Advice Sheet 6: Understanding Soil Nitrogen

Why is nitrogen the first nutrient we think about?

Nitrogen is critical for plant growth. It is used in the formation of amino acids, which are the essential building blocks of proteins. It is important in the formation of chlorophyll, which the plant uses when converting carbon dioxide (CO_2) and sunlight into energy.

Nitrogen (as N_2 gas) is the most abundant element in the atmosphere. Unfortunately, for most plants this rich pool is not available to them because the energy required to access atmospheric nitrogen is very high. However, natural symbiosis between soil micro-organisms and some plant groups, particularly legumes, exist in which plants provide carbon to bacteria in exchange for fixed nitrogen that they use for growth.

The plant takes up most nitrogen in mineral forms, such as NH_4^+ ammonium ions or NO_3^- nitrate ions. The term used to describe this supply is Soil Mineral Nitrogen (SMN). In a natural ecosystem these ions are supplied to the plant by microbial mineralisation of unavailable organic nitrogen in organic matter. The mineralisation process generally coincides when plants begin to grow in spring and soil temperatures warm above 5-6°C. Mineralisation generally peaks during the latter half of April into May, but it is very difficult to determine how much becomes available by when.

Generally, lighter textured soils begin to mineralise nitrogen earlier in the spring because they warm up quicker than soils that are heavier textured in nature. Agricultural soils vary in how much nitrogen they contain and generally, but not always, supply too little naturally occurring plant available nitrogen to meet the needs of a crop. The supply of additional nitrogen via the process of mineralisation also varies but can be significant, particularly in organic and peaty soils. However, where large amounts of organic manures/materials have been applied over consecutive years, soil nitrogen supplies can be relatively large irrespective of soil texture.

Understanding how low the soil nitrogen supply (SNS) is likely to be is also useful in determining the yield potential of the site and subsequent crop nitrogen need. Determining the SNS is the first necessary step to understanding the shortfall between what the soil contains and crop requirement.

What are the symptoms of nitrogen deficiency?

Nitrogen deficiency symptoms are some of the most obvious. Stunted, yellow growth is typical, where cell production and extension are limited and chlorophyll production low. The addition of nitrogen to a plant typically has a large effect on crop vigour, yield and quality. As cell production and growth increases, more protein is formed and the plant will turn a much darker green as the chlorophyll content is raised.

Applying nitrogen fertiliser

A nutrient management plan should aim to apply nitrogen at a rate that increases yield up to the economic optimum. The economic optimum is based on the principle of diminishing returns and considers the minimum amount of grain that will pay for 1 kilo of applied nitrogen. The current RB209 recommendations for cereals are based on a ratio of 5:1—five kilos of grain needed to pay for one kilo of applied nitrogen. The largest yield response to nitrogen occurs within the first 100 kilos applied. Yield produced beyond this level, whilst still increasing, is doing so at a slower rate with every additional kilo and therefore it is critical to only apply up to the economic rate.

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Maximum yields are achieved when the nitrogen is applied at a greater rate than the economic optimum, but the yield gain is worth less than the cost of the extra nitrogen applied to achieve it, increasing the cost of production and reducing farm profitability.

It is also important to appreciate that excessive supplies of nitrogen beyond requirement can in fact reduce yield by inducing problems such as lodging of cereals, foliar diseases, and poor silage fermentation. Excess nitrogen applications always have a financial cost and they also negatively impact the local and wider environment. Applying more than crop requirement results in a surplus, with unused nitrogen at risk of being leached to ground and surface waters. Any surplus residual nitrogen is usually present in the soil as nitrate-N after harvest, which is highly mobile. Typically, not enough is utilised by the following crop in autumn to minimise the risk of nitrate leaching over winter. The excess nitrate is also at risk of loss not only by leaching but through the process of denitrification to nitrous oxide, a very potent greenhouse gas.

How do we determine the Crop Nitrogen Requirement (CNR)?

The key to applying the correct amount of nitrogen is by determining the SNS index through either the measurement method or the field assessment method. The SNS is the total amount of nitrogen (kg N/ha) in the soil and in the crop (if autumn sown) that is available for uptake by the crop between spring and harvest, taking into account nitrogen losses and deposition.

Soil Nitrogen Supply (SNS) = Soil Mineral Nitrogen + estimate of N already in the crop + estimate of mineralisable soil N

Where:

Soil mineral nitrogen (kg N/ha) is the nitrate-N plus ammonium-N content of the soil within 90cm or the potential rooting depth of the crop.

Crop nitrogen (kg N/ha) is already in the crop by spring estimated at the same time the soil is sampled for SMN.

