samples were stored at 2-4°C for <1, 2, 4 or 7 days or at room temperature for 7 days. In 2009, one treatment also tested samples frozen for 14 days. After storage, samples were extracted with KCl at ADAS Boxworth. Sample extracts were frozen and then sent to the laboratory (HCFR) for determination of nitrate-N and ammonium-N. For the sampling and sample handling exercises samples were generated from each of the four fields in each year by taking soil cores, either within a 10m x 10m area, or a wider 100m x 100m area. From each of four replicates, half of each sample was mixed thoroughly and sub-sampled carefully, the other half was not mixed and sub-samples were taken at random. In 2009, samples were stored at room temperature or 2-4°C for <1.5 or 7 days; in 2010, samples were stored at 2-4°C for <1.5 days before extraction at ADAS Boxworth.

All results were analysed by ANOVA in Genstat to assess treatment differences.

Task 5: Studies of crop N in oilseed rape

In situations that allow substantial growth during autumn and over-winter, oilseed rape crops can take up over 150 kg/ha N by the spring. It is not certain whether all of the crop N in large crops should be subtracted from the target N uptake and should be regarded as equivalent to SMN. This is because oilseed plants may not be 100% efficient at remobilising N from dying leaves. Studies were conducted to investigate this by comparison of small and large crops. Twenty nine 'paired' sites were investigated over three seasons (2007/08, 2008/09 and 2009/10). Areas with small and large crops were either selected within adjacent areas of a field or engineered through the use of different sowing dates, seed rates, plant hoeing or the use of fleece covering over winter. N fertiliser was withheld from each plot area so that N uptake of the unfertilised crop could be measured at harvest to give harvested SNS. Soil and crop samples were taken in autumn and spring to measure SMN, crop N and with which to calculate the autumn and spring SNS. Digital photos were also taken at each sampling to allow estimation of GAI using the canopy GAI tool (www.totaloilseedcare.co.uk/GAI/index.html).

Crop samples were taken from six 0.5m^2 quadrats before harvest, at the point where N uptake was deemed maximal and before pods started to shatter, in order to calculate final crop N uptake (treated here as 'harvested SNS').

Task 6: Cost-benefit analyses to give best practice advice

Three different criteria were used to assess the 'best' SNS predictor for a category of crop.

Accuracy

The difference (bias) between the average prediction and average harvested SNS.

Note that, because over-predicting harvested SNS (thus using sub-optimal fertiliser N and incurring yield losses) tends to be more costly than under-predicting harvested SNS, profit from use of any predictor is maximised if it has a small negative bias (zero to -20 kg/ha SNS).

Precision

The extent to which a potential predictor accounted for each value of harvested SNS over a number of sites was assessed using:

- the coefficient of determination (r^2) of the linear regression equation.
- the frequency with which a predictor gave 'right' or 'wrong' predictions, i.e. the proportion of times that the prediction was within +/- 20 kg/ha or more than +/- 50 kg outside of the harvested SNS.

The combined effects of imprecision and bias were assessed in two ways:

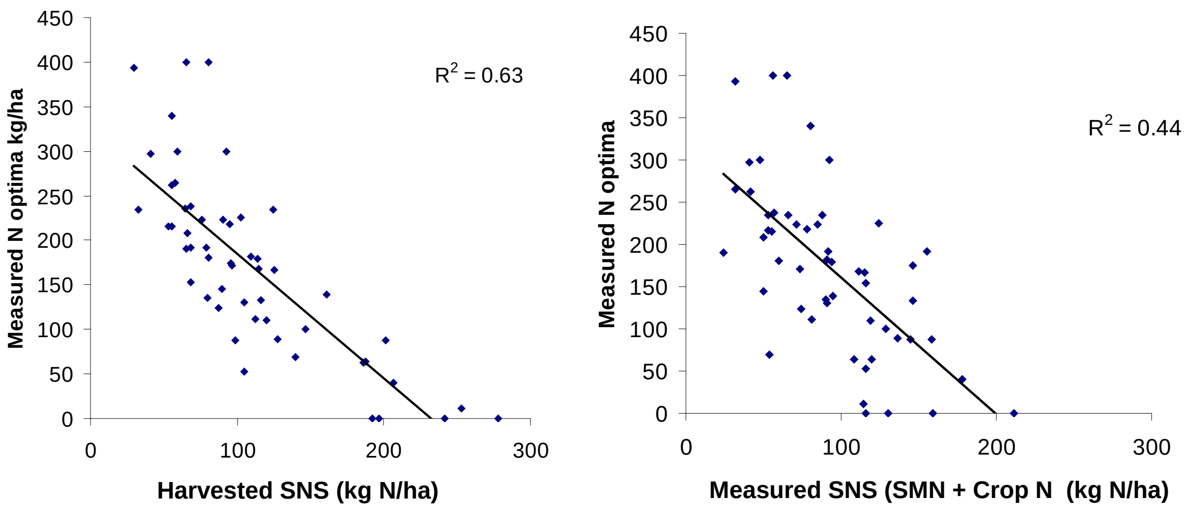
- Statistically: For any prediction, the coefficient of determination (r^2) for y = x shows how much of the variation in harvested SNS was explained by the actual values of any SNS predictor (without an intercept or slope).
- Economically: The effect on margin over N cost ('profit foregone') of using a particular SNS prediction at each site. For this we assumed N was applied according to the SNS prediction and then subtracted the margin over N cost if N had been applied according to actual harvested SNS; we used a typical yield response curve to fertiliser N (taken from HGCA Report PR438), a grain price of £150/t, and an AN price of £300/t.

Note that large errors in fertiliser N use are disproportionately costly compared to small errors, and average profit foregone (or the frequency of >£40/ha profit foregone) is affected by bias, especially if large (<-20 or >0 kg/ha SNS), as well as by imprecision. Prediction costs e.g. of SMN measurements, were not included in profit calculations.

