Nutrient Management Guide (RB209)

Updated January 2019

Section 1 Principles of nutrient management and fertiliser use

Using the Nutrient Management Guide (RB209)

This latest revision of RB209 is based on research carried out since the previous edition was published in 2010. The revision includes updated recommendations, including those for additional crops and information on the nutrient content of additional organic materials.

RB209 was first published in 1973 and was the first comprehensive set of fertiliser recommendations from the Ministry of Agriculture, Fisheries and Food (MAFF). RB209 stands for Reference Book 209.

To improve the accessibility of the recommendations and information AHDB's Nutrient Management Guide (RB209) is published as seven sections that will be updated individually.

Further information
The Nutrient Management Guide (RB209) will be updated regularly.

Please email your contact details to AHDB so that we can send you updates when they are published - comms@ahdb.org.uk

RB209: Nutrient Management
Download the app for Apple or Android phones to access the current version of all sections of the guide. With quick and easy access to videos, information and recommendations from the guide, it is practical for use in the field.

Always consider your local conditions and consult a FACTS Qualified Adviser if necessary.

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Summary of main changes from previous edition

1. Overall presentation
   a. The principles of nutrient management and fertiliser use are now presented in **Section 1: Principles of nutrient management and fertiliser use**.
   b. The section has been revised, making information more concise and accessible.
2. Guidance on assessing Soil Nitrogen Supply (SNS)
   a. The guidance on assessing Soil Nitrogen Supply (SNS) has been revised to include guidance on when Soil Mineral Nitrogen (SMN) sampling can be most useful and interpretation of SMN analysis results for crops with different rooting depths.
3. Improved guidance on sampling
   a. The guidance on soil sampling for P, K and Mg analysis has been updated.
   b. The guidance on leaf sampling has been updated.
4. Sulphur recommendations
   a. As risk of sulphur deficiency is becoming more widespread, the need for sulphur fertilisers is emphasised. A method of assessing the risk of sulphur deficiency is provided, based on soil type and climate factors.
5. Phosphate and potash recommendations
   a. The system of soil target Indices and replacing offtake in harvested crops is retained but guidance is provided on the importance of soil structure and on building up low Indices more rapidly, where appropriate.

The basis of good practice

Practices that make the best economic use of nutrients also help protect the wider environment.

Obtain relevant information

- Soil type
- Field cropping, fertilising and manuring history every 3–5 years
- Regular soil analysis for pH, P, K and Mg
- Nutrient balances – surplus or deficit from applications to previous crops
- An assessment of Soil Nitrogen Supply every spring before applying nitrogen fertiliser
- Winter rainfall
- Crop tissue analysis where appropriate (eg for micronutrients for arable and fruit crops and for sulphur and potassium on grassland)

Assess crop yield potential, economics and markets

- Take account of fertiliser nitrogen and crop produce prices
- Consider market requirements for quality and quantity of harvested produce
- Adjust phosphate and potash for expected crop yield (including straw where removal is planned)

Assessment of available nutrients from organic materials

- Apply manures in spring if possible and incorporate rapidly into the soil following surface application to tillage land or use of trailing hose, trailing shoe or injection equipment for slurry
- Make use of manure analysis (on-farm and laboratory testing) or use of standard values **(Section 2: Organic materials)**
- Calculate available nutrients based on manure type, method and time of application

Decisions on the rate, method and timing of fertiliser application for individual crops

- Apply nitrogen to meet periods of greatest demand for it
- Consider placement of fertilisers for responsive crops

Careful selection of fertilisers

- Consider the cost effectiveness of alternative fertiliser materials
- Take account of the nutrient percentage and the availability of nutrients for crop uptake
- Make sure that the physical quality of the fertiliser will allow accurate spreading

Accurate application of fertilisers and manures

- Regularly maintain and calibrate fertiliser spreaders and sprayers
- Regularly check and maintain manure spreaders

Record keeping

- Keep accurate field records to help with decisions on fertiliser use

Good nutrient management

Maintaining a profitable farming business requires continued development and use of a wide range of skills by farmers and their advisers. Good nutrient management is an important aspect of this and can contribute both to the efficiency of the farming business and to reducing environmental impacts. AHDB's Nutrient Management Guide (RB209) provides information to help operate a profitable farm business, while protecting the environment.

This guide helps farmers and advisers to make the most of organic materials and balance the benefits of fertiliser use against the costs – both economic and environmental. It explains the value of nutrients, soil and why good nutrient management is about more than just the fertilisers you buy; it can save you money as well as help protect the environment. To help your forward planning, it also outlines possible future changes that could further affect fertiliser use.

The growing challenges

The agricultural sector faces a number of challenges, including producing more food to feed a growing population, while impacting less on the environment. Agricultural production relies on environmental resources such as soil, water and air and is vulnerable to climate change, including flood and drought. Good nutrient management using a balanced long-term approach is part of a sustainable agricultural system that is resilient to climate and economic change.

Sources of inorganic nutrients are limited and manufacture of fertilisers requires energy, so recycling of nutrients through organic materials and improving nutrient availability from well-structured biologically active soils makes better use of resources and economic sense.

Ensuring the carefully managed application of all nutrients, including manufactured fertilisers and organic materials, helps to close the 'nutrient gap' that arises when the crop is removed at harvest. Optimising nutrient uptake by crops helps minimise an excess in the soil where, for example, nitrogen can be lost as nitrous oxide or ammonia to the air or nitrate to water.

Demand for land to grow non-food crops, such as biomass crops, and from non-farming uses may well increase. This is one factor which may mean that higher crop yields will be necessary to supply the increased demand for food.

Greenhouse gases

At present, agriculture is estimated to contribute around 9% of total UK greenhouse gas emissions. An estimated 70% of the UK's nitrous oxide emissions, a greenhouse gas around 300 times more potent than carbon dioxide, comes from agriculture. Soil nitrous oxide emissions come from three on-farm sources: grazing returns, storage and application of organic manures and nitrogen fertiliser.

Careful planning that maximises the efficiency of fertiliser use and better management of manures can help reduce the amount of nitrogen that is lost as nitrous oxide. The farming industry has published its Greenhouse Gas Action Plan, which confirms its intent to play its part in helping to reduce greenhouse gas emissions.

Further information

Greenhouse Gas Action Plan
ahdb.org.uk/knowledge-library/greenhouse-gas-action-plan-ghgap

Protecting our Water, Soil and Air: A Code of Good Agricultural Practice for farmers, growers and land managers
www.gov.uk

Water quality

Farming is one of many influences on water quality and water-dependent ecosystems. The main agricultural pollutants are nutrients (phosphates and nitrates), pesticides and other agrochemicals, faecal bacteria and sediment. Losses from the application of manufactured fertilisers and spreading of organic manures contribute to diffuse water pollution.

In England and Wales, around 60% of nitrates and 25% of phosphates in our waters originate from agricultural land. Elevated levels of these nutrients can harm the aquatic environment and have an impact on biodiversity. In addition, excessive amounts of agricultural pollutants, including nitrates and phosphates, have to be removed before water can be supplied to consumers.

The Water Framework Directive requires our rivers, lakes, ground and coastal waters to reach or maintain good ecological and chemical status. Therefore, it is important that agricultural land is managed carefully to avoid losses of soil, nutrients and faecal bacteria.

Key measures to reduce the risk of phosphate movement to water include:

- Following the recommendations in this guide to maintain the target level of crop-available soil phosphate and avoiding any unnecessary build-up above the target Index and taking full account of the phosphate content of organic materials **(Section 2: Organic materials)**
- Minimising the risk of soil erosion
- Avoiding surface applications of all organic manures (solid or liquid) when soils are snow-covered, frozen hard, waterlogged, deeply cracked, or on steeply sloping ground adjacent to watercourses
- Applying inorganic fertiliser in smaller amounts as annual dressings, rather than as a single, large dressing, except where the aim is to increase the soil Index. Such applications should be ploughed in

Soils

Incorporating organic materials (eg composts, manure and biosolids) plays an important role in increasing levels of organic matter in soil. It can have important agricultural and ecological benefits such as reducing fertiliser requirements, improving soil condition and biological activity, and diverting materials from landfill.

Certain materials spread on land can also contain low concentrations of pollutants, especially heavy metals which, following repeated applications, can accumulate in the soil. This could pose a risk to human health and the environment. Remediating soils which contain pollutants is difficult and costly, so it is important to prevent unacceptable levels of pollutants getting into the soil.

Further information

AHDB Field drainage guide
ahdb.org.uk/knowledge-library/field-drainage-guide

Think soils
ahdb.org.uk/knowledge-library/thinksoils

Air quality

Agricultural activities account for around 90% of ammonia emissions. High concentrations of ammonia in the air can mean that nitrogen is deposited from the air onto the land. This can damage some habitats by changing the species of plants present and pollute streams, rivers and other water bodies. The ammonia can also be converted to nitrous oxide, a potent greenhouse gas and released from soils. Ammonia also combines with other substances in the air to form fine particles, which can harm human health.

There are strong pressures within the EU to reduce ammonia emissions from agriculture. Large pig and poultry farms are already covered by environmental permitting regulations which implement the EU Integrated Pollution Prevention and Control (IPPC) Directive. There may be controls on a wider range of farms in the future.

The UN/ECE Gothenburg Protocol, and the EU National Emissions Ceiling Directive have been implemented to control ammonia emissions (among other pollutants) at the national level. Both the Protocol and the Directive have national emission ceilings for 2010, and both are currently undergoing revision to include more stringent ceilings for 2030.

Several measures can be used to decrease the ammonia emissions from agricultural activities eg effective manure management from collection and storage to application to land. Substantial reduction in ammonia emissions from slurry and digestate applications can be achieved through injection, trailing shoe and trailing hose techniques, when compared to splash-plate or broadcast application methods.

Further information

Understanding carbon footprinting for cereals and oilseeds
cereals.ahdb.org.uk/crop-management/stewardship

Low emissions – focus on ammonia
ahdb.org.uk/knowledge-library/low-emissions-focus-on-ammonia

Crop nutrient requirements

In addition to carbon (C), hydrogen (H) and oxygen (O), there are 13 known elements which are essential for plant growth and they can be divided into two groups:

- **Macronutrients – nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sulphur (S) are required in relatively large amounts**
- **Micronutrients (trace elements) – iron (Fe), copper (Cu), manganese (Mn), zinc (Zn), boron (B), molybdenum (Mo) and chlorine (Cl) and are required in smaller amounts than the macronutrients**

The names macronutrient and micronutrient do not refer to relative importance in plant nutrition. A deficiency of any one of these elements can limit growth and result in decreased yield and less efficient use of other nutrients.

It is, therefore, important to ensure there is an optimum supply of all nutrients. For example, if a plant is seriously deficient in potassium it will not be able to fully utilise any added nitrogen and reach its full potential yield; any unutilised nitrogen may be lost from the field.

In the UK, the following two conventions are used:

- **For fertiliser contents and recommendations, phosphorus is expressed in the oxide form, phosphate (P_2O_5), and potassium as potash (K_2O). Sulphur, magnesium and sodium are also expressed in oxide forms (SO_3, MgO and Na_2O)**
- **Soil and crop analysis reports usually show elemental forms, for example mg P/kg or mg K/l**

Timing nutrient application correctly is as important as applying the right amount. Crop demand varies throughout the season and is greatest when a crop is growing quickly. Rapid development of leaves and roots during the early stages of plant growth is crucial to reach the optimum yield at harvest, and an adequate supply of all nutrients must be available during this time.

The amount of a nutrient taken up by a crop may exceed the amount that will be removed in the crop at harvest. For example, at its peak, a high yielding cereal crop may have taken up the equivalent of 300 kg/ha K_2O, but less than half of this amount may be removed in the grain plus straw at harvest.

Excess application of nutrients, or application at the wrong time, can reduce crop quality and cause problems such as lodging of cereals or increases in foliar pathogens. Excessively large amounts of one nutrient in a readily plant-available form in the soil solution may also decrease the availability or uptake of another nutrient by the root.

Other elements found in plants, which may not be essential for their growth, include cobalt (Co), nickel (Ni), selenium (Se), silicon (Si) and sodium (Na). Sodium has a positive effect on the growth of a few crops, eg sugar beet. Some elements, such as cobalt, iodine (I), nickel and selenium are important in animal nutrition and are normally supplied to the animal via plants and through supplementary feeds. Therefore, it is important that they are available in the soil for uptake by plant roots.

All these elements are taken up by plant roots from the supply in the soil solution (the water in the soil). They are absorbed in different forms, have different functions and mobility within the plant so cause different deficiency, or, very occasionally, toxicity effects and symptoms.