Mineralisable nitrogen (kg N/ha) is the estimated amount of nitrogen which becomes available for crop uptake from mineralisation of soil organic matter and crop debris between spring and harvest.

The SNS index can be determined by using specific field information via the Field Assessment Method (FAM) without analysis, or by the measurement method. The measurement method includes soil mineral nitrogen analysis, an assessment of any nitrogen already taken up by the crop, and an estimate of additional organic nitrogen mineralised during the season. These combined measurements and estimates contribute to an SNS value (kg N/ha) that is related to the RB209 SNS index system. The SNS index can then be used to determine crop nitrogen requirement from the RB209 recommendations tables.

The N recommendation tables are based on six SNS indices and each index is related to a quantity of SNS in kg N/ha. The amount of SNS is dependant on the soil type, the previous crop, and the amount of water draining through the soil. When using the FAM, separate SNS index tables are given for different rainfall situations to account for both annual and excess rainfall. Excess rainfall is the amount of rain between the time a soil reaches its field's capacity and the end of drainage, less evapotranspiration. Please refer to RB209 for full guidance.

RB209 guidance suggests that the measurement method is best where:

1. The rooting depth may contain large or uncertain amounts of soil mineral nitrogen;
2. In fields where organic manures have been used regularly in recent years;
3. Following on from a vegetable crop that has left N-rich residues or where a previous crop was fertilised for a high yield which it didn't achieve;
4. Evidence of crop lodging or crops which have underperformed.

However, there are a number of agronomic situations where SMN measurements should also be considered, such as with silty and clay soils in low rainfall areas, or avoided, such as with peat soils or very deep silts. Understanding the supply of nitrogen by measurement in reference fields across farms can help calibrate the SNS index to a particular farming situation. This approach helps to reduce the risk of over or under fertilising crops.

Even if the FAM is the approach of choice, undertaking the measurement method across a few fields can provide a useful check on how the true SNS on a farm compares to that estimated by the field assessment method.

Why is nitrogen not included in standard soil analysis?

To accurately measure the amount of SMN, it is essential to perform the analysis on a fresh sample that is kept at fridge temperature at all times after it has been taken. If the soil is allowed to warm, microbial activity will be encouraged, mineralising more of the unavailable organic nitrogen pool to ammonium and nitrate, distorting the result. Soil samples must not be placed in the freezer. This avoids the increased risk of organic nitrogen mineralisation when the sample begins to thaw and warm up.

Due to the nature of the analysis, the packaging requirements, and the urgency of the results needed, SMN is not a routine service. SMN content is largely dependant on temperature (as it is microbially controlled) over winter rainfall, soil texture, soil organic matter and crop cover. Therefore, soil values change and it is important to sample as near to the first application of fertiliser or organic inputs as possible.

The optimum sampling period is typically in early spring before any nitrogen inputs have been made. Few samples are taken in the autumn when the majority of samples are taken for standard soil analysis (pH, P, K, Mg). The SMN sampling depth in autumn is much deeper than a standard soil sample: a depth of 60cm is recommended.

It is important not to confuse the analysis of SMN content with total soil nitrogen content. This can be measured but is of little use when calculating fertiliser or organic manure inputs because it includes relatively large amounts of organic nitrogen, which is unavailable to the crop. The organic nitrogen fraction can be estimated by measuring the amount of organic matter a soil contains when SMN samples are taken. The latest guidance suggests that for every 1% increase in organic matter above 4%, the soil has the capacity to mineralise an additional 10kg N/ha. Accounting for this extra supply is critical in terms of improving nitrogen use efficiency and reducing any potential nitrogen surpluses in the soil system.

Spring crop nitrogen

Deriving the SNS via the measurement method not only relies on measuring SMN and estimating the additional organic nitrogen supply, but also an estimate of how much crop nitrogen an autumn sown crop has taken up over winter. It is critical that this component is accounted for so the SNS can be calculated. Over winter, autumn sown cereal crops generally contain small amounts of nitrogen compared to oilseed rape, but including an estimate remains an important element of the SNS index formula.

The table below estimates the crop nitrogen content depending on the number of tillers counted.

Table 1 – Autumn sown cereal crop nitrogen contents using tiller number

Tiller number/m²	*Crop nitrogen content kg N/ha*	
	Autumn assessment	Spring assessment
500	5	15
1000	15	30
1500	25	50

If you count more, or less tillers than the table suggests, then you can adjust the calculation by the following formula:

$$Adjusted\ Crop\ N\ kg\ ha = \ actual\ tiller\ count \div 500\ tillers\ per\ m2 \times 15\ kg\ N/ha$$

The crop nitrogen content of an average density autumn sown cereal crop can also be determined by measuring the average crop height. The guidance suggests the following nitrogen content estimates.