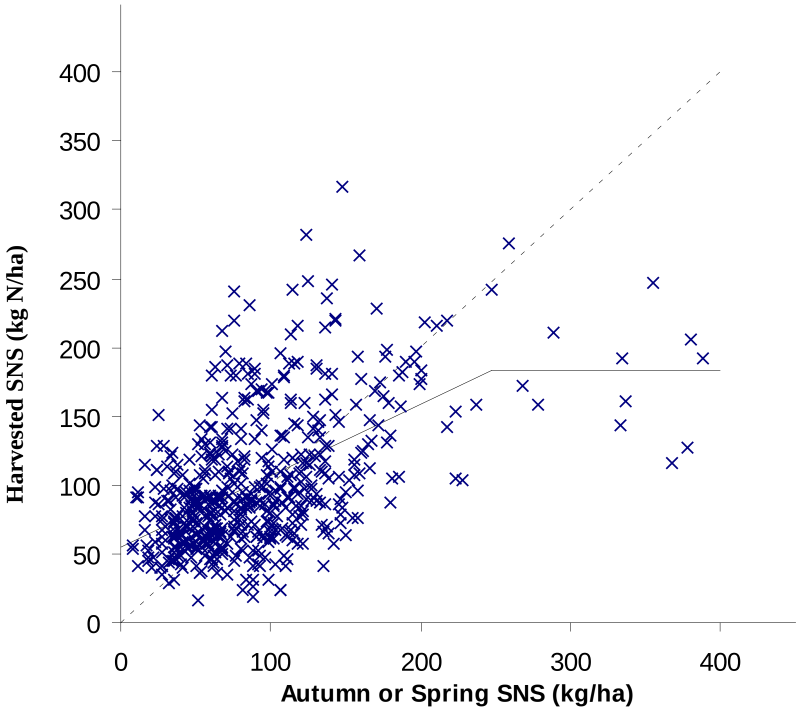
Key results

Lessons from past data

An analysis of 53 recent N response datasets showed harvested SNS to account for 62% of the variation in N optima across past N response experiments (Summary Figure 1). Harvested SNS was confirmed to be the most important and most predictable component of N requirement when considering sites with a wide range of SNS, even though predictions of harvested SNS are not precise. Unexplained variation in N optima is considerable, especially where harvested SNS is at normal to low levels (below ~100 kg/ha).



Summary Figure 1. Relationship of N optima with a) harvested SNS and (b) measured SNS in autumn or spring (according to whichever data was available).

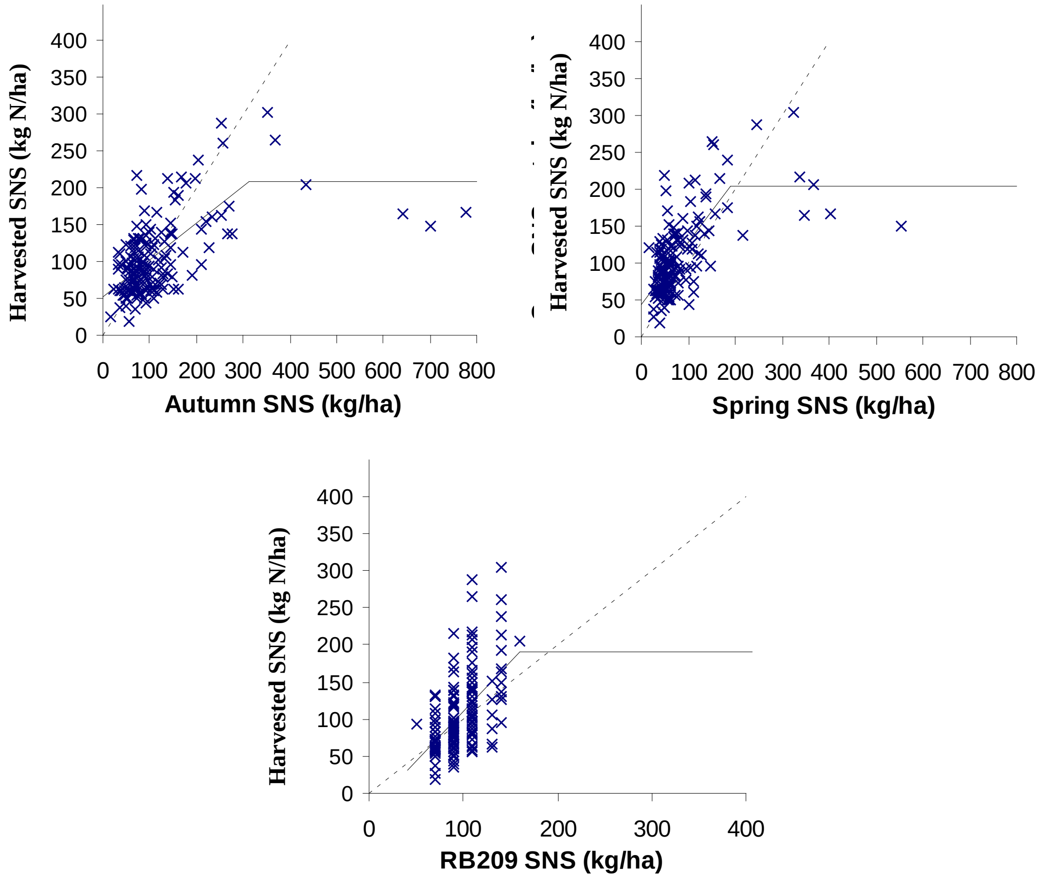


Summary Figure 2. Relationship between measured SNS in autumn or spring and harvested SNS for >550 sites since 1980. Solid line shows fitted broken stick regression model, dashed line shows y=x. Slope of the first line of broken stick = 0.46; variation explained = 38%.

An analysis of a past dataset with >550 comparisons showed that measured SNS related to harvested SNS, but the relationships were not strong, probably due to large spatial and temporal variation in SNS. Some of this variation might be avoided by good practice, but probably not all. The relationship was strongest in the subset of data from uniform, N retentive soils where the spread in expected SNS was high.