Further information

Fertiliser conversion calculator
cereals.ahdb.org.uk/tools/agronomy-calculators

Trace Element Supplementation of Beef Cattle and Sheep
beefandlamb.ahdb.org.uk/returns/nutrition-and-forage

Integrated plant nutrient management

Crops obtain nutrients from several sources:

- Mineralisation of soil organic matter (all nutrients)
- Deposition from the atmosphere (mainly nitrogen and sulphur)
- Weathering of soil minerals (especially potash)
- Biological nitrogen fixation (legumes)
- Application of organic materials (all nutrients)
- Application of manufactured fertilisers (all nutrients)

For good nutrient management, the total supply of nutrients from all these sources must meet, but not exceed, crop demand. Crop demand varies with species (and sometimes variety of the crop), yield potential (this in turn depends on soil properties, weather and water supply) and intended use (eg feed wheat).

Nutrients should be applied as organic materials or fertilisers if the supply from other sources fails to meet crop demand. Where nutrients are applied, the amounts should be just sufficient to bring the total supply to meet crop need, however, in some cases, it might be appropriate to build the soil Index and will require the application of more fertiliser than crop demand.

Recommendation methods used in this guide allow the user to take account of all sources of nutrients, maximising economic return and minimising costly nutrient loss to water and air.

Information in this guide can be used to develop a whole farm nutrient management plan to make the best cropping choices and use of resources across the farm throughout the rotation. It can be used to make the most of on-farm nutrient supply in soil and organic manures as well as bought in nutrient inputs such as fertiliser, feed and organic manures. Planning cropping and grass rotations (including cover cropping and the use of legumes), incorporating soil, nutrient, manure and crop management over several years can help build soil fertility and reduce reliance on purchased inputs.

Important soil properties

Soil texture

Knowledge of the soil type in each field is important for making accurate decisions on lime and fertiliser use. Assessment of topsoil texture is essential to determine lime requirement; both topsoil and subsoil texture are needed to determine soil retention properties and associated nitrogen and sulphur recommendations.

Without this knowledge, it is not possible to use the recommendations in this guide effectively. Time is well spent, therefore, in acquiring this information because it is an intrinsic property of the soil that does not change with time.

In this guide, soil type, is related to soil texture. Soil texture is defined by the proportion of sand, silt and clay-sized mineral particles in the soil and can be determined in a number of ways:

- Assessment of texture by hand using the method described in Figure 1.1
- Laboratory analysis of the proportion of the different mineral particles in the soil, followed by classification using the texture triangular diagram given in the Think soils guide
- Use of the UK Soils Observatory (UKSO) “Soils Map Viewer” or the UKSO ‘mySoil’ App, which gives access to a European soil properties map
- Identification of the Soil Series for each field from the Regional Soil Maps for England and Wales, with classification from the accompanying Brown Book (available from the National Soil Resources Institute at Cranfield University)

Further information

Think soils
ahdb.org.uk/knowledge-library/thinksoils

UK Soils Observatory mySoil app
www.ukso.org/apps.html

Assessment of soil texture

1. Take about a dessert spoonful of soil.
2. If dry, wet up gradually, kneading thoroughly between finger and thumb until soil crumbs are broken down.
3. Enough moisture is needed to hold the soil together and to show its maximum stickiness.
4. Follow the paths in the diagram to determine the texture.

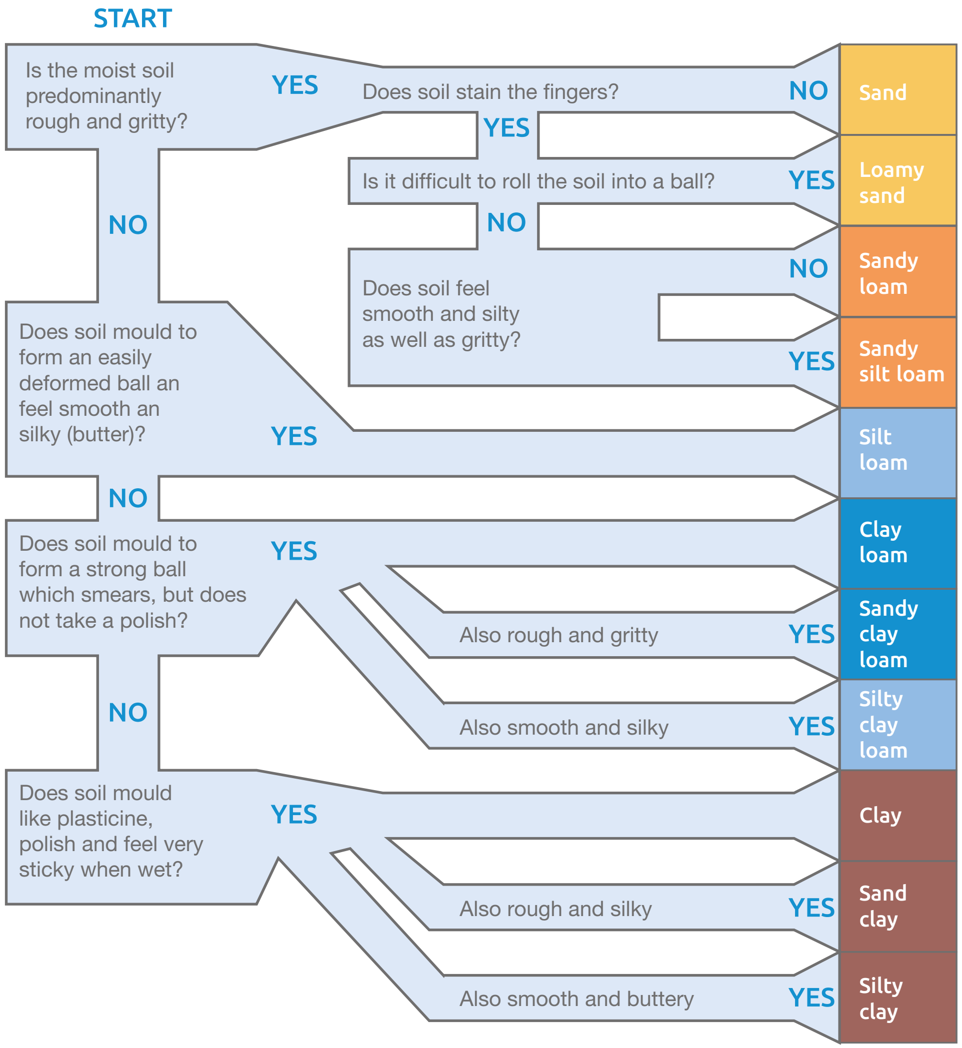

Figure 1.1 Assessment of soil texture by hand

Soil structure

To achieve optimum economic yields, crops have to acquire sufficient nutrients and water from the soil via the roots. It is, therefore, important to maintain good soil structure so that root growth is not adversely affected by poor physical soil conditions, such as compaction.

Soil mineral particles can be aggregated together and stabilised, either by clay or organic matter, to form crumbs. Within and between these crumbs are pores (voids) that can be occupied by air or water, both of which are required for roots to function properly.

If the diameter of the pores is too small, root tips cannot enter and roots cannot grow to find water and nutrients. If pores are too large, water drains rapidly from the soil and roots will not grow because the soil contains too little moisture.

The aggregation of soil mineral particles defines soil structure. For example, sands are often without any recognised structure while loamy soils can have an excellent one. Developing and maintaining a good soil structure depends greatly on good soil management, including cultivation at appropriate times and depths and minimising traffic over the soil when it is too wet.

Soil organic matter

Soil organic matter helps bind soil mineral particles of sand, silt and clay into crumbs. It has a number of important functions in crop nutrition, such as:

- Improving soil structure, enabling roots to grow more easily throughout the soil to find nutrients
- Holding phosphorus and potassium ions (the forms taken up by roots) very weakly so that they are readily available for uptake by roots
- Holding a store of organic forms of nitrogen, phosphate and sulphur from which available forms of these nutrients are released by microbial action

The amount of organic matter in a soil depends on the farming system, the soil type and climate. The interplay between the first two factors is that, in general, for the same farming system, a clay soil holds more organic matter than a sandy soil and, for the same soil type, a grassland soil holds more organic matter than an arable soil.

It is difficult to define a critical level of soil organic matter because there are so many combinations of soil type and farming system. However, maintaining and, where possible, increasing soil organic matter should be a priority.

Soil organic matter can be improved by applying bulky organic manures such as green compost and farmyard manure and, over the longer term, by incorporating green manures and cover crops into rotations.

Soil mineral matter

The types of mineral matter in a soil affect the reserves of plant nutrients and their availability. For example, a soil containing minerals from igneous sources is likely to contain more potash and iron than a chalky soil, which will contain more calcium. Soils overlying chalk are typically alkaline (pH above 7) while those overlying sandstone are typically acidic.

Stone content and rooting depth

A large content of impermeable stones increases the speed of water movement through the soil and because there is less fine soil to hold nutrients, the availability of water and nutrients is lower than in largely stone-free soils.

Soil rooting depth is important and many crops have root systems with the potential to grow to a metre deep or more. In deep friable soils where roots can grow to depth, they can take up water and nutrients leached from the surface soil. Shallow soils over hard rock and compacted soil layers limit root growth, restricting nutrient and water availability, limiting crop yields.

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Soil acidity and liming

Soil pH is a measure of acidity or alkalinity; it is a logarithmic scale, where pH 6.0 is 10 times more acidic than pH 7.0. It is important to maintain the appropriate soil pH. It can be measured in the laboratory using a soil sample taken from the field or directly in the field using a soil test kit.

When determined in the laboratory, pH is usually measured in a soil/water suspension. The natural pH of a soil depends on the nature of the material from which it was formed. It ranges from about pH 4 (very acid), when most crops will fail, to about pH 8 for soils naturally rich in calcium carbonate (lime) or magnesium carbonate.

For soils with a pH lower than 7, natural processes (eg rainfall, crop growth and leaching of calcium in drainage water) and some farming practices (eg use of some nitrogen fertilisers) tend to acidify soil. Acidifying processes can cause soil pH to fall quite quickly and regular pH checks are advisable. Such acidifying processes rarely affect the pH of calcareous soils, except perhaps in the top few centimetres where the soil is undisturbed. If problems are suspected, soil pH should be checked.

The optimum availability of most plant nutrients in soil occurs over a small range of soil pH values. Unfortunately the range for each nutrient is not the same but there is sufficient overlap in the ranges to decide the best possible compromise for each cropping system and soil type. The optimum pH for each soil type and cropping system is shown in Table 1.1.

Table 1.1 Optimum soil pH

	Optimum soil pH[a]	
	Mineral soils	Peaty soils
Continuous arable cropping	6.5[b]	5.8
Grass with an occasional barley crop	6.2	5.5
Grass with an occasional wheat or oat crop	6.0	5.3
Continuous grass or grass/clover swards	6.0	5.3

Soil pH can vary considerably metre by metre and maintaining the mean pH in each field or 5 ha block at the optimum level, should avoid patches that are well below target (eg below pH 5.6 on mineral soils), thereby maintaining crop yield and quality.

Alternatively, in variable fields, Global Positioning Systems (GPS) sampling for soil pH, combined with variable rate lime application can be cost-effective. Identifying major soil types and yield variation in the field is a key step in establishing the need for GPS sampling.

Not correcting soil acidity can cause large yield losses but over-use of lime is wasteful and costly and can create problems with the availability of some micronutrients.

Further information

AgLime Quality Standard

- Guarantees the regulatory quality of AQS-certified agricultural liming products on the UK market
- Provides clear, concise and independent analysis and certification

a. The optimum pH is based on soil that has been correctly sampled. In some soil samples containing fragments of free lime, analysis of the ground soil sample in the laboratory can give a misleadingly high value for pH.

b. In arable rotations, growing acid-sensitive crops such as sugar beet, maintaining soil pH between 6.5 and 7.0 is justified.

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Table 1.2 Lime recommendations in terms of tonnes of lime (NV50) to apply per hectare

Initial soil pH	Sands and loamy sands		Sandy loams and silt loams		Clay loams and clays		Organic soils[a]		Peaty soils[b]	
	Arable	Grass	Arable	Grass	Arable	Grass	Arable	Grass	Arable	Grass
Liming factor										
	6	4	7	5	8	6	8	6	16	12
t/ha										
6.2	3	0	4	0	4	0	4	0	0	0
6.0	4	0	5	0	6	0	6	0	0	0
5.5	7	3	8	4	10	4	10	4	8	0
5.0	10	5	12	6	14	7	14	7	16	6

a. For mineral and organic soils, the target soil pH is 6.7 for continuous arable cropping and 6.2 for grass. Aim for 0.2 units above the optimum pH.

b. For peaty soils, the target soil pH is 6.0 for continuous arable cropping and 5.5 for grass. Aim for 0.2 units above the optimum pH.