Table 2 – Autumn sown cereal crop nitrogen contents using average crop height

Crop Height [cm]	*Crop nitrogen content [kg N/ha]*	
	Autumn	Spring
10	35	45
15	55	65
20	75	85

Using this method requires care and it is not recommended for established semi-dwarf varieties or crops that have been flattened by weather and the true crop height is difficult to determine.

Oilseed rape

The best approach to calculating the size of oilseed rape is to estimate the green area index (GAI) of the crop. This can be done by using the BASF GAI app. The guidance suggests that for every 1 unit of GAI estimated the crop will contain 50kg N/ha. This method is good for crops predicted to be less than GAI of 3.0. For crops larger than GAI 3.0, the 'cut and weigh' approach is more accurate. This method requires a known area, usually 1m^2, of crop to be cut and all the above ground biomass weighed. To determine the GAI, multiply the biomass weight in kgs by 0.8 (factor). By further multiplying the GAI value by 50, an estimated crop nitrogen content can be determined.

For potatoes, field vegetable crops and other spring sown crops, there is no need to make allowances for crop nitrogen content because samples are taken before planting or drilling.

Soil sampling for SMN

When to sample

Sampling in spring before nitrogen fertiliser is applied is essential, especially in high rainfall areas or on shallow or light sand soils, to account for overwinter leaching. On soils less prone to leaching, sampling earlier in winter is possible. However, most samples are taken close to when fertiliser or manure applications are due to begin. Avoid sampling within 2-3 months after an application of nitrogen fertiliser or organic manure to ensure that the sample result reflects the true soil nitrogen supply and isn't distorted by nitrogen supplied by the inputs.

Depth of sampling

Each field sampling position should have samples taken at three depths: 0-30cm, 30-60cm, and 60-90cm. Sampling to the full 90cm, or to the rooting depth of the crop if the ground is shallower than 90cm, is recommended from the beginning of January. Sampling to 60cm is satisfactory when sampling in the autumn. However, if sampling to 60cm and deep rooted crops are to be grown, an estimate of the mineral nitrogen in the 60-90cm layer must be carried out. In the absence of any better estimate, assume a uniform distribution of nitrogen throughout the soil profile. The SNS for shallow rooting crops needs to be scaled up because the SNS index system is based on measurements of SMN to 90cm. For example, if the soil mineral nitrogen result is 100kg N/ha at 45cm for a crisp lettuce crop, the equivalent 90cm soil depth value would be 200kg N/ha. This is calculated by multiplying the SMN result (at 45cm) by 2 (90cm divided by 45cm). The SNS value (kg N/ha) in this example relates to an SNS index of 5.

For shallower rooting crops, please refer to HDC factsheet 09/12 for more guidance on using the measurement method.

Method of sampling

Samples must be taken from representative areas of the field. Do not sample from field areas, such as ex-manure heaps, headlands or gateways. If differences in soil type or past management are significantly different within fields then consider sampling these areas separately. A minimum of 15 soil cores should be taken per 20 ha field size, and a minimum of 25 cores for field sizes greater than 20ha.

Samples from each depth should be bulked together to form a representative sample. If the bulked sample is too big, sub-sample by taking many small representative portions. Do not mix excessively—this introduces warming and can encourage mineralisation. Avoid cross contamination of samples from different soil depths and be careful not to introduce soil surface litter contamination.

Sample depths can be combined to represent the whole 90cm sample depth, but it is important to state the overall depth sampled. It is this depth that is used to calculate the total SMN and SNS values.

Top tips to be prepared well in advance to get the best out of our N-Check service

- Arrange all courier bookings in GOOD TIME between Monday-Thursday ONLY. If sampling the same day, allow a minimum 4 hour window for collection.
- Ideally, plan to sample at the beginning of the week (Monday to Wednesday). If sampling on Thursday, a same day collection is required. **Courier collections will be refused on a Friday.**
- Freeze ice packs the night before field sampling.
- Label bags with the field name and sample depth before going into field.

- Place ice packs in the insulated box and take the box to the field.
- Place the mixed subsampled cores in the labelled sample bags and immediately place soil samples in the insulated box.
- Dispatch to laboratory via the courier on the same day as sampling or the following day.
- Place samples in the fridge overnight if the courier collection is the next day after sampling and refreeze the ice packs.
- Ensure completed paperwork is submitted with the samples, identifying:
    a. Who owns the sample(s)
    b. The sample depth
    c. Estimate of stone content (if applicable)
    d. Estimate of crop N (if an autumn sown arable crop).