Relationships in newly generated data

Analysis of the dataset generated in this project also showed the relationship between measured SNS and harvested SNS to be fairly weak, explaining ~40% of the variation. Measures of SNS explained more variation in harvested SNS than the FAM, but the FAM tended to be more accurate on average (Summary Figure 3; FAM measures are closer to the y=x line) as long as it was estimated with close attention to defining soil type, soil organic matter and field history accurately. On average measured SNS underestimated harvested SNS.



Summary Figure 3. Relationship between SNS measured in autumn, spring or estimated by FAM (RB209) for 164 sites 2008-2010.

The relationships between measured SNS and harvested SNS were best on clay and silt soils, and worst on light and shallow soils. They were also poorer where SNS was expected to be less than 100 kg N/ha (Summary Table 1).

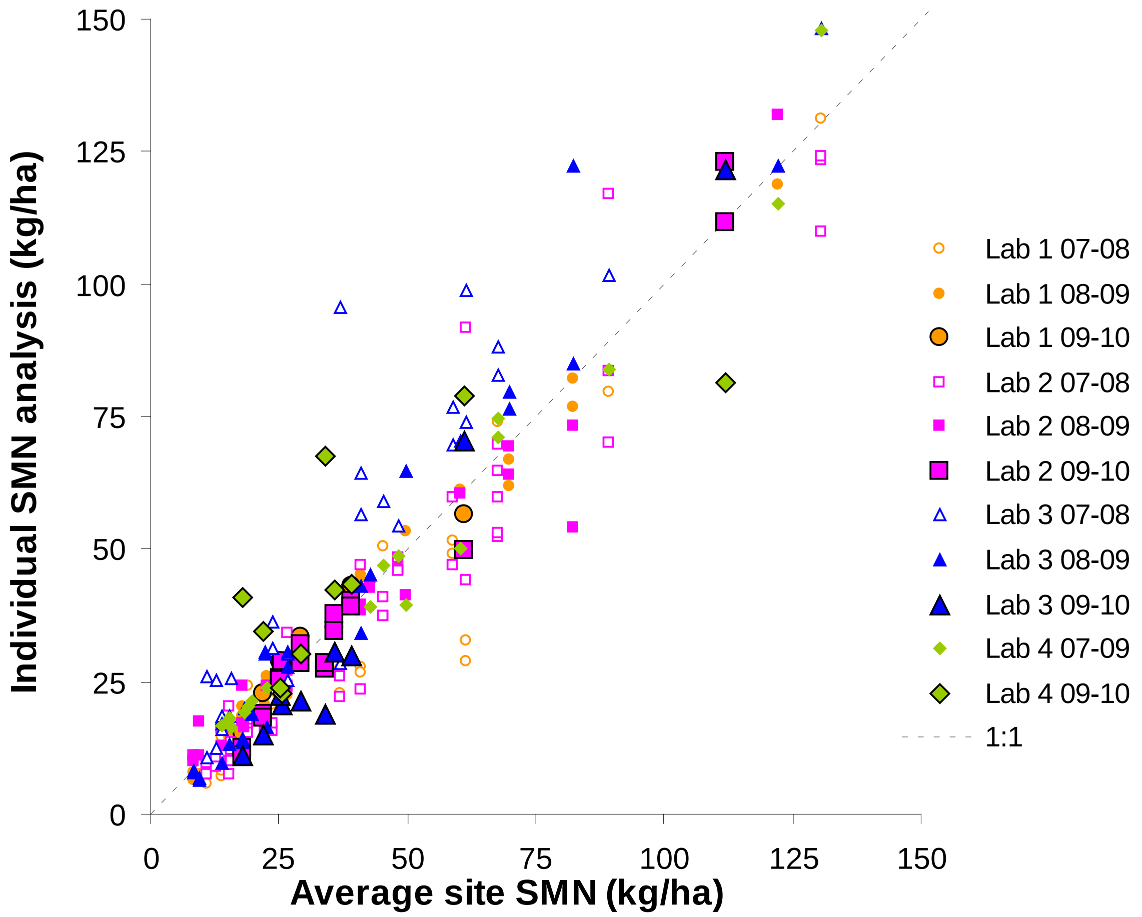
These split line regression analyses, both on past data and new data, show that the relationships between measured SNS and harvested SNS were characterised by intercepts greater than zero, slopes of less than 1 and limits of around 200 kg/ha beyond which harvested SNS did not increase. It was therefore concluded that any prediction of harvested SNS, by whatever method, should be constrained to an upper limit of 200 kg/ha.

Summary Table 1. Percentages of variation in harvested SNS explained by split-line regression of autumn SNS, spring SNS and FAM SNS for the new dataset (2008-2010), for different sub-groups of the data.

		Percentage variation explained		
Group	***Number of sites***	**Autumn SNS**	**Spring SNS**	**FAM SNS**
All	*164*	45	49	31
Silt soils	*34*	52	50	32
Clay soils	*33*	58	62	30
Medium soils	*70*	23	44	9
Shallow soils	*9*	0	0	5
Light sands	*13*	0	23	0
Low rainfall areas	*44*	39	35	27
Moderate rainfall	*75*	48	54	23
High rainfall	*45*	6	36	16
Grass or manure history	*57*	39	47	13
No grass or manure history	*107*	42	48	39
“Normal” arable situations	*52*	22	5	14
Non-“normal” arable situations	*112*	46	59	34
FAM SNS INDEX 0-2	*97*	25	33	5
FAM SNS INDEX 3-5	*67*	43	49	8

Sampling methodology studies

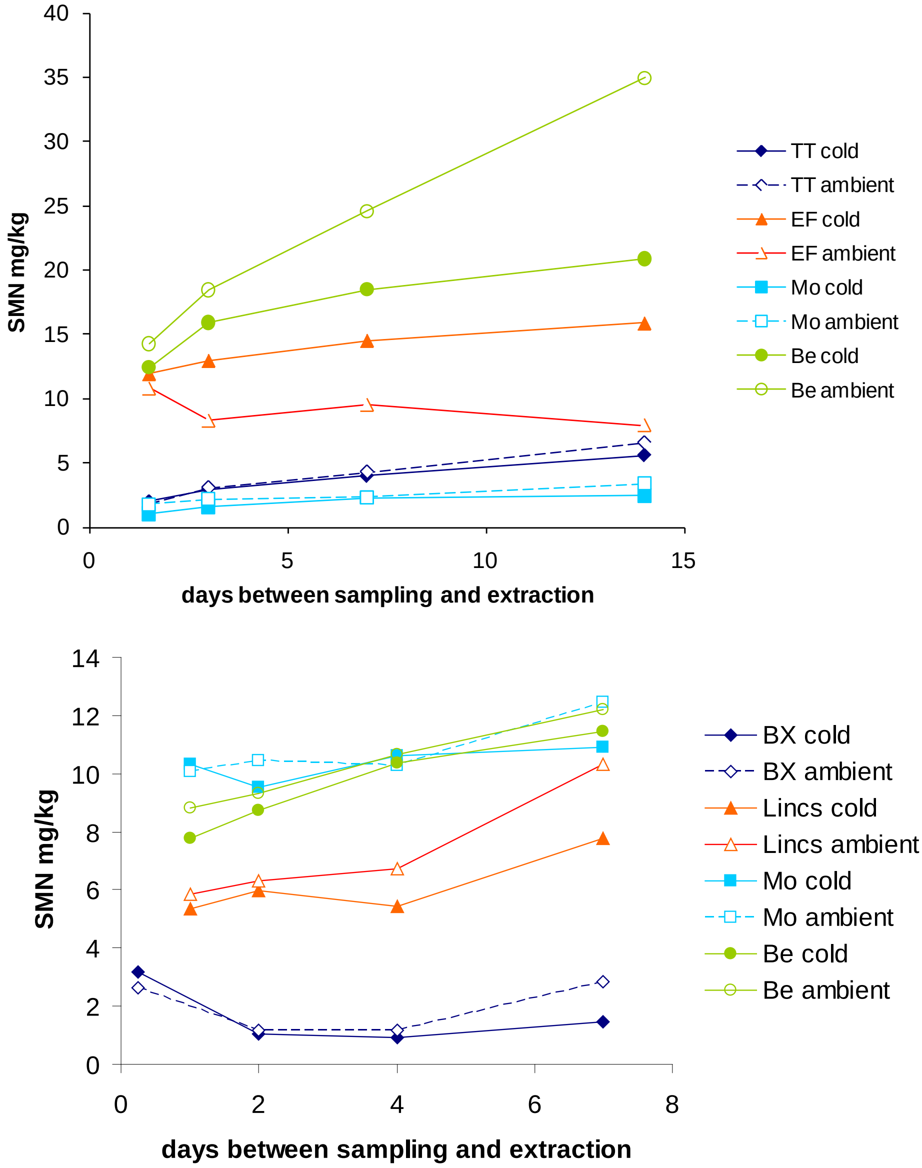
Laboratory standardisation exercises (Summary Figure 4) showed (with a few exceptions) differences between and within laboratories to be relatively small, given the inherent sample variability. The ‘ring-tests’ initiated in this project are now being continued by the major labs. on an annual basis.



Summary Figure 4. Range of SMN values (kg/ha) recorded by different laboratories for individual soil sub-samples from the same field sample, compared to the mean value for those sub-samples. Dotted line 1:1.

Sample storage studies (Summary Figure 5) showed SMN of refrigerated samples to increase steadily with delay in analysis after sampling. Subsoils changed less than topsoils. Average SMN 0-90 cm increased by 2.5 kg/ha per day delay. Increases were larger and more variable at room temperature. It was concluded that samples should be kept cold and storage standardised at 1 to 3 days.

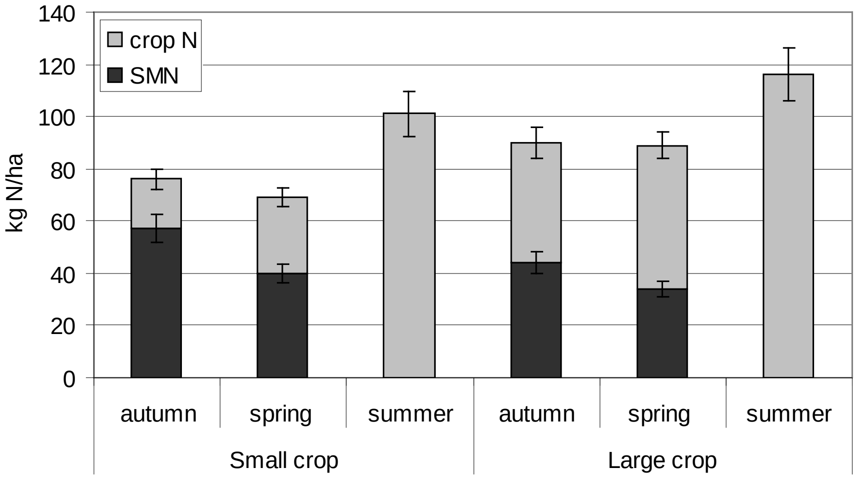
Sub-sampling studies showed that thorough mixing of soil could increase measured SMN. However, mixing also reduced the coefficient of variation (cv) from 36% to 30%. There therefore needs to be a compromise between acquiring representative sub-samples and avoiding stimulation of N mineralisation by excessive mixing.



Summary Figure 5. Effect of interval between sampling and extraction on measured SMN for soil samples taken from four fields and stored at two temperatures in 2009 (top) and 2010 (bottom). Abbreviations are site codes; TT= Terrington, EF= Lincs site, Mo = Morley, Be = Beccles, BX = Boxworth.

SMN and Crop N in oilseed rape

In autumn, the average crop N contents were 19 kg/ha for the small crops and 46 kg/ha for the large crops, yet there was no significant difference in total measured SNS because the small crop treatments had more SMN (Summary Figure 6). In spring the small crops contained 29 kg/ha N and the large crops contained 55 kg/ha N. The large crop treatments did have a greater SNS at this stage because there was no difference in SMN due to crop size treatments. Linear regression revealed no significant differences in the relationships of autumn or spring SNS with harvested SNS between the small and large crop treatments. This was also the case when the regression analyses were performed for individual seasons or across all three seasons. A paired T-test showed no significant difference in the proportion of the autumn or spring SNS that was taken up by summer between the small and large crop treatments, even when the analysis was restricted to the 15 sites with the largest difference between the small and large canopies (average of 24 kg/ha N compared with 66 kg/ha N). These results indicate that SMN and crop N may be considered as equivalent in terms of how they are used to predict harvested SNS.



Summary Figure 6. Effect of crop size on SMN (kg/ha) and crop N (kg/ha) in autumn, spring and summer (harvested SNS) in three years (2007/08, 2008/09 and 2009/10). N=28 ± SEM per crop size.

Relationships for oilseed rape between autumn or spring measured SNS and harvested SNS were very similar to those reported for cereals in Section 2.3.2.

Best and cost-effective predictions of harvested SNS

Correcting bias in a predictor is much easier than improving its precision, yet both bias and imprecision determine its economic performance. Economic outcomes of different predictors are, therefore, best compared with a common small level of bias (-20 to 0 kg/ha SNS).

Almost all SNS prediction methods, including FAM, performed better (by reducing profit foregone) than assuming a fixed SNS of 100 kg/ha (Summary Table 2). However, this should not be taken to represent current practice, and other potential simple methods based on fixed values were not tested. Whilst measures of SNS explained more variation in harvested SNS than FAM, unadjusted SNS measures were often less accurate than FAM (Summary Table 2), even after constraining maximum predictions to 200 kg/ha, so the economic performance of the unadjusted SNS measures (i.e. SMN + Crop N without estimates of mineralisation or recovery) was worse than FAM. This arose because autumn SNS tended to over-predict harvested SNS especially at high SNS levels, and spring SNS under-predicted harvested SNS (by 32 kg/ha on average). In addition, there was greater scope to get predictions very wrong using measured SNS than when using FAM SNS as high (>160 kg/ha) or very low (<50 kg/ha) predictions are not possible with the FAM.

Summary Table 2. For the new dataset, effects on accuracy (mean bias), precision (coefficient of determination; r^2), and profit of using different methods to predict harvested SNS. In each case, maximum predicted SNS was 200 kg/ha.

Prediction approach	Accuracy		Precision			Profit foregone	
	Mean bias kg/ha	slope	r^2 with lin. regres'n	r^2 'as is' i.e. y=x	% errors >50 kg/ha	Average £/ha	% sites >£40/ha
Without adjustment							

Fixed 100 kg/ha	-6	0	0.00	0.00	20%	16.61	10%
FAM	-10	1.27	0.27	0.14	18%	12.20	8%
Autumn SNS 0-90	-6	0.65	0.39	0.27	15%	14.65	7%
Autumn SNS 0-60	-20	0.67	0.41	0.16	27%	14.74	9%
Spring SNS 0-60	-46	0.85	0.39	0.00	40%	22.21	20%
Spring SNS 0-90	-32	0.82	0.49	0.08	30%	14.93	9%
Spring SNS 0-90 + AAN*	-9	0.84	0.52	0.47	14%	9.61	4%
Spring SNS 0-60 + AAN*	-10	0.82	0.44	0.38	16%	11.07	5%
Spring SNS 0-90 + SOM	-29	0.79	0.50	0.14	28%	14.15	9%
Spring SNS 0-90 + 20	-13	0.87	0.49	0.42	17%	10.22	7%
Spring SNS 90+20+SOM	-11	0.83	0.48	0.41	18%	10.53	7%
With slope and intercept adjustment							
Autumn SNS 0-90	-3	0.90	0.42	0.41	21%	11.13	5%
Spring SNS 0-90	-3	1.00	0.49	0.49	13%	9.50	6%
With leaching adjustment							
Spring SNS 0-90 + AAN	- 10	0.87	0.56	0.51	13%	8.63	4%
With leaching, slope and intercept adjustment							
Autumn SNS 0-90	-5	0.88	0.49	0.47	17%	10.06	4%
Spring SNS 0-90 + AAN	-3	0.97	0.57	0.57	12%	8.01	3%

*GrowHow Nmin Method Options

If appropriate adjustments are made to SMN-based predictions to correct for bias, then they could be more worthwhile than predictions from FAM by up to an average £4/ha overall, or up to £10/ha in situations where SNS was expected to be high and uncertain. These benefits, however, were without considering the costs of sampling and analysis. Clearly, costs need to be less than ~£10 /ha for measurements to prove worthwhile. Where SNS is expected to be low (<120 kg/ha) e.g. on light, shallow or medium soils, no average benefit could be shown from SMN-based predictions of SNS.

Comparing SMN-based predictions, sampling in spring explained more of the variation than autumn sampling, and gave a better economic performance, but only if adjustments for deposition/mineralisation (i.e. an intercept) or AAN measures were used. Without these adjustments there was little difference between autumn and spring measured SNS. Sampling in autumn to 60 cm rather than 90 cm depth gave similar results, whereas in spring, shallower sampling was substantially worse at predicting harvested SNS.

Mineralisation measures improved predictive power in spring, but not in autumn. Total soil N% and SOM% give useful information regarding mineralisation potential. The implied relationship within RB209 of 10kg/ha N being mineralised for each 1% increase in SOM% above 4% provides a sensible basis for judging mineralisation, but further calibration is required to provide robust predictions of likely additional mineralisation. GrowHow calibrated AAN measures gave improved prediction of harvested SNS, and reduced the value of slope and intercept adjustments.

Using a mineralisation/deposition estimate of 20kg/ha across the board improves predictions from spring SMN measurements in this dataset. There is some uncertainty whether such an adjustment would still be appropriate following a dry mild winter is spring SMN measures were generally high. The implications for such an adjustment on fertiliser recommendations need to be carefully considered.

Both autumn and spring predictions could be improved by estimating N leaching after sampling, using soil type and rainfall information. Inclusion of estimates of bulk density or soil stone content provided little overall improvement in predictions, and crop N estimation method had little effect.

The analysis suggests that for a benefit to be seen from soil sampling, especially in spring, adjustments are required to account for the difference in the relationship between measured SNS and harvested SNS from 1:1; intercepts were around 40 kg/ha and slopes were around 0.6 for autumn and 0.8 for spring measures. Such adjustments for deposition and recovery have been suggested before by Knight et al. (2008). The relationships found between soil measured SNS and harvested SNS in this project support the concept that an amount of N will become available to the crop through deposition and mineralisation (~40kg/ha), however low the measured SMN, and that only a proportion of the SMN will actually be recovered by the crop (perhaps 70% by harvest, or less before yield is determined). In the past it has been assumed that there is a 100% equivalence between measured SNS and crop N uptake, because it has been assumed for the sake of simplicity that N that becomes available from deposition or mineralisation approximately balances the SMN that is not recovered by the crop. Indeed, on average this is found to be the case, other than in situations where SMN is very high or very low. Given that specific adjustments for intercept and slope, or deposition and recovery, add complexity to the estimation of SNS, and in the majority of cases make relatively little difference to the SNS estimate, further consideration is required before recommending them for widespread use. There is also a risk that the use of inappropriate slope and intercept adjustments risks making predictions worse on average. A simpler approach which would limit the extent of under or over prediction might to fix SNS predictions of <50 or >160 kg/ha at 50 and 160 kg/ha respectively except for situations where there is confidence based on past experience that harvested SNS will really be very low or very high. However, this approach would need wider discussion before it could be advocated generally.

Discussion and key conclusions

Data examined in this project (from previous research) show that estimating SNS is an important part of N decision-making. Harvested SNS explained around 60% of the variation in fertiliser N optima (the N requirement); the other components of N demand and fertiliser recovery had less influence on N requirements and were less predictable. Thus all SNS prediction methods, whether cost-free (i.e. FAM), or based on soil and crop measurements, had clear advantages over ignoring variation in SNS altogether (i.e. fixed SNS in Summary Table 2) when deciding on N use. However, the range of SNS values encompassed within this project was much wider than would be typical of most ‘normal’ arable farms, and it was clear that our current ability to predict harvested SNS is (scientifically) weak. The best adjusted SNS prediction methods explained about half of the variation in harvested SNS, and only one quarter of variation was explained by the FAM (Summary Table 2). Nevertheless, it is doubtful whether the more sophisticated and costly prediction methods could be justified economically, except in a minority of circumstances, e.g. high grain and fertiliser prices, and large, uniform areas with high expected SNS.

This conclusion arose because (although they explained more variation than the FAM overall) SNS predictions from soil measures could include larger errors and bigger inaccuracies than the FAM. FAM approaches could never hope to explain all the variation seen in harvested SNS across different farm situations, but FAM performed surprisingly well in predicting harvested SNS on average. However, getting good value from the FAM clearly depended on its careful use; inaccurate assessments, especially of organic soil status, and grass and manure history, could substantially reduce the value of FAM predictions.

This is perhaps a more challenging conclusion than in some previous studies (e.g. Sylvester-Bradley et al., 2008), but it concurs with others (e.g. Orson, 2010). The strength of the relationship between measured SNS and harvested SNS was greatest on silty and clayey soils where the spread in expected SNS values was large. It was weakest on light and shallow soils and where the spread in expected SNS values was modest, e.g. <~120 kg/ha.

It seems likely that the weakness of SNS predictions is largely due to inherent spatial variability of soil properties and temporal variability of many processes (N inputs crop uptake, immobilisation, mineralisation, deposition and N leaching). However, variability in measured SNS can be minimised by:

- ensuring sufficient cores are taken to give a representative sample;
- judicious sample mixing and sub-sampling;
- keeping samples cool (but not frozen) once taken;
- minimising sample storage before analysis;
- regularly standardising lab tests; and
- assessing crop N appropriately at the time of sampling.

Autumn SNS predictions based on SMN measures risk over-predicting harvested SNS on average, especially where 0-90 cm measures rather than 0-60 cm measures are made. Leaching adjustments based on soil type and rainfall, and / or slope (recovery) adjustments are required to mitigate this risk.

Spring SNS predictions based on SMN measures risk under-predicting harvested SNS on average. Measures of likely mineralisation, or inclusion of a ‘deposition / mineralisation’ estimate help to mitigate this risk.

While benefits could accrue from use of slope and intercept adjustments to measured SNS, differences to the SNS predictions used would be small except at the extremes. Further investigation is needed to assess the potential to make such adjustments as they would add complexity and could risk causing confusion.

Given the relatively small (or even negative) economic benefits found from knowledge of SMN to inform SNS predictions over FAM, even before the costs of sampling are accounted for, consideration needs to be given to where and how SMN sampling should be advised.

It is clear that in normal situations SMN sampling cannot be advocated as a tool to be used to determine N recommendations for every field in every year; as well as being expensive this would probably also lead to spurious minor adjustments to N use which would risk delivering worse average financial returns than following the FAM or ‘farmer experience’. It seems that SMN testing cannot be advised for profitable use in minor ‘fine-tuning’ of N use on a field by field basis.

It appears that there remain two situations in which SMN testing may prove useful in informing N management on the farm:

- In helping to ascertain average levels of SNS for a farm, or for blocks on a farm with different soil types, rotational positions and management, and in showing how these relate to FAM estimates for those situations. Whilst information on seasonal variability may be provided, the biggest benefit may derive from understanding SNS levels on the farm on average. This use of SMN testing will mainly arise when a grower initially assumes responsibility for land. The benefit of such SMN testing is likely to diminish with time, unless substantial changes are made to the farming system.
- In helping to identify and manage individual fields where expected SNS levels are very different to the average for the farm, especially where SNS is very high or uncertain.

Key messages and recommendations

Assessment of harvested SNS

- A prediction of harvested SNS should always be made as part of decision making on N for arable crops, whether by FAM or by soil sampling.
- It should be appreciated that all current prediction methods for harvested SNS have poor precision, so the decision-making process should employ appropriate caution, including double-checking.
- The Field Assessment Method described by RB209 or SAC-TN625 should be used with care, paying particular attention to accurate description of soil type, assessment of soil organic matter content if this is likely to be moderate or high, and acknowledgement of field history, especially if grass or manures have been involved at least in the last decade.
- FAM predictions of SNS are best used where SNS is likely to be moderate or small (<120 kg/ha, below SNS Index 4) e.g. on mineral soils with arable crops without grass or manures in a field’s history. In most arable situations FAM is the most cost effective method for estimating SNS.

- Measuring SMN becomes progressively more worthwhile as SNS (as predicted by the FAM) increases beyond 120 kg/ha, or where SNS is uncertain. This includes situations where organic manures have regularly been used in the past, where there is a history of long term grass and following vegetable crops which have left N-rich residues. SMN testing gives best predictions on deep retentive (clay and silt) soils in low rainfall areas. Conversely, SMN measurement can give poor predictions of harvested SNS on light and shallow soils, or where SNS is expected to be small.
- SMN measurement may prove useful as part of a more comprehensive N monitoring approach (e.g. including FAM, crop growth, lodging, grain yield and grain N%) applied to large areas across a farm, and especially as a grower seeks familiarity with new blocks of land. In particular, SMN measures can provide a check of how SNS levels on the farm compare to RB209 expectations.

Sampling methods for SMN determination

When to sample

- Sampling in spring (February) gives slightly better predictions of harvested SNS than sampling in autumn (November), though the difference on clay and silt soils is small.
- Autumn SMN measurements have the advantage that soils only need to be sampled to 60 cm, whereas spring sampling should be to 90 cm.

How to sample

- The number of samples per field that should be taken depends upon the level of SNS expected, the variability expected and the size of the field. Generally 10-15 samples is sufficient; taking more than this is unlikely to be cost effective, except where fields are highly variable or are large (<20ha) and SNS is expected to be high (<160kg ha).
- Sampling in a W pattern (as opposed to more complex arrangements) is adequate to give representative samples.
- Ideally sub-sampling in the field should be avoided. If bulk samples are too large for dispatch to the labs, then representative sub-sampling is required. Excessive mixing of samples should be avoided as this can stimulate mineralisation. The best approach is to take many small portions of soil from the bulk sample to form the sub-sample.

Transport and analysis

- It is crucial that samples are kept cool during storage and transport, to the laboratory, and they should be analysed within three days. Samples should not be frozen except for research purposes.
- Continued annual ring-tests are important to ensure that any systematic differences between analytical laboratories are identified and corrected.
- A standard bulk density (1.33 kg/l) is adequate to predict harvested SNS; bulk densities specific to soil type and depth give little improvement in predictions.
- No evidence has been found to show value in adjusting for stone content. If adjustments are made, care is needed to ensure that stone contents are not over-estimated.
- It is important that crop N at the time of SMN sampling is estimated and included in the estimate of SNS. Visual estimation methods are usually adequate. A number of approaches for estimating crop N in wheat and oilseed rape are available, estimates from shoot counts of GAI in wheat are satisfactory, in oilseed rape assessment of GAI gives the best estimate of crop N. There is no evidence that crop N in oilseed rape should be treated differently to that in other crops when estimating SNS.

Mineralisation tests

- Indicators of mineralisation do not seem to add predictive power to SNS estimates made in autumn.
- Measures of AAN (PMN estimated by a proprietary calibration from anaerobic incubation) improve predictions of SNS in spring.
- Measures of total soil N (%) and SOM (%) are also useful indicators of mineralisation, and they might overcome the need for annual measurements of AAN, but they have not yet been calibrated to give predictions of AAN. The implied relationship within RB209 of 10kg/ha N being mineralised for each 1% increase in SOM% above 4% provides a sensible basis for judging mineralisation, but does not perform as well as a predictor of mineralisation as AAN.
- Using a mineralisation/deposition estimate of 20kg/ha across the board improves predictions from spring SMN measurements in this dataset. There is some uncertainty whether such an adjustment would still be appropriate following a dry mild winter is spring SMN measures were generally high. The implications for such an adjustment on fertiliser recommendations needs to be carefully considered.

Interpretation issues

We suggest that organisations offering N advice based on SMN testing could jointly consider the following points in order to standardise their approaches and hence improve the confidence of their clients in SMN testing:

- Estimates of SNS from large SMN values can seriously over-predict harvested SNS. It may be sensible to treat SNS estimates exceeding 160 kg/ha as predictions of 160 kg/ha and no more, unless field experience has shown that greater amounts of soil N can confidently be expected to be taken up by the crop.
- Estimates of SNS from small SMN values can under-predict harvested SNS. It may be sensible to treat SNS estimates of less than 50 kg/ha as predictions of 50 kg/ha, not less, unless field experience can be used to confidently expect that very little N will become available.
- Where SNS predictions are very high, and fertiliser N rates are cut back, growers could be advised to monitor the crop closely through spring for signs of N deficiency. Then where necessary, adjustments to the planned N strategy could be made as appropriate.
- SMN measures in autumn tend to over-predict harvested SNS, so they may require adjustment to give predictions better accuracy on average. Possible adjustments are for over-winter rainfall, or for SNS recovery.
- SMN measures in spring tend to under-estimate harvested SNS. This could be rectified by adding a fixed amount (representing N deposition or mineralisaton) and/or by including a measure of mineralisable N. Consideration is needed as to whether such adjustments are appropriate in all situations, and whether such adjustments are really appropriate in the context of current recommendation systems.

Recommendations for future work

Given the estimate that a combined use of FAM on most fields (and SNS measurement on a minority) can achieve ~98% of fields with margins over N cost within £40/ha of the maximum possible, it is questionable whether further experimentation specifically on SNS measurement will be worthwhile. This is not to say that SNS prediction using FAM could not be improved, and confirmation of maximum harvested SNS uptake on light and shallow soils would be valuable to growers with potentially high SNS on these soils.

There is possible scope for further analysis and modelling of the extensive and valuable new dataset generated here, e.g. developing predictions of AAN from soil N%, or refining predictions of N retention after sampling in autumn or spring. However, it is doubtful whether extensive further research specifically on SNS prediction systems, which could only save an average of ~£10/ha, could be considered worthwhile.

What may prove more beneficial is the development and validation of a more holistic approach to managing N fertiliser decision-making on the farm, which acknowledges farm to farm differences separately from within-farm aspects of farming systems. We suggest a 'Farm N profiling' approach should be tested that would integrate a wide range of information sources, including farmer experience as well as soil and crop assessments, to build a picture of how current N use on a farm relates to optimal N management. This could identify and resolve the farm to farm differences that are seldom explicit in multi-site experimentation but which some allied research projects have shown to be important. Thus, future work should address prediction of crop N requirements holistically, by assessing all its components together (harvested SNS, crop N demand, and fertiliser N efficiency), not just SNS (as here). This work should examine variation in crop N requirements at different levels separately: farm to farm, between rotational positions, between years, between fields and within fields; and it should develop and evaluate targeted approaches for predicting and managing each level of variability.

APPENDIX 2 – Tables to convert SMN to SNS and SAC Indices

Range SMN kg/ha 0-90cm	**0-60**	**61-80**	**81-100**	**101-120**	**121-160**	**161-240**	**>240**
Nominal value	50	70	90	110	140	200	260
SNS Index	0	1	2	3	4	5	6
SAC Nitrogen residue group	1	2	3	4	5	6	6

SNS Index used in Fertiliser Manual (RB209)
SAC Nitrogen residue group as used in TN621 and TN625 (SAC 2009a+b)

Taken from Table 5 - Sylvester-Bradley, R. (2009). HGCA Nitrogen for Winter Wheat Management Guidelines Autumn 2009

Technical Note TN621 Fertiliser recommendations for vegetables, minority arable crops and bulbs SAC August 2009.

Technical Note TN625 Nitrogen recommendations for cereals, oilseed rape and potatoes. SAC October 2009.

APPENDIX 3 – Data collected from Brassica Sites.

Field ID	Harvest Year	Rotation[1]	Soil Type (RB209)	Previous crop	Fertiliser N to previous crop kg/ha	Residue class[2]	Harvesting Date Veg	Mineral N sampling Autumn	Mineral N sampling Spring
9H-121	2009	Intensive	Deep Silt	Calabrese	190	high N veg	Sept	03/12/08	15/02/09
9H-122	2009	Intensive	Deep Silt	Calabrese	150	high N veg	Sept	03/12/08	15/02/09
9H-123	2009	veg/arable	Deep Silt	Cabbage Processing	192	medium N veg	Late Oct	03/12/08	15/02/09
9H-124	2009	Intensive	Deep Silt	Cauliflower	120	med/high N veg	Late Oct	28/11/08	16/02/09
9H-125	2009	veg/arable	Deep Silt	Cauliflower	250	med/high N veg	Late Oct	08/12/08	15/02/09
10h-150	2010	veg/arable	Deep Silt	Cabbage	234	medium N veg	early Nov	17/11/09	14/02/10
10h-151	2010	veg/arable	Deep Silt	Calabrese	230	high N veg	early Sept	17/11/09	14/02/10
10h-152	2010	veg/arable	Medium	CauliflowerX 2	240	med/high N veg	early Oct	17/11/09	16/02/10
10h-153	2010	veg/arable	Deep Silt	Cauliflower	180	med/high N veg	Late Aug	27/11/09	16/02/10
10h-154	2010	Intensive	Deep Silt	Calabrese[1]	220	high N veg	Late Aug	27/11/09	14/02/10

1 – Only 50% of crop harvested.
2 – Residue class from Fertiliser Manual (RB209).

Field ID	Harvested SNS (N in unfertilised wheat crop)	Soil N %	Soil OM %	Soil % C	C:N	Anaerobic PMN	Actual winter rainfall (Sep - Apr) mm	Actual winter drainage (Sep - Apr) mm	RB209 Drainage Group
9H-121	213.3	0.19	3.20	1.9	9.8	239.7	320	102.4	dry
9H-122	193.4	0.15	2.60	1.5	10.1	105.0	321	105.7	dry
9H-123	121.5	0.13	2.50	1.5	11.2	264.3	323	100.9	dry
9H-124	95.0	0.12	1.90	1.1	9.2	107.0	321	101.2	dry
9H-125	130.2	0.13	2.60	1.5	11.6	204.7	330	126.5	dry
10h-150	95.1	0.13	3.08	1.8	13.8	68.6	371	113.4	dry
10h-151	238.5	0.12	4.35	2.5	21.1	111.7	371	136.3	dry
10h-152	125.8	0.10	3.7	2.2	21.5	309.4	384	144.6	dry
10h-153	260.8	0.10	4.1	2.4	23.8	84.5	381	129.4	dry
10h-154	303.4	0.13	4.53	2.6	20.3	127.0	377	168.4	moderate