Lime recommendations

For each field, the amount of lime to apply will depend on the current soil pH, soil texture, soil organic matter and the target pH, which should be 0.2 pH points above optimum. Clay and organic soils need more lime than sandy soils to increase pH by one unit. A lime recommendation is usually for a 20 cm depth of cultivated soil or a 15 cm depth of grassland soil.

Table 1.2 gives examples of the recommended amounts of lime (t/ha of ground limestone or chalk, neutralising value (NV) 50–55) required to raise the pH of different soil types to achieve the target pH level shown in the footnotes.

To estimate the lime recommendation (in t/ha of ground limestone or chalk), multiply the liming factor for each soil type and land use combination by the difference between the initial (measured) and target soil pH.

Where soil is acid below 20 cm and soils are ploughed for arable crops, a proportionately larger quantity of lime should be applied. However, if more than 10 t/ha is needed, half should be deeply cultivated into the soil and ploughed down, with the remainder applied to the surface and worked in.

For established grassland or other situations where there is no, or only minimal, soil cultivation, no more than 7.5 t/ha of lime should be applied in one application. In these situations, applications of lime change the soil pH below the surface very slowly. Consequently, the underlying soil should not be allowed to become too acid because this will affect root growth and thus limit nutrient and water uptake, which will adversely affect yield.

Liming materials

The effectiveness of a liming material depends on its neutralising value (NV), its fineness of grinding and the hardness of the parent rock.

The NV is the relative effectiveness of a liming material compared to that of pure calcium oxide (CaO). Lime recommendations are usually given in terms of ground limestone or ground chalk (NV 50–55) but other liming materials can be used, provided allowance is made for differences in NV, fineness of grinding (which affects the speed of reaction in the soil) and cost.

The application rate is adjusted to take account of differences in NV. The Fertilisers Regulations 1991 give details of the meaning and required declarations of different named liming products. In addition, materials such as sugar beet lime and lime-treated sewage cake contain a useful amounts of lime.

The cost of different liming materials can be compared by calculating the cost per unit of NV but allowance should also be made for any differences in particle fineness.

Some liming materials contain other useful nutrients which should be taken into account when deciding which to use. For example, magnesian limestone (dolomitic limestone) contains large amounts of magnesium and is effective for correcting soil magnesium deficiency as well as acidity. However, many years of using magnesian limestone can result in an excessively high soil Mg Index and excess magnesium in the soil solution may induce potash deficiency in crops.

Further information
Agricultural Lime – the Natural Solution
www.aglime.org.uk/library

Example 1.1

Ground limestone has an NV of 50 and costs £20/t delivered and spread. An alternative liming material (A) has an NV of 30 and costs £17/t delivered and spread.

Ground limestone costs (20 x 100) / 50 = 40 pence per unit of NV.

Liming material A costs (17 x 100) / 30 = 57 pence per unit of NV.

Provided the two materials have the same physical characteristics, the ground limestone is the more cost-effective liming material.

Lime application

It is important to maintain the appropriate soil pH for the cropping system and soil type and soil pH should not vary by more than ± 0.5 pH unit from the optimum. However, when to apply lime can be fitted in with the crops being grown. For example:

- Sugar beet and barley are sensitive to soil acidity; when needed, lime should be applied before these crops are grown
- Clover is more sensitive to soil acidity than many grass species and soil pH should be maintained to encourage a clover-rich sward

A liming material should always be well worked into the cultivated soil because it can take some months to increase pH throughout the topsoil. It is unwise to grow a crop which is sensitive to acidity immediately after liming a very acid soil. If it is important to try to achieve a rapid effect then the use of a fast-acting liming material could be considered.

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Nitrogen for field crops

Most agricultural soils contain too little naturally occurring plant-available nitrogen to meet the needs of a crop throughout the growing season. Supplementary nitrogen applications are normally made each year to meet crop demand. Applying the correct amount of nitrogen at the correct time is an essential feature of good crop management.

Crop nitrogen requirement

The crop nitrogen requirement is the amount of nitrogen that should be applied to give the on-farm economic optimum yield. Nitrogen recommendations for all arable crops in this guide are defined in this way. Crop nitrogen requirement should not be confused with crop nitrogen demand ie the total supply of nitrogen (including that from the soil) that is needed by the crop.

Basis of the recommendations

Provided there are adequate supplies of water and other nutrients, nitrogen usually has a large effect on crop growth, yield and quality. Figure 1.2 shows a typical nitrogen response curve. Applying nitrogen gives a large increase in yield but applying too much can reduce yield by aggravating problems such as lodging, foliar diseases and poor silage fermentation.

When too much nitrogen is applied, a larger proportion is unused by the crop. This is a financial cost and can also increase the risk of nitrogen losses to water and air.

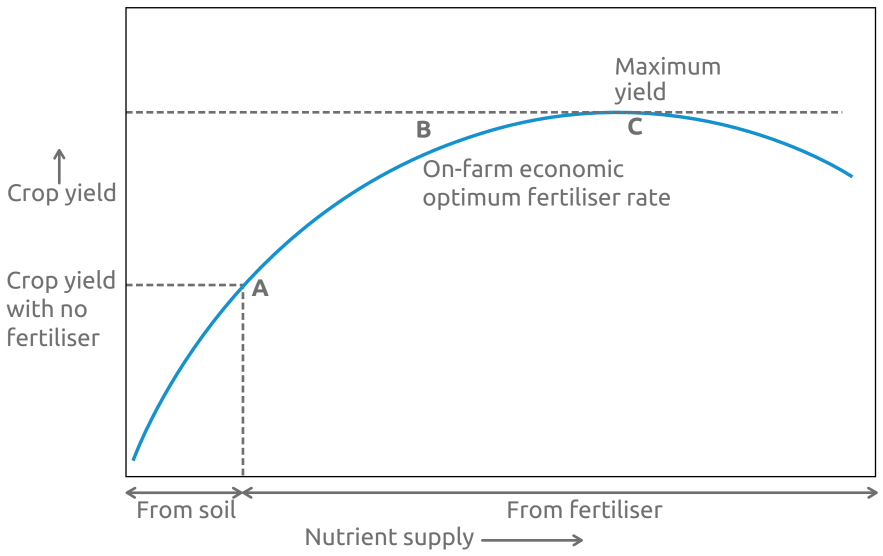

Figure 1.2 A typical nitrogen response curve

- **Without applied nitrogen, yield typically is low (A)**
- **As nitrogen use increases from very small amounts, there is a large increase in yield up to the 'on-farm economic optimum' nitrogen rate (B). This rate depends on the cost of the applied nitrogen and on the value of the crop ('breakeven ratio') as well as on the shape of the response curve**
- **Recommendations for cereals and oilseeds are calculated using a typical breakeven ratio to provide the best on farm economic rate of nitrogen to apply. Substantial changes in the value of the crop produce or in the cost of nitrogen are needed to alter the recommendations. Where appropriate, different recommendations are given to achieve crop quality specifications required for different markets**
- **Application of nitrogen above the on-farm economic optimum will increase yield slightly but this yield increase will be worth less than the cost of the extra nitrogen**
- **Maximum yield (C) is reached at a nitrogen rate greater than the on-farm economic optimum and is never a target if farm profits are to be maximised. Application of nitrogen above point C does not increase yield and yield falls with further applications**
- **The nitrogen can be supplied from fertiliser and/or organic materials**

At nitrogen rates up to the on-farm economic optimum, there is a roughly constant amount of nitrogen left in the soil at harvest. At nitrogen rates above the on-farm economic optimum, there will be a larger surplus of residual nitrogen, usually as nitrate, in soil after harvest. This nitrate is at risk of loss which can cause environmental problems like leaching to ground or surface water and denitrification to nitrous oxide (a greenhouse gas).

Nitrogen supply and losses

Nitrogen supply can be from the soil, the atmosphere and organic manures as well as from fertiliser. Nitrogen losses may be by leaching, run-off, ammonia volatilisation and denitrification.

Nitrogen supply

Soil Mineral Nitrogen (SMN) – Nitrate-N (NO_3-N) and ammonium-N (NH_4-N) are often called mineral nitrogen. Both are potentially available for crop uptake and the amount in the soil depends on the recent history of cropping, organic material and nitrogen fertiliser use.

Nitrogen mineralised from organic matter – Mineralisation results in the conversion of organic nitrogen to mineral nitrogen by soil microbes. The amount of organic nitrogen mineralised can be large:

- On organic and peaty soils
- Where organic manures have been used for many years
- Where nitrogen-rich, organic material is ploughed into the soil

Nitrogen from the atmosphere – Small amounts of nitrogen are deposited in rainfall and directly from the atmosphere. Leguminous crops, like peas, beans and clover, have bacteria in the nodules on the roots that can ‘fix’ atmospheric nitrogen into a form that can be used by the plant.

Nitrogen from organic materials – Most organic materials contain some mineral nitrogen, which is equivalent to mineral nitrogen in manufactured fertilisers. The remaining organic nitrogen becomes available more slowly (see **Section 2: Organic materials**).

Manufactured fertiliser nitrogen – Manufactured fertiliser nitrogen is used to make up any shortfall in the crop’s requirement for nitrogen.

Nitrogen losses

Leaching – Nitrate is soluble in the soil solution and, unlike ammonium, is not held on soil particles. Once the soil is fully wetted, nitrate may leach into field drains or subsurface aquifers as drainage water moves through the soil. The amount of winter rainfall has an important influence on the amount of nitrate leached.

Under normal conditions, ammonium-N in the soil is rapidly converted to nitrate. Therefore, sources of ammonium-N will have a similar risk of leaching as sources containing nitrate when used in excess of the requirement of a crop.

Run-off – During and following heavy rainfall, nitrogen in solution or in organic form can move across the soil surface and/or via drains and enter watercourses. The amount of nitrogen lost from soil in this way will vary widely from field to field and season to season depending on the amount, timing and intensity of rainfall and nitrogen applications. Sloping ground, proximity to surface waters and surface application of organic manures present particular risks of nitrogen loss in run-off.

Denitrification – In anaerobic soils (poorly aerated soils lacking oxygen), nitrate can be denitrified and lost to the atmosphere as the gases nitrous oxide, a greenhouse gas, and nitrogen (N_2). Denitrification is a biological process and is most significant in wet and warm soils where there is a supply of nitrate after harvest or where there has been a recent nitrogen application and there is enough organic matter for the microbes to feed on. Some nitrous oxide is formed during nitrification of ammonium-N to nitrate-N and some of this also can be lost to the atmosphere.

Ammonia volatilisation – Nitrogen may be lost to the atmosphere as ammonia gas. Significant losses commonly occur from livestock housing, livestock grazing and where organic manures are applied to fields and are not immediately incorporated by cultivation. There can also be significantly larger losses of ammonia when urea is applied to a growing crop compared to losses when other forms of nitrogen fertiliser, such as ammonium nitrate, or inhibitor treated urea, are used.

Factors influencing decisions about nitrogen use

The crop nitrogen requirement (the ‘on-farm economic optimum’) will depend on:

- The amount of nitrogen from all sources, including the soil and organic materials, which is available to achieve the optimum on-farm economic yield
- The cost of nitrogen fertiliser and the likely value of the crop
- Any particular crop quality requirements, for example, grain protein in bread-making wheat or in malting barley

In addition to identifying crop nitrogen requirement as accurately as possible, it may be necessary to comply with regulatory restrictions on the amount or timing of applications, for instance, in Nitrate Vulnerable Zones (NVZs).

When calculating how much manufactured fertiliser nitrogen to use, all supplies and losses of nitrogen and the efficiency of fertiliser nitrogen use by the crop must be considered.

Soil nitrogen may be immobilised by addition of organic materials with a high carbon:nitrogen ratio. This may result in a short-term increase in nitrogen requirement. More information on paper crumble is provided in **Section 2: Organic materials**. Data are not available on additional nitrogen requirements related to straw or high carbon:nitrogen ratio compost.

Assessing the Soil Nitrogen Supply (SNS)

Soil Nitrogen Supply is defined as the amount of nitrogen (kg N/ha) available for uptake from the soil by the crop throughout its entire life. It takes account of nitrogen losses but excludes nitrogen applied to the crop in manufactured fertilisers or manures.

The SNS includes three separate components:

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

Where:

- **Soil Mineral Nitrogen (kg N/ha) is the nitrate-N plus ammonium-N content of the soil within the normal maximum rooting depth of the crop**
- **Nitrogen already in the crop (kg N/ha) is the total content of nitrogen in the crop when the soil is sampled for SMN**
- **Mineralisable soil 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 during the growing season after sampling for SMN**

The SNS depends on a range of factors which commonly vary from field to field and from season to season. It is, therefore, important to assess the SNS for each field each year. The key factors influencing SNS are:

- **Nitrogen residues left in the soil from fertiliser applied for the previous crop**
- **Nitrogen residues from any organic manure applied for the previous crop and in previous seasons**
- **Soil type and soil organic matter content**
- **Losses of nitrogen by leaching and other processes (the amount of winter rainfall is important)**
- **Nitrogen made available for crop uptake from mineralisation of soil organic matter and crop debris during the growing season**

Mineral nitrogen residues after harvest

The management and performance of a crop can have a significant effect on the amount of residual mineral nitrogen (nitrate-N and ammonium-N) in the soil at harvest. Residues are likely to be small if the amount of nitrogen applied matched or was less than crop requirement. The residues may be larger than average when yields are unusually small due to disease or drought.

Residues following cereals are generally lower than those following break crops. In ley–arable rotations, the nitrogen released from grass leys may persist for up to three years following ploughing but the most useful nitrogen becomes available within the first one or two seasons.

Winter cover crops

Well-established cover crops, such as mustard, forage rape or Phacelia, sown after harvest can take up significant amounts of Soil Mineral Nitrogen and reduce the risk of nitrate leaching over winter. Generally, the earlier the cover crop can be established, the more mineral nitrogen will be taken up. However, there is limited evidence on the use of starter nitrogen fertiliser on cover crops for better establishment; evidence to date does not show consistent benefits from its use.

Early destruction of a well-established cover crop by the end of February can release useful quantities of nitrogen for the following spring crop; sufficient to increase the SNS by up to two Indices.

However, when cover crops are destroyed in March or later, the amount and timing of nitrogen release is difficult to predict, with factors such as a high carbon to nitrogen ratios likely to delay mineralisation. The timing and duration of nutrient uptake in the following crop is also a factor, such that short-season crops may not have time to benefit from any mineralised nitrogen from a previous cover crop.

Further information

Opportunities for cover crops in conventional arable rotations
ahdb.org.uk/knowledge-library/cover-crops

Effect of excess winter rainfall

The amount of nitrate leached will depend on the quantity in the soil when the soil reaches field capacity and through-drainage starts, the soil type and the amount of water draining through the soil (excess winter rainfall).

The excess winter rainfall is the rainfall between the time when the soil profile becomes fully wetted in the autumn (field capacity) and the end of drainage in the spring, less evapotranspiration during this period (ie water lost through the growing crop).

Excess winter rainfall (mm)	=	**Rainfall between the time a soil reaches field capacity and the end of drainage**	–	**evapotranspiration**

Further information

AHDB provides Excess Winter Rainfall (EWR) data for the current season
cereals.ahdb.org.uk/ewr

Light sand soils and some shallow soils can be described as 'leaky'. Nitrate in these soils following harvest is fully leached in an average winter, even where substantial residues are present in the autumn. The SNS Index is nearly always 0 or 1 and is independent of previous cropping, except in low rainfall areas or after dry winters.

Deep clay and silt soils can be described as 'retentive'. The leaching process is much slower and more of the nitrate residues in autumn will be available for crop uptake in the following spring. Differences in excess winter rainfall will have a large effect on SNS in these soils. Low levels of SNS (Index 0 and 1) are less frequent than on sandy soils. Other mineral soil types are intermediate between these two extremes.

Because of both regional and seasonal differences, separate SNS Index tables are given in Sections 3–6 for low, medium or high rainfall situations.

Nitrogen released from mineralisation of organic matter

Nitrogen is released in mineral forms when microbial action breaks down soil organic matter. The rate of mineralisation depends on temperature and is usually slow over winter until soil temperature reaches around 4°C. In organic and peaty soils, mineralisation of soil organic matter in late spring and summer results in large quantities of nitrate becoming available for crop uptake.

Soil temperature often remains higher than 4°C for some weeks after harvest supporting mineralisation in autumn that can contribute to the nitrogen requirement of an autumn-sown crop or to the risk and extent of nitrate leaching where the land remains uncropped.

Long season crops (eg sugar beet) will utilise more mineralised nitrogen than crops which are harvested in mid- or late-summer. For example, cereals make little use of nitrogen mineralised after June.

For the purposes of this guide, organic soils are considered to contain between 10 and 20% organic matter. The recommendations in the tables for organic soils are based on an organic matter content of 15%.

Peaty soils contain over 20% organic matter. They are always at SNS Index 5 or 6 irrespective of previous cropping, manuring history, or excess winter rainfall. This is because the large amounts of organic nitrogen mineralised will usually be much greater than variations in the nitrogen residues due to previous cropping.

The amount of nitrogen mineralised from past applications of organic manures (over one year old) is difficult to estimate. The amount will generally be small. It can be greater where there has been a history of large regular applications of organic manures and in these situations it can be worthwhile to sample the soil and analyse it for Soil Mineral Nitrogen (SMN).

Organic nitrogen in crop debris from autumn harvested crops usually mineralises quickly and nitrate is liable to loss by leaching over winter in the same way as mineral nitrate residues from fertilisers. Mineralisation of nitrogen-rich leafy debris is quicker than that of nitrogen-poor straw debris.

Organic nitrogen that is not mineralised quickly becomes available over a long time and may contribute little to the nitrogen supply of the following crop. Examples of cropping situations where mineralised nitrogen from crop residues can make a useful contribution are:

- **Incorporation of sugar beet tops, especially before a late autumn sown crop.**
- **Where a second cauliflower crop is grown in the same season. Large amounts of leafy, nitrogen-rich crop debris will be returned to the soil after harvest of the first crop and will quickly release nitrate available for the next crop.**

Soil Nitrogen Supply (SNS) Index system

The nitrogen recommendations in this guide are based on seven SNS Indices and each Index is related to a quantity of SNS in kg N/ha. The SNS Index can be determined using field specific information (the Field Assessment Method) without sampling and analysis for SMN. It can also be deduced using the results of soil sampling and analysis for SMN and an assessment of any nitrogen already taken up by the crop (the Measurement Method).

A nitrogen recommendation is obtained by determining the SNS Index of the field using one of these methods, then referring to the appropriate crop table to obtain the nitrogen recommendation for the selected Index. The SNS Index system used for arable crops, such as cereals and oilseeds **(Section 4: Arable crops)**, is not applicable for established grassland, field vegetables or established fruit crops.

Full details of the SNS Index system and how to use it (with examples) are given in Sections 3–6.

Field Assessment Method

In most situations the SNS Index will be identified using the Field Assessment Method, which is based on field specific information for previous cropping, previous fertiliser and manure use, soil type and winter rainfall. The SNS Index is read from tables and there is no requirement for soil sampling or analysis.

This method usually provides a satisfactory assessment of the SNS in typical arable rotations but the Measurement Method may give a better result where the SNS is uncertain or could be above 120 kg N/ha.

Measurement Method

SNS is related to the cumulative effects of farming practice over several years and can be difficult to predict in some circumstances.

The Measurement Method should be targeted to fields where the supply of plant-available nitrogen in the soil could be unusually large (for example above 120 kg N/ha in arable rotations), particularly where organic manures have been used regularly in recent years.

The crop nitrogen content of cereals and oilseed rape at the time of SMN sampling can be estimated using the scheme given in **Section 4: Arable crops**. No similar scheme is available for estimating the nitrogen content of other crops at this time of year.

It is much more difficult to obtain a reliable estimate of the nitrogen that will be made available from mineralisation of organic matter. On many mineral soils with 4% or less soil organic matter, this will be relatively small and no further adjustment is needed. On organic and peaty soils, or where a large amount of organic material (crop residues or organic manure) has been applied in recent years, large quantities of nitrogen can be mineralised.

Nitrogen uptake efficiency by crops

The efficiency of uptake of nitrogen from different sources varies, even for well-grown crops. Provided that the total SNS does not exceed demand, where the amount of SMN present within normal rooting depth is in the range 50–100 kg N/ha, on average, crops will take up an amount of soil nitrogen that is roughly equivalent, ie SMN is used with apparently 100% efficiency.

The efficiency with which SMN is recovered is likely to be less than 100% (and might typically be closer to 60%). This should be compensated for by additional soil nitrogen that becomes available for uptake during the growing season, mainly through mineralisation of crop residues and soil organic matter. However, for individual situations, actual efficiency of SMN use and the supply of mineralised N are likely to vary.

SNS estimates of less than 50 kg N/ha should be treated as 50 and no less. Unless high SNS results (>160 kg N/ha) are confidently expected due to the regular addition of organic manures or crop residues, they should be treated with caution.

The efficiency with which SMN is recovered is likely to be lower where a large amount is present, especially in the autumn below topsoil depth, on sandy soils or in high rainfall situations where nitrate leaching losses will be greater. Early establishment of crops may help to reduce losses and increase the uptake of SMN.

The application of amounts of nitrogen in line with crop requirement does not appear to decrease the uptake of soil nitrogen. However, the efficiency of uptake of both fertiliser and soil-derived nitrogen is often reduced for crops suffering from the adverse effects of disease, poor soil conditions, drought or other growth inhibiting problems.

Research has shown that the uptake efficiency of fertiliser nitrogen by winter wheat and winter barley varies depending on the soil type. The values shown below are largely based on work with ammonium nitrate and values for other types of nitrogen fertiliser may be different in some circumstances. For example, on light sand soils, 70 kg N/ha is taken up by the crop for every 100 kg N/ha applied as fertiliser.

Table 1.3 Uptake efficiency of fertiliser nitrogen depending on the soil type

Soil type	Uptake efficiency %
Light sand soils	70
Medium, clay, silty, organic and peaty soils	60
Shallow soils over chalk and limestone	55

The winter wheat and winter barley recommendations in this guide are adjusted to take account of these differences in nitrogen fertiliser uptake efficiency due to soil type.

Timing of nitrogen applications

Correct timing of nitrogen fertiliser application is important so that crops make best use of the nitrogen applied and there is minimum risk of losses and adverse environmental impact. As a general principle, nitrogen should be applied at the start of periods of rapid crop growth and nitrogen uptake.

The timing of nitrogen application can also have a range of other important effects on crop growth and quality.

- Too much seedbed nitrogen can reduce the establishment of small seeded crops
- Early spring nitrogen will increase tillering of cereals. This may be beneficial, but too much nitrogen at this stage can increase the risk of lodging and reduce the potential bushel weight
- Late applied nitrogen will increase the grain nitrogen/protein concentration of cereals

Recommended nitrogen timings for individual crops are given in the recommendation tables. However, NVZ rules relating to closed periods take priority and may also influence timing of nitrogen applications.

Figure 1.3 shows the typical pattern of nitrogen uptake by a winter wheat crop. It is easy to see why there is no benefit from applying autumn nitrogen to winter cereal crops. The nitrogen requirement is small during the autumn and winter and the supply from soil reserves is adequate to meet the requirement. However, autumn nitrogen is recommended for establishment of some winter oilseed rape crops, reflecting the larger requirement for nitrogen of this crop in autumn.

Figure 1.3 shows:

- **In autumn/winter (A), there is only a small crop nitrogen requirement that can easily be met by soil nitrogen reserves. There is no need to apply nitrogen in autumn**
- **The main period of nitrogen uptake (B) is March–June and during this growth period, there is usually insufficient soil nitrogen to support unrestricted growth. Nitrogen fertiliser should be applied at the start and during this period of growth**

Further information
Tried & Tested
www.nutrientmanagement.org

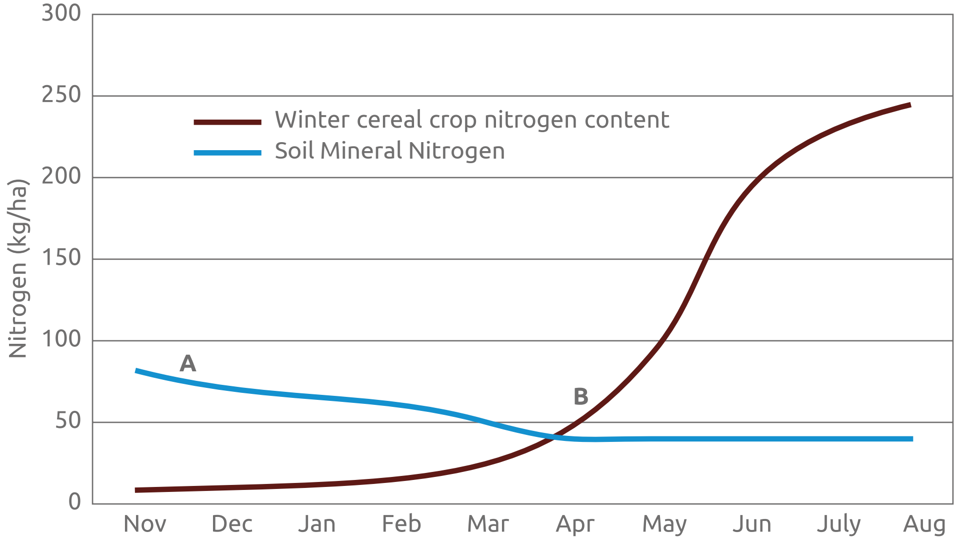

Figure 1.3 Nitrogen uptake by a winter cereal crop in relation to available soil nitrogen

The effect of economic changes

As a general principle, the recommendations are insensitive to changes in the value of the crop produce or the cost of nitrogen fertiliser. It would normally require a large change in the ratio of the value of a crop and the cost of nitrogen fertiliser to alter the recommendation.

The breakeven ratio is the crop yield (kg) needed to pay for 1 kg of nitrogen. If there are large changes in the ratio (the breakeven ratio) it will be appropriate to make adjustments in the recommendations.

$$\text{Breakeven ratio} = \frac{\text{Cost of nitrogen (pence/kg)}}{\text{Value of crop produce (pence/kg)}}$$

The prices can be expressed in £/kg as long as both are in the same units (p/kg or £/kg). The nitrogen recommendation tables for wheat, barley and oilseed rape **(Section 4: Arable crops)** show how to calculate adjustments to take account of the cost of nitrogen and the selling price of the grain produced.

Example 1.2

Ammonium nitrate (34.5% N) costs £230/t or $\frac{230 \times 100}{34.5 \times 10}$ = 67p/kg N

Wheat is sold for £110/t or $\frac{110 \times 100}{1000}$ = 11 pence/kg

The breakeven ratio is 67 ÷ 11 = 6

Further information
AHDB UK Fertiliser Price Series
www.ahdb.org.uk/fertiliser-information

Alternative approaches to nitrogen decisions

There is ongoing research into new approaches and techniques for deciding on nitrogen fertiliser use. The use of spectral reflectance sensors is one example that is increasingly being used to assess nitrogen requirement in the field. Other fertiliser nitrogen recommendation systems are based on models of crop growth and nitrogen uptake or on soil sampling to shallower depths than 90 cm. Some include a measurement of mineralisable nitrogen in a soil sample.

Provided a recommendation system takes proper account of the total amount of nitrogen needed by a crop and of the supplies available from the soil and organic manures, it should give a recommendation close to crop nitrogen requirement.

Phosphate, potash and magnesium for field crops

Phosphate, potash and magnesium applied in fertilisers and manures move slowly through the soil. Many soils can hold large quantities of these nutrients in forms that are readily available for crop uptake. Consequently, managing the supply of these nutrients for optimum yield is based on maintaining appropriate amounts in the soil for the needs of the rotation, rather than on those of an individual crop. In practice, this means maintaining target soil Indices that ensure optimal phosphate, potash and magnesium nutrition.

As the amount of crop-available phosphate or potash in the soil increases from a very low level, crop yield increases, rapidly at first then more slowly until it reaches a maximum. Typically, maximum yield of arable crops or grass is reached at Index 2 for phosphorus and Index 2- for potassium.

The principle for phosphate and potash management is to maintain the soil at the appropriate target Index. If the Index is lower than the target, yield may be reduced and additional phosphate and potash should be applied. If the Index is higher than the target, applications can be reduced or omitted until the soil level falls to the target Index.

Effective use of target Indices depends on representative soil sampling. If it is felt that significant areas of the field could differ in P or K Index, these areas should be sampled and treated separately.

To maintain soils at the correct Index it is usually sufficient to replace the amount of each nutrient expected to be removed from the field in the harvested crop. This amount can be calculated from the estimated yield (including straw where removal is planned) and an average concentration of the nutrient in the harvested product(s) as shown in Sections 3–6.

To check that this approach is maintaining the required P or K Index (ie the phosphate and potash status of the soil), soil sampling should be carried out every 3–5 years, at a suitable time in the crop rotation. Maintaining the appropriate level of phosphate and potash in the soil is especially important, as once a deficiency has occurred, a fresh application of phosphate and potash is unlikely to be available for uptake by roots in time to benefit the crop being grown.

Managing soil phosphate, potash and magnesium supply

An appropriate approach for managing phosphate, potash and magnesium to maintain soil fertility must take account of:

- The current soil Index in the field
- The target Index or critical level of each nutrient for the rotation
- The need to build up, maintain or run down the soil Index
- The responsiveness of a crop to a fresh application of each nutrient
- The quantity of each nutrient removed from the field in crop produce
- The quantity of nutrients supplied from any organic material that is available for application **(Section 2: Organic materials)**

Recommendations for phosphate and potash applications to build up soils and maintenance applications are given in Sections 3–7. The recommendations in this guide are given as kg/ha of P_2O_5, K_2O and MgO. This is because the concentrations of phosphorus and potassium are expressed in this way in fertilisers and this makes it easier to calculate the amount of fertiliser to apply.

Soil sampling and analysis

Good management of soil phosphate, potash and magnesium depends on soil sampling and analysis. Levels of these nutrients in the soil change only slowly so soil sampling and analysis can be done every 3–5 years at an appropriate time in the crop rotation. It is usually safe to use soil analysis results for phosphorus, potassium and magnesium as a basis for fertiliser recommendations for up to four years from the date of sampling.

In variable fields, GPS sampling soils for P, K and Mg, combined with variable rate nutrient application, can be cost-effective. Identifying major soil types and yield variation in the field is a key step in establishing the need for GPS sampling.

The analytical results will only be meaningful if an adequate, representative soil sample is taken. The recommended procedure for sampling soils is described in Sections 3–7.

For advisory purposes, the results are usually given as milligrammes of phosphorus, potassium and magnesium per litre of soil (mg P/litre, mg K/litre, and mg Mg/litre). The results are also given as an Index and the Indices range from 0 to 9.

The Index system is based on the likely response of a crop to a fresh application of the nutrient. Index 0 soils are deficient and there would be an increase in yield by applying phosphate or potash. As the Index number increases the response to a fresh application of fertiliser declines and for most soils growing arable crops there would be no or only a very small response at Index 2.

The fertiliser recommendations given in this guide are based on the results of soil analysis using the following standard laboratory methods. These methods, which are well-tried and tested over many years, are appropriate for soils in England and Wales.

Table 1.4 Method of extraction for phosphorus, potassium and magnesium

Element	Method of extraction
Phosphorus (P)	Measured in a sodium bicarbonate soil extract at pH 8.5 (Olsen P)
Potassium (K) and magnesium (Mg)	Measured in an ammonium nitrate soil extract (exchangeable K and exchangeable Mg)

Leaf analysis

Leaf analysis can be used to indicate whether the P or K concentrations in a plant are at, or below, optimum levels at a particular point in time. It is not useful as a predictor of potential nutrient uptake by a crop, or a crop's nutrient requirement over a season. Tissue analysis is therefore best used to complement, and not replace, soil analysis.

To provide meaningful information, testing should be carried out at a defined growth stage and on a specific part of the plant. For example, for winter wheat, testing is best carried out on the newest fully expanded leaf blade during stem extension (between GS31 and GS39). At such times, diagnostic sampling in good and bad parts of a crop can be a useful method to determine whether there is a nutrient deficiency.

Laboratories typically analyse plant tissue for P and K by measuring their concentrations in the dry matter. Nutrient concentrations can vary with season, growth stage, fertiliser application, weather or other factors that affect nutrient uptake and rate of growth. P and K concentrations can also be measured in the leaf tissue water (cell sap) on-farm using appropriate equipment, but these are prone to short-term fluctuations and may be less useful.

Potash-releasing clay soils

Depending on the nature of the minerals in the parent material from which they were developed, some heavy clay soils contain large quantities of potash. Weathering (breakdown) of these minerals releases the potash, which gradually becomes available for crop uptake.

Unfortunately, no routine soil analysis method is available to estimate the amount or rate of release of this potash. However, the potash that is released goes to the readily crop-available pool measured by soil analysis so that this value does not decline as quickly if the amount of potash applied is less than that removed in the harvested crops.

Local knowledge and past experience can be useful when assessing the potash release characteristics of clay soils. If the crop-available potash status of a clay soil changes little when the potash balance is consistently negative over a number of years, this is a useful indicator that potash is being released from the clay by weathering.

As a rough guide, potash-releasing clay soils could release around 50 kg K_2O/ha each year in a crop-available form. Remember that the annual rate of potash release may not be sufficient to meet the requirement of crops with a large yield potential, which require large amounts of potash.

It is essential to monitor crop yields to ensure that the yield potential of the site is being reached; if this is not the case then potash fertilisers should be applied. Where the soil K level is allowed to fall below the target Index, the quantity of potash required (over and above offtake) to raise the level in the soil may be greater for potash-releasing clays than for other clay soils. This is because part of the potash applied may be used to replace that previously released from the clay minerals. A rough classification of clays based on their likely potash release characteristics is given below.

Potash-releasing clays

- Chalky boulder clay
- Gault clay
- Weald clay
- Kimmeridge clay
- Oxford clay
- Lias clay

Clays which do not release much potash

- Carboniferous clay

Target soil Indices

The readily crop-available pool of these nutrients is measured by the laboratory methods given on page 26. The critical value for all three nutrients is related to a target Index. Fertiliser and material applications should aim to raise the Index to the appropriate target for the rotation and then to maintain this target by maintenance applications.

Table 1.5 Target soil Indices for soil P and K

	Soil P	Soil K
Arable, grassland and forage crops	Index 2 (16–25 mg/litre)	Index 2- (121–180 mg/litre)
Vegetables[a]	Index 3 (26–45 mg/litre)	Index 2+ (181–240 mg/litre)

a. If vegetables are only grown occasionally as part of an arable rotation, use the target Indices for arable and forage crops.

The amount of applied P required (over and above offtake) to raise soil P levels will vary according to soil type. On calcareous soils (with free calcium carbonate), it may not be possible to maintain Olsen P at the target Index due to the rapid P reversion processes. In these situations, it may be more appropriate to maintain soils at P Index 1 and apply fresh P fertiliser on an annual basis to achieve the yields expected at P Index 2.

Where crops are grown on soils at P Index 1, in some circumstances, it may be possible to raise yields to the level achieved at Index 2 by applying phosphate fertiliser at higher than recommended rates. However, this is not possible at P Index 0.

Optimal yields are most likely to be achieved on soils that are well structured and enable good rooting.

Maintaining the soil Index

The amount of phosphate and potash required for maintenance, in kg P_2O_5/ha and kg K_2O/ha, can be calculated from the targeted yield of the crop that is to be removed from the field and its nutrient content. Typical values for the content of phosphate and potash in crops are given in Sections 3–6.

For cereals, offtake in grain plus straw (where removed) can be determined from an estimate of grain yield alone. Where that applies, recommendations in this guide assume that, on average, straw yield is 50% of grain yield. However, straw yields can vary substantially and may be higher or lower than 50% of grain yield.

The phosphate and potash recommendations in this guide for arable crops grown on Index 2 soils are based on typical yields as indicated in the individual crop recommendations (for example, 8 t/ha for winter wheat). For cereals and oilseeds, where targeted yield is significantly greater or less than typical, the amounts of phosphate and potash likely to be removed by the crop should be calculated as shown in Example 1.4. This amount should be used as the maintenance application at the target Index.

For potatoes, only potash should be adjusted in this way. The amount of phosphate removed by potatoes is usually much less than the amount applied. The residue from this surplus application should be taken into account for the following crop.

If replacing the phosphate and potash removed in the harvested crop does not maintain the appropriate Index, it is because there is a slow transfer of phosphate and potash into a less readily available pool. For this reason it is important to sample and analyse the soil every 3–5 years to check that the target Index is being maintained.

No replacement application is shown for magnesium for a number of reasons. The amounts of magnesium removed in a harvested crop tend to be small, perhaps 10–15 kg MgO/ha and it appears that this amount of magnesium can be released during the weathering of clay minerals in many soils.

Consequently, the amount of exchangeable magnesium in soil tends to change slowly. Rather than an annual replacement, it is better to monitor change in exchangeable magnesium and apply fertiliser when the soil declines to Mg Index 1, especially to sensitive crops like sugar beet and some vegetable crops.

Building up or running down soil Indices

To raise the level of a soil at Index 0 and 1 to Index 2 requires the application of more fertiliser than that needed for the maintenance dressing. The amount of extra fertiliser needed each time is determined by the number of years over which the Index is to be raised (Table 1.6). Raising Indices over a shorter period of time minimises the period of yield loss, but in the short term will increase the annual cost and risk of water pollution.

Large amounts of phosphate and potash may be required to raise the crop-available phosphate and potash in the soil by one Index and it is difficult to give accurate amounts. However, as an example, 400 kg P_2O_5/ha as a phosphate fertiliser (ie 850 kg/ha of triple superphosphate) may be needed to increase soil phosphate by 10 mg P/litre. To increase soil potash by 50 mg K/l, 300–500 kg K_2O/ha as a potash fertiliser (ie 500–800 kg/ha of muriate of potash) may be required.

The amount to apply at each dressing is a business decision that depends on how quickly the land manager aims to increase the asset value of the land. Consequently, two sets of build-up application rates are shown in Table 1.6 with the approximate time over which Index 2 can be reached. These amounts have been calculated using the mid-point values for each initial Index (as mg/l) compared to the mid-point value of the target Index.

Further information

Potash Development Association PK calculator

www.pda.org.uk/calculator/pkcalculator

Table 1.6 Adjusting applications for soil Index

Period over which to adjust soil index	Current P or K Index		
	0	1	2 or higher
	Adjustment to application (kg/ha)		
10–15 years	+60	+30	No phosphate or potash required
5–10 years	+100	+50	

In some situations (eg phosphate for potatoes), the crop is likely to respond to larger amounts of nutrients than would be recommended using the above adjustments. The recommendations given in Sections 3 to 7 are the higher of:

- **The rate of nutrient required for maximum crop response**
- **The rate of nutrient based on the maintenance dressing plus the amount suggested in Table 1.6 to increase the soil Index in 10–15 years**

Where a rapid increase in the soil Index level is required, larger amounts of fertiliser may be applied but they should be ploughed-in and well mixed with the soil by cultivation. In this situation, frequent soil analysis is recommended to ensure that the desired Index level is not exceeded.

Where the soil Index is well above the target level, not applying fertiliser will allow for a gradual decline to the target level. For many arable crops and grassland it could be appropriate not to apply any fertiliser unless the crop responds to a small amount placed near the seed.

If plant-available phosphate and potash are being run down then it is essential to follow the decline by regular soil analysis to ensure that the level does not fall below the appropriate target Index.

Example 1.4

Adjusting the application of phosphate and potash to a winter wheat crop according to the soil Index and expected yield. Regular soil analysis is essential to ensure the Index does not fall below the target.

Offtake						Application to replace offtake (to nearest 5 kg/ha)	
Grain yield (t/ha)	P_2O_5 (kg/ha)	K_2O (kg/ha)	Straw yield (t/ha)[a]	P_2O_5 (kg/ha)	K_2O (kg/ha)	P_2O_5 (kg/ha)	K_2O (kg/ha)
6	47	34	3	4	29	50	65
8	62	45	4	5	38	65	85
10	78	56	5	6	48	85	105
12	94	67	6	7	57	100	125

a. Standard recommendations assume straw yield will be 50% of grain yield.

Building up crop-available levels of phosphate and potash in soil or letting them decline, is a decision for the farmer to make. However, the following should be considered:

- **Experimental evidence shows that applying the maintenance dressing of phosphate and potash fertilisers to soils at Index 0 and 1, even with the suggested addition for build-up, will rarely increase the yield of many arable crops to that achieved on Index 2 soils given the maintenance dressing alone**
- **Continuing to apply phosphate and potash as fertilisers or manures to soils at P and K Index 3 and above is an unnecessary expense**

Soil P Index and loss of phosphate from soil

Particular care should be taken to avoid building up crop-available phosphate above the target Index. Recent research has shown that there is an increased risk of phosphate transfer from soil to surface water when soils are at P Index 3 and above. Much of this transfer is due to phosphate being attached to eroded soil.

To reduce the risk of phosphate transfer, every effort should be made to minimise the chance of soil erosion and prevent the unnecessary build-up of available soil phosphate. Phosphate transferred from soil to surface fresh water bodies may cause algal blooms and other adverse effects on the biological balance in the water.

Potash use in sandy and sandy loam soils

Sandy and sandy loam soils together with other soils containing very little clay, have a limited capacity to hold potash. On such soils it is almost impossible to achieve the target soil K Indices of 2- (for arable, grass and forage crops) or 2+ (for vegetables).

For sandy loams it is generally possible to maintain soil at 150 mg K/l (Index 2-) but for sands and loamy sands, the realistic upper limit is 100 mg K/l (upper Index 1). Adding potash fertilisers to try to exceed these values will result in movement of potash into the subsoil where it may only be available to deep-rooted crops.

On sands, it is preferable to apply and cultivate into the topsoil an amount of potash fertiliser each year to meet the potash requirements of the crop to be grown. Note that this may be higher than the expected offtake at harvest.

Responsive situations
Some field vegetables and forage maize may respond to fresh applications of phosphate, even where the soil P Index is at or slightly above the target Index level for the rotation. For these crops, special methods of application, such as placement or band spreading, may be recommended.

For some crops, particularly small seeded vegetables, starter applications of phosphate placed close to the seed improve early germination and establishment, even on soils at P Index 3 and above. On soils at P Index 2 and above, the amount of phosphate applied as a starter dose, together with the amount added in the base dressing should not exceed the amount of phosphate required to replace that removed by the previous crop.

Points to consider

- There is a serious risk of damage to germinating seedlings if base fertiliser formulations containing potash salts are used as starter fertilisers. For further information consult a FACTS Qualified Adviser

Magnesium

Soil analysis gives the quantity of readily available magnesium in mg Mg/l of soil, along with an Index. The analysis is done on the same soil extract as that used to determine potassium.

Potatoes and sugar beet are susceptible to magnesium deficiency and may show yield responses to magnesium fertiliser on soils at Mg Index 0 and 1. Other arable crops may show deficiency symptoms at soil Mg Index 0 but seldom give a yield response to applications of magnesium.

Deficiency symptoms often occur early in the growing season when root growth is restricted, for example, by soil compaction or excessive soil moisture, but they disappear as the roots grow and explore the soil for nutrients.

Soil should be sampled and tested regularly, every 3–5 years. For soils at Mg Index 0, 50–100 kg MgO/ha can be applied every three or four years.

Where the Mg Index is low and soil acidity needs to be corrected, applying magnesian limestone may be cost-effective. An application of 5 t/ha of magnesian limestone will add at least 750 kg MgO/ha and this magnesium will become available to the crop over many years. However, if used too frequently, the soil Mg Index can exceed 3, which can have implications for potash deficiency if available potassium is not supplied in adequate quantities.

Further information
Conversion calculators
cereals.ahdb.org.uk/tools/agronomy-calculators

Sulphur

Sulphur is a major plant nutrient. Plants need about the same amount of sulphur as phosphorus.

In the past, large amounts of sulphur were released into the atmosphere from industrial processes and this was deposited on land. However, atmospheric deposition has declined greatly in recent decades and the majority of crops grown in the UK can no longer be expected to obtain much of their sulphur requirements from sulphur deposition.

Sulphur is important because:

- **Yield can be reduced when sulphur is deficient but visual symptoms are absent**
- **Nitrogen fertiliser may not be fully utilised if sulphur is deficient**
- **Correct sulphur fertilisation improves quality of grains and oilseeds**
- **Sulphur application is currently very cost-effective and is not associated with any major environmental problems**

Points to consider

- **Although roots take up sulphur as sulphate (SO_4), recommended rates and the content of fertilisers and organic material are expressed as either SO_3 or sulphur.**

Sulphur deficiency

There is an increasing risk of sulphur deficiency in the UK in a wide range of crops including cereals, oilseed rape, Brassica vegetables, peas and grass. Oilseed rape and grass grown for silage are particularly sensitive to sulphur deficiency.

Most soils, especially chalky or sandy soils, store very little sulphate from one year to the next. This is because sulphate is water soluble and easily leached.

As atmospheric deposition of sulphur continues to decline, it is likely that the risk of deficiency will affect an increasingly wide range of crops grown on many different soil types.

The best guide for assessing the risk of sulphur deficiency is soil type and field location, although fields that have received regular applications of organic manure are less likely to show deficiency.

Sulphur is retained in soil organic matter and can become available to plants when organic matter is decomposed by soil microbes. On mineral soils, sulphur should be applied to all winter oilseed rape crops and to all cereal, grass, grain legume, Brassica vegetable and sugar beet crops grown in high risk sulphur deficiency situations (Table 1.7).

Where sulphur deficiency has been diagnosed or is expected, it can be corrected by applying a manufactured sulphur fertiliser and/or livestock manure or biosolids (Section 2: Organic materials). As most soils store very little sulphur from one year to the next, applications of sulphur will be necessary year after year for the susceptible crop.

Sulphur in livestock manures and biosolids is available in two main forms:

- **Readily available sulphur, which can be taken up immediately by the crop**
- **Organic sulphur, which is not immediately available for crop uptake but may be mineralised to readily available sulphur over subsequent months and years**

Readily available sulphur + organic sulphur = Total sulphur

When planning the use of nutrients, it is important to make allowance for those contained in organic materials. Use Table 2.1 (Section 2: Organic materials) to determine sulphur availability from different organic materials.

Diagnostic methods

Visual symptoms such as paling of young leaves and crop stunting can be used to diagnose moderate to severe cases of sulphur deficiency. However, these symptoms can be easily confused with other nutrient deficiencies or crop stress and, by the time they appear, it can be too late to correct the deficiency. It is likely to be difficult to identify the slight visual symptoms normally associated with minor sulphur deficiency that may still result in significant yield loss.

If a deficiency is suspected, tissue analysis in the spring can be a useful diagnostic tool used in combination with the sulphur deficiency risk matrix, based on soil type and over-winter rainfall (Table 1.7).

The procedures for plant sampling and interpretation of analytical results are given with each crop recommendation table.

Table 1.7. Sulphur deficiency risk categories

<table>
<tr><th rowspan="2">Soil type</th><th colspan="3">Winter rainfall (Nov–Feb)</th></tr>
<tr><th>Low
(<175 mm)</th><th>Medium
(175–375 mm)</th><th>High
(>375 mm)</th></tr>
<tr><td>Light sand and shallow</td><td colspan="3">High</td></tr>
<tr><td>Medium</td><td>Low</td><td colspan="2">High</td></tr>
<tr><td>Deep clayey, deep silty, organic and peaty</td><td colspan="2">Low</td><td>High</td></tr>
</table>

Sodium

Sodium is recommended for certain crops (eg sugar beet and carrots). Soil analysis can be used to identify the need to apply sodium for sugar beet.

If a deficiency is suspected, ensure that an analysis package is chosen that includes sodium.

The interpretation of soil analysis results is given in the crop recommendation tables. At recommended rates, sodium should have no adverse effect on the physical condition of soils.

In grassland systems, it is important to maintain an adequate amount of sodium in livestock diets. Sodium application will not have any effect on grass growth but has been reported to improve the palatability of grass.

Micronutrients (trace elements)

Micronutrients are those crop nutrients required in small amounts for essential growth processes in plants and animals. Some micronutrients that are essential for animals are not required by plants but the animal usually acquires them via the plant.

In practice, only a few micronutrients are known to be present in such small amounts in soil that there is a risk of deficiency in plants and animals. Deficiency is most frequently related to soil type, soil pH, soil structural conditions and their effect on root growth and crop susceptibility.

For continuous arable cropping on mineral soils, the maximum availability of nutrients from the soil is achieved at pH 6.5. To maintain an appropriate pH, test soils every 3–5 years and treat acidic soils with a liming material.

Visual symptoms of a deficiency of a specific micronutrient are often short-lived and can be confused with those produced by other growth problems. Furthermore, by the time symptoms appear, it can be too late to correct a deficiency.

Consequently, decisions about when to apply micronutrients should be informed by crop and soil risk factors (Sections 3–7) and visual diagnosis of a micronutrient deficiency should, where appropriate, be confirmed by plant and/or soil analysis.

Soil analysis for micronutrient deficiencies may be done on the same samples taken every 3–5 years for routine analysis of P, K, Mg and pH. If a deficiency is suspected, ensure that an analysis package is chosen that includes the micronutrients in question.

If a deficiency is suspected, leaf analysis in the spring can be a useful diagnostic tool. If leaf analysis indicates a deficiency, it is still important to take soil samples after harvest as leaf analysis only provides an indication of the nutrient status of the crop at the time the sample was taken. The soil may contain adequate amounts of the nutrient and the deficiency may simply have been caused by reduced availability, due to adverse weather conditions or inappropriate pH.

Deficiencies affecting crop growth

Boron (B) – Deficiency can affect sugar beet, Brassica crops and carrots on light textured soils with a pH above 6.5, particularly in dry seasons. Symptoms include death of the apical growing point and growth of lateral buds. In sugar beet, there is blackening at the leaf base and beneath the crown ('heart-rot'). Carrots can show a darkening of the root surface ('shadow').

Soil analysis prior to growing a susceptible crop is recommended. When extracted with hot water, a value less than 0.8 mg B/l dry soil is associated with a risk of deficiency. Leaf analysis is also a useful diagnostic guide and a value lower than 20 mg B/kg dry matter may indicate deficiency (although the deficiency value varies between crop species).

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Copper (Cu) – Deficiency is not widespread in crops but can occur mainly in cereals on sands, peats, reclaimed heathland and shallow soils over chalk. Sugar beet may also be affected.

In cereals, symptoms are yellowing of the tip of the youngest leaf followed by spiralling and distortion of the leaf. Ears can be trapped in the leaf sheath and those that emerge have white tips. Barley awns can become white. Soil analysis is useful for identifying whether deficiency is likely.

When extracted with EDTA, a value lower than 1 mg Cu/l dry soil indicates possible deficiency. The copper content of the leaf does not reliably indicate the copper status of the plant.

Iron (Fe) – Deficiency occurs commonly in fruit crops grown on calcareous soils but is not a problem in annual field crops. Symptoms in fruit are yellowing of the young leaves with veins remaining green. Deficiency cannot be reliably diagnosed using soil or plant analysis.

Manganese (Mn) – Manganese is the micronutrient most commonly deficient in field crops. Deficiency occurs in many crops on peaty, organic and sandy soils at high pH but can occur less severely on other soils when over-limed.

Susceptible crops include sugar beet, cereals and peas. In cereals, deficiency often shows as patches of pale green, limp foliage. Sugar beet leaves develop interveinal mottling and leaf margins curl inwards. Dried peas show internal discolouration when the pea is split (‘marsh spot’). Leaf analysis provides a reliable means of diagnosis with a value lower than 20 mg/kg dry matter indicating possible deficiency. Soil analysis is not a reliable guide to deficiency.

Molybdenum (Mo) – Deficiency is associated with acid soils and is not generally a problem in limed soils. Cauliflower may be affected and symptoms include restricted growth of the leaf lamina (‘whiptail’).

Soil or plant tissue analyses may be used to diagnose molybdenum deficiency. Soil analysis is usually by extraction with acid ammonium oxalate (‘Tamms reagent’). The leaf and curd content in dry material is around 2.0 mg Mo/kg in normal cauliflower plants and around 0.35 mg Mo/kg in deficient plants.

Zinc (Zn) – Deficiency is rarely found in field crops. In the few cases where deficiency has been found, it has been on sandy soils, with a high pH and phosphate status. Top fruit and forest nursery stock are most likely to be affected.

Leaf analysis is the most useful diagnostic guide and, in susceptible crops, less than 15 mg Zn/kg dry matter may indicate deficiency. Soil analysis is usually by EDTA extraction; for susceptible crops, a value less than 0.5 mg Zn/kg indicates a risk of probable deficiency while less than 1.50 mg Zn/kg indicates possible deficiency.

Deficiencies affecting livestock performance

The availability of cobalt, copper and selenium does not restrict grass growth but too little in grazed crops can lead to deficiency in some animals. Where a deficiency has been correctly diagnosed, treatment of the animal with the appropriate trace element is usually the most effective means of control, though application of selenium and cobalt to grazing pastures can be effective.

Further information
Trace Element Supplementation of Beef Cattle and Sheep
beefandlamb.ahdb.org.uk/returns/nutrition-and-forage

Fertiliser types and quality

It is important to select the most appropriate and cost-effective material from the many different types of fertiliser that are available in both solid and fluid forms. The following features of a fertiliser should be considered:

- The total concentration and the ratio of nutrients in the fertiliser
- The chemical form of each nutrient
- The physical quality of a solid fertiliser and its suitability for accurate spreading
- The form of a liquid fertiliser, true solution or suspension
- The cost of the nutrients

The total concentration and the ratio of nutrients in the fertiliser
The total concentration of each nutrient in a fertiliser has to be declared. Straight fertilisers contain just one nutrient, whereas many fertilisers contain more than one. The requirements for nutrient declaration, including the chemical form of each nutrient and its availability for crop uptake, are controlled by national legislation originally transposed from European regulations. The nutrient content of some common fertilisers is given on page 39.

The concentration of nutrients in fluid fertilisers may be expressed as kg nutrient per tonne of fertiliser product (w/w basis) or as kg nutrient per cubic metre (1,000 litres) of fertiliser product (w/v basis). To convert from one basis to the other, it is necessary to know the specific gravity of the fertiliser. The fertiliser supplier can provide this information.

Concentration as w/v (kg/m^3) = concentration as w/w (kg/t) x specific gravity

The concentration of the nutrient or nutrients in a fertiliser dictates the application rate. When there is more than one nutrient, the ratio should be reasonably close to the required application of each nutrient.

Physical nature, quality and suitability of fertiliser
Fertilisers may be sold in many different physical forms, some of which may be difficult to apply accurately. Good fertiliser practice must include accurate, uniform application as well as correct decisions on rate and timing.

Inaccurate application of fertiliser will result in uneven crops with lower than expected yields and the quality may be poor. Over application may result in adverse environmental impact from pollution.

When spreading, it is important that the particle size of a solid fertiliser is consistent, free of lumps and low in dust, while the components of a fluid fertiliser should remain as a uniform solution or suspension.

The cost of the nutrients
The cost of the nutrients in fertilisers can vary significantly. When comparing fertiliser prices it is necessary to calculate and compare the cost of each kg of nutrient. It is cost per hectare, not cost per tonne, which determines the economics of a fertiliser application.

Low-cost fertilisers can have a poor chemical or physical quality. The availability of the nutrients for crop uptake must be considered as well as the accuracy of the fertiliser spreader or sprayer that is used.

Nitrogen fertilisers

Ammonium nitrate (33.5–34.5% N) Ammonium sulphate (21% N, 60% SO_3) Calcium ammonium nitrate (26–28% N)	Urea (46% N)	Liquid nitrogen (18–30% N)
The nitrate-N is immediately available for crop uptake, the ammonium-N can be taken up directly but is quickly converted to nitrate by soil microbes.	Urea is quickly converted to plant-available ammonium-N by the enzyme urease which occurs in all soils.	Liquid nitrogen fertilisers are solutions of urea and ammonium nitrate. The nitrogen is in forms that are quickly available for crop uptake. Solutions based on urea alone will contain no more than 18% N because at low ambient temperatures, urea crystallises out of solution.

The nitrogen content of applied urea lost to the atmosphere as ammonia varies depending on soil and weather conditions and is typically 10 to 30%. Losses may be minimised if urea is applied shortly before rain is expected and/or is shallowly cultivated into the soil.

Recommended nitrogen rates are based on the main nitrogen source being ammonium nitrate, ammonium sulphate or calcium ammonium nitrate. Urea can be treated with urease inhibitors to reduce losses through volatilisation.

If untreated urea is to be used, recommended rates may need to be adjusted to allow for losses as ammonia. It is unlikely that this adjustment will be necessary if urea is treated with a urease inhibitor. For complete agronomic advice on product choice and guidelines for use, consult a FACTS Qualified Adviser.

Nitrification inhibitors can slow the conversion of ammonium-N to nitrate-N. They can be added to liquid fertilisers prior to application or sprayed onto soil prior to spreading solid fertilisers. Nitrification inhibitors can delay the release of nitrate following fertiliser application which can reduce nitrate leaching and nitrous oxide emissions.

Water-soluble phosphate	Water-insoluble phosphate
Diammonium phosphate (DAP), monoammonium phosphate (MAP), triple superphosphate (TSP) and single superphosphate (SSP) contain phosphate that is mainly in a water-soluble form (93–95%).	There are many different types of water-insoluble phosphate with different chemical and physical characteristics. The fertiliser declaration should give details of the amount of phosphate soluble in different acid extractants. This information does not indicate the effectiveness of these sources of phosphate on different soil types. Care should be taken not to compare the solubility of water-insoluble phosphates in different reagents (for example, formic acid and citric acid) that extract different forms of phosphate.

Phosphate fertilisers

Lack of water-solubility does not mean the phosphate is unavailable to crops. For example, finely ground, phosphate rocks with close to zero water-solubility, can be used successfully as a phosphate source on grassland where the surface soil pH is maintained below pH 6.0. Some other water-insoluble phosphates are an effective source of phosphate under appropriate soil and weather conditions; in these situations seek advice from a FACTS Qualified Adviser about their use.

Potash and magnesium fertilisers

Potash in most potash fertilisers is quickly available to crops. The most common potash source is muriate of potash (MOP) which is potassium chloride (60% K_2O). Kainit and sylvinite are naturally-occurring mixtures of mainly potassium chloride and sodium chloride.

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Potassium sulphate (SOP, 50% K_2O) is used for some high-value crops. Potassium nitrate supplies both potassium and nitrogen and is used as a source of both nutrients when added to irrigation systems.

Some magnesium fertilisers are quickly available (eg kieserite, typically 25% MgO; and Epsom salts, 16% MgO) though others are only slowly available (eg calcined magnesite and magnesian limestone).

Where both lime and magnesium are needed, magnesian limestone will often provide a cheap, though slow acting, source of magnesium. An application of 5 t/ha of magnesian limestone will provide at least 750 kg MgO/ha and the magnesium becomes slowly available to crops over time.

Sulphur fertilisers

Ammonium sulphate (60% SO_3) and kieserite (typically 52–55% SO_3) provide sulphur in an immediately available form. Gypsum (calcium sulphate) is somewhat less soluble but is an effective source. Polyhalite is principally a sulphur fertiliser that contains 48% SO_3, 14% K_2O, 6% MgO and 17% CaO.

Elemental sulphur must be oxidised to sulphate before it becomes available for uptake. The speed of oxidation depends largely on particle size and only very finely divided ('micronised') elemental sulphur will be rapidly effective. Where particle size is larger, elemental sulphur fertilisers can be used to raise the sulphur supply capacity of the soil over a longer period of time.

Further information

Fertiliser Spreaders – Choosing, Maintaining and Using

www.nutrientmanagement.org/fertiliser-spreader-manual

Fertiliser application

Accurate and even application of fertilisers is very important in order to maximise the benefits from their use to improve crop yield, quality and profitability. Even where correct decisions have been made on the amount of fertiliser to apply, inaccurate application, uneven spreading or spreading into hedgerows or ditches can cause a range of potentially serious problems, including:

- **Reduced yields and/or quality caused by uneven crops (stripes), lodging and disease**
- **Higher risk of the transfer of nutrients to watercourses at field margins, causing nutrient pollution**
- **Higher risk of causing botanical changes in hedgerows and field margins**

Spreading nitrogen fertilisers and organic materials as uniformly and accurately as is practically possible to the cropped area is a requirement in NVZs. Avoiding spreading into the edges of hedgerows and ditches is a requirement of Cross Compliance.

Fertiliser spreaders and sprayers should be regularly maintained and serviced, replacing worn out parts as necessary. To do this, follow the manufacturer's instructions. Spreaders should be calibrated for rate of application every spring and whenever the fertiliser type is changed. To check spreading uniformity, catch-trays can be used. Ideally, this should be done annually or whenever faulty spreading is suspected.

Computerised analysis of the data will give the Coefficient of Variation (CV), which is a measure of the non-uniformity of spreading. Where the CV is larger than 15%, significant inaccuracies in fertiliser spreading are occurring. Action should then be taken to improve the performance of the spreader.

For manure and slurry spreaders, checks should be made for mechanical condition before spreading and for rate of application during spreading.

Other useful sources of information

ADAS
www.adas.co.uk

Agricultural Industries Confederation
www.agindustries.org.uk

Catchment Sensitive Farming (CSF)
www.gov.uk/guidance/catchment-sensitive-farming-reduce-agricultural-water-pollution

FACTS
www.basis-reg.co.uk

International Fertiliser Society
www.fertiliser-society.org

Potash Development Association (PDA)
www.pda.org.uk

SRUC
www.sruc.ac.uk/info/120067/publications

Tried & Tested
www.nutrientmanagement.org.uk

Nitrate Vulnerable Zones (NVZs) – England
www.gov.uk/guidance/nutrient-management-nitrate-vulnerable-zones

Nitrate Vulnerable Zones (NVZs) – Scotland
www.gov.scot/Topics/farmingrural/Agriculture/Environment/NVZintro/NVZGuidanceforFarmers

Nitrate Vulnerable Zones (NVZs) – Wales
http://gov.wales/topics/environmentcountryside/epq/waterflooding/nitrates-directive

Nitrate Vulnerable Zones (NVZs) – Northern Ireland
www.daera-ni.gov.uk/articles/nitrates-directive

Statutory Instruments

- The Ammonium Nitrate Materials (High Nitrogen Content) Safety Regulations 2003 (SI 1082)
- The EC Fertilisers (England and Wales) Regulations 2006 (SI 2486)
- The Fertilisers (Amendment) Regulations 1995, No 16
- The Fertilisers (Amendment) Regulations 1997, No 1543
- The Fertilisers (Amendment) Regulations 1998, No 2024
- The Fertilisers (Sampling and Analysis) Regulations 1996 (SI 1342)
- The Fertilisers Regulations 1991 (SI 2197)
- The Pollution Prevention and Control (England and Wales) Regulations 2000 (SI 800)
- The Sludge (Use in Agriculture) Regulations 1989 (SI 1263); The Sludge (Use in Agriculture) (Amendment) regulations 1990 (SI 880)

www.legislation.hmso.gov.uk

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Analysis of fertilisers and liming materials

The materials listed below are used individually and some are used as components of compound or multi-nutrient fertilisers. The chemical and physical forms of nutrient sources, as well as growing conditions, can influence the effectiveness of fertilisers. A FACTS Qualified Adviser can give advice on appropriate forms for different soil and crop conditions.

The reactivity, or fineness of grinding, of liming materials determines their speed of action. However, the amount of lime needed is determined mainly by its neutralising value.

Nitrogen fertilisers	**Typical % nutrient content**
Ammonium nitrate	33.5–34.5% N
Liquid nitrogen solutions	18–30% N (w/w)
Calcium ammonium nitrate (CAN)	26–28% N
Ammonium sulphate	21% N, 60% SO_3
Urea	46% N
Calcium nitrate	15.5% N, 26% CaO
Phosphate fertilisers	
Single superphosphate (SSP)	18–21% P_2O_5, typically 30% SO_3
Triple superphosphate (TSP)	45–46% P_2O_5
Di-ammonium phosphate (DAP)	18% N, 46% P_2O_5
Mono-ammonium phosphate (MAP)	12% N, 52% P_2O_5
Rock phosphate (eg Gafsa)	27–33% P_2O_5
Potash, magnesium and sodium fertilisers	
Muriate of potash (MOP)	60% K_2O
Sulphate of potash (SOP)	50% K_2O, 45% SO_3
Potassium nitrate	13% N, 45% K_2O
Kainit	11% K_2O, 5% MgO, 26% Na_2O, 10% SO_3
Sylvinite	minimum 16% K_2O, typically 32% Na_2O
Kieserite (magnesium sulphate)	25% MgO, 50% SO_3
Calcined magnesite	typically 80% MgO
Epsom salts (magnesium sulphate)	16% MgO, 33% SO_3
Agricultural salt	50% Na_2O
Sulphur fertilisers	
Ammonium sulphate	21% N, 60% SO_3
Epsom salts (magnesium sulphate)	16% MgO, 33% SO_3
Elemental sulphur	typically 200-225% SO_3 (80–90% S)
Quarried gypsum (calcium sulphate)	40% SO_3
Polyhalite (e.g. Polysulphate)	minimum 48% SO_3, 14% K_2O, 6% MgO, 17% CaO.
Liming materials	**Neutralising Value (NV)**
Ground chalk or limestone	50–55
Magnesian limestone	50–55, over 15% MgO
Hydrated lime	c.70
Burnt lime	c.80
Sugar beet lime	22–32 + typically 7-10 kg P_2O_5, 5–7 kg MgO, 3–5kg SO_3/tonne

Glossary

Anion Negatively charged form of an atom or molecule for example nitrate (NO_3^-) and sulphate (SO_4^{2-}).

Available (nutrient) Form of a nutrient that can be taken up by a crop immediately or within a short period so acting as an effective source of that nutrient for the crop.

Bandspreading Application of fertiliser or slurry in bands along a row of seeds or crop plants.

Biosolids Treated sewage sludge.

Calcareous soil Soil that is alkaline due to the presence of free calcium carbonate or magnesium carbonate or both.

Cation Positively charged form of an atom or molecule for example potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}) and ammonium (NH^{4+}).

Cation exchange capacity Capacity of the soil to hold cations by electrostatic forces. Cations are held at exchange sites mainly on clay particles and organic matter.

Clay Finely divided inorganic crystalline particles in soils, less than 0.002 mm in diameter.

Closed period Period of the year when nitrogen fertilisers or certain manures should not be applied unless specifically permitted. Closed periods apply within NVZs.

Coefficient of variation (CV) Measure of the unevenness of application of fertilisers or manures. CV of 0% indicates perfectly even spreading, unachievable in practice. Correct operation of a well set up spreader should give a CV of 10% for fertilisers and 25% for manures under field conditions.

Compost Organic material produced by aerobic decomposition of biodegradable organic materials.

Content (nutrient) Commonly used instead of the more accurate 'concentration' to describe nutrients in fertiliser or organic manure. For example, 6 kg N/t often is described as the nitrogen content of a manure.

Cover crop A crop sown primarily for the purpose of taking up nitrogen from the soil and which is not harvested. Also called green manure.

Crop available nitrogen The total nitrogen content of organic manure that is available for crop uptake in the growing season in which it is spread on land.

Crop nitrogen requirement The amount of crop available nitrogen that must be applied to achieve the economically optimum yield.

Denitrification Microbial conversion of nitrate and nitrite in anaerobic soil to nitrogen gas and some nitrous oxide.

Deposition Transfer of nutrients from the atmosphere to soil or to plant surfaces. The nutrients, mainly nitrogen and sulphur, may be dissolved in rainwater (wet deposition) or transferred in particulate or gaseous forms (dry deposition).

Digestate Organic material produced by anaerobic digestion of biodegradable organic materials. May be separated into liquid and fibre fractions after digestion.

Dirty water Lightly contaminated run-off from lightly fouled concrete yards or from the dairy/parlour that is collected separately from slurry. It does not include liquids from weeping-wall stores, strainer boxes, slurry separators or silage effluent which are rich in nitrogen and regarded as slurries.

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Economic optimum (nitrogen rate) Rate of nitrogen application that achieves the greatest economic return from a crop, taking account of crop value and nitrogen cost.

Efficiency factor Percentage of total nitrogen in a manure that is available to the crop for which the manure was applied. There are mandatory minimum values in NVZs for use when estimating the nitrogen availability of manures.

Erosion Movement (transport) of the soil by running water or wind.

Eutrophication Enrichment of ecosystems by nitrogen or phosphorus. In water it causes algae and higher forms of plant life to grow too fast. This disturbs the balance of organisms present in the water and the quality of the water concerned. On land, it can stimulate the growth of certain plants which then become dominant so that natural diversity is lost.

Excess winter rainfall Rainfall between the time when the soil profile becomes fully wetted in the autumn (field capacity) and the end of drainage in the spring, less evapotranspiration during this period (ie water lost through the growing crop).

FACTS UK national certification scheme for advisers on crop nutrition and nutrient management. Membership is renewable annually. A FACTS Qualified Adviser has a certificate and an identity card.

Farmyard manure (FYM) Livestock excreta that is mixed with straw bedding material that can be stacked in a heap without slumping.

Fertiliser See Manufactured fertiliser.

Fluid fertiliser Pumpable fertiliser in which nutrients are dissolved in water (solutions) or held partly as very finely divided particles in suspension (suspensions).

Frozen hard Soil that is frozen for more than 12 hours. Days when soil is frozen overnight but thaws out during the day do not count.

Granular fertiliser Fertiliser in which particles are formed by rolling a mixture of liquid and dry components in a drum or pan. Typically, particles are in the 2–4 mm diameter range.

Grassland Land on which the vegetation consists predominantly of grass species.

Greenhouse gas Gas such as carbon dioxide, methane or nitrous oxide that contributes to global warming by absorbing infra-red radiation that otherwise would escape to space.

Green manure See Cover crop.

Heavy metal Cadmium, copper, lead, mercury, nickel or zinc. Elements that are potentially toxic to mammals above critical levels. Copper, nickel and zinc are required by plants in very small amounts.

Incorporation A technique (discing, rotovating, ploughing or other methods of cultivation) that achieves some mixing between an organic manure and the soil. Helps to minimise loss of nitrogen to the air through volatilisation and nutrient runoff to surface waters.

Inorganic fertiliser Manufactured fertiliser that contains only inorganic ingredients or urea.

Layer manure Poultry excreta with little or no bedding.

Leaching Process by which soluble materials such as nitrate or sulphate are removed from the soil by drainage water passing through it.

Ley	Temporary grass, usually ploughed up one to five years (sometimes longer) after sowing.
Lime requirement	Amount of standard limestone needed in tonnes/ha to increase soil pH from the measured value to a higher specified value (often 6.5 for arable crops). Can be determined by a laboratory test or inferred from soil pH.
Liquid fertiliser	See Fluid fertiliser.
Livestock manure	Dung and urine excreted by livestock or a mixture of litter, dung and urine excreted by livestock, even in processed organic form. Includes FYM, slurry, poultry litter, poultry manure, separated manures and granular or pelletised manures.
Macronutrient	See Major nutrient or Secondary nutrient.
Maintenance application	Amount of phosphate or potash that must be applied to replace (phosphate or potash) the amount removed from a field at harvest (including that in any straw, tops or haulm removed).
Major nutrient	Nitrogen, phosphorus, potassium, magnesium, sulphur, calcium or sodium that are needed in relatively large amounts by crops.
Manufactured fertiliser	Any fertiliser that is manufactured by an industrial process. Includes conventional straight and NPK products (solid or fluid), organo-mineral fertilisers, rock phosphates, slags, ashed poultry manure, liming materials that contain nutrients.
Manure	See Livestock manure and Organic manure.
Micronutrient	Boron, copper, iron, manganese, molybdenum, zinc that are needed in very small amounts by crops (see Major nutrients). Cobalt and selenium are taken up in small amounts by crops and are needed in human and livestock diets.
Mineral nitrogen	Nitrogen in ammonium (NH_4) and nitrate (NO_3) forms.
Mineralisable nitrogen	Organic nitrogen that is readily converted to ammonium and nitrate by microbes in the soil, for example during spring.
Mineralisation	Microbial breakdown of organic matter in the soil, releasing nutrients in crop-available, inorganic forms.
Neutralizing Value (NV)	Percentage calcium oxide (CaO) equivalent in a material. 100 kg of a material with a neutralising value of 52% will have the same neutralising value as 52 kg of pure CaO. NV is determined by a laboratory test.
Nitrate Vulnerable Zone (NVZ)	Areas designated by Defra as being at risk from agricultural nitrate pollution.
Nitrogen uptake efficiency	Uptake of nitrogen from soil, fertiliser or manure expressed as a percentage of nitrogen supply from that source.
Nitrogen use efficiency	Ratio of additional yield produced to the amount of nitrogen applied to achieve that increase. Often expressed as kg additional yield per kg N applied.

Nitrous oxide (N_2O)	A potent greenhouse gas that is emitted naturally from soils. The amount emitted is related to supply of mineral nitrogen in the soil so increases with application of manures and fertilisers, incorporation of crop residues and growth of legumes. It is greater in organic and peaty soils than in other soils.
Offtake	Amount of a nutrient contained in the harvested crop (including straw, tops or haulm) and removed from the field. Usually applied to phosphate and potash.
Olsen P	Concentration of available P in soil determined by a standard method (developed by Olsen) involving extraction with sodium bicarbonate solution at pH 8.5. The main method used in England, Wales and Northern Ireland and the basis for the Soil Index for P.
Organic manure	Any bulky organic nitrogen source of livestock, human or plant origin, including livestock manures.
Organic soil	Soil containing between 10% and 20% organic matter (in this Manual). Elsewhere, sometimes refers to soils with between 6% and 20% organic matter.
Peaty soil (peat)	Soil containing more than 20% organic matter.
Placement	Application of fertiliser to a zone of the soil usually close to the seed or tuber.
Poultry manure	Excreta produced by poultry, including bedding material that is mixed with excreta, but excluding duck manure with a readily available nitrogen content of 30% or less.
Prilled fertiliser	Fertiliser in which particles (prills) are formed by allowing molten material to fall as droplets in a tower. Droplets solidify during the fall and tend to be more spherical and somewhat smaller than granules (see Granular fertiliser).
Readily available nitrogen	Nitrogen that is present in livestock and other organic manures at the time of sampling in molecular forms that can be taken up immediately by the crop (ammonium or nitrate, or in poultry manure uric-acid N). High in slurries and poultry manures (typically 35–70% of total N) and low in FYM (typically 10–25%).
Removal	See Offtake.
Run-