To get the best out of the N-Check services, this process must be adhered to. The reported results are only as good as the sample taken and prepared. Unrepresentative samples not kept cool and despatched to the laboratory in good time can result in misleading calculations of crop nitrogen requirement. This could lead to economic loss and reduced confidence in the process of SMN analysis and its benefits.

Soil mineral nitrogen results

Once the samples arrive at the laboratory, they will be analysed for nitrate-N and ammonium-N using potassium chloride as the extracting solution. The results will be reported as kg/ha of ammonium-nitrogen, nitrate-nitrogen, and SMN for each depth separately, and overall as a total soil nitrogen supply.

Estimation of nitrogen that will be released from mineralisation of organic matter and the crop nitrogen content

Nitrogen mineralised from soil organic matter and crop debris after sampling is an important source of nitrogen for crop uptake. However, the amount of mineralisable nitrogen or Additionally Available Nitrogen (AAN) may be small in mineral soils of low to average organic matter content, but contributions still needs to be accounted for.

Nitrogen mineralisation tends to be greater where soil organic matter is high and organic inputs have been historically applied. As discussed above, the guidance suggests around 10kg/ha of additional nitrogen may be expected for each 1% increase in soil organic matter above 4% in England and Wales or above 10% in Scotland and Northern Ireland. Where soil organic matter is less than this, mineralisation has largely been ignored, but recent research indicates that an estimate of around 20kg/ha may be appropriate, particularly after cold winters.

The proportion of mineralisable nitrogen that becomes available throughout the spring generally peaks during May. Unfortunately, it is very difficult to determine how much becomes available by a certain date. The only certainty is that the extra available nitrogen will be crop available between spring and harvest.

If an estimated stone content was submitted with the sample, the final SNS will be adjusted accordingly. It is interesting to note that stone content proportion should reflect the distribution of stone throughout the soil profile. Generally, stone contents of less than 30% do not significantly impact the crop available SNS.

To complete the SNS equation, the final component is the spring crop nitrogen content. By combining the measured soil mineral nitrogen result, estimated mineralisable nitrogen, and crop nitrogen estimate, the SNS can be determined and the SNS index reported. Reference should then be made to the RB209 SNS index system and the nitrogen recommendation obtained from the appropriate crop table. The optimum amount of nitrogen fertiliser recommended in RB209 is based on a break-even ratio (BER) of 5:1 (5 kilos of grain to pay for 1 kilo of nitrogen). If the economic circumstances change, then the optimum nitrogen fertiliser recommendation should also be adjusted.

For every 1 unit increase in BER from 5:1, 10kgs nitrogen should be subtracted from the nitrogen rate reported in the RB209 crop table. For every 1 unit decrease in BER from 5:1, 10kg nitrogen should be added to the nitrogen rate reported in the RB209 crop table. RB209 describes the impact of the economic BER at different fertiliser and crop prices. Please refer to section 1: principles of nutrient management and fertiliser use.

Adopting changes to N use

Large SMN measurements can overestimate SNS and small SMN measurements can underestimate SNS. If SNS estimates indicates that large increases or decreases in nitrogen fertiliser use are required, caution must be applied and confirmatory evidence should be sought. Crops should be monitored closely throughout spring for signs of nitrogen deficiency or excess, and the planned strategy should be adjusted if necessary. It may be prudent to introduce the changes in nitrogen use gradually over a few seasons.

Use of the measurement method

Measuring the soil to determine the SNS index is reliable for combinable crops, root vegetable crops, and soil grown strawberries where relevant. Estimating the index by measurement is not

recommended for grassland, fruit (excluding soil grown strawberries), vines and hops. Please refer to relevant sections of the nutrient management guide for the latest advice.

The use of the measurement method in grassland systems is not recommended due to the high amount of nitrogen cycling in the crop-soil system partly due to the regular inputs of organic manures. For detailed information on determining the SNS index for fruit, vines, and hops, please refer to section 7 of the nutrient management guide. Clear guidance is available here for crops before/at planting for established orchards and established soft fruit/vine plantations.

The measurement method can be successfully used on vegetable crops but it is advised to follow guidance set out in section 6 of the nutrient management guide or to refer to the HDC factsheet.

More information on soil nitrogen

For more information on nitrogen in soil, see the new 9th edition of RB209. This contains indepth information on the topics covered in this technical bulletin and the HGCA Topic Sheet 115 'Estimating Soil Nitrogen Supply'.

References

AHDB Nutrient Management Guide (RB209) 2017

HDC factsheet 09/12

AHDB Topic Sheet 115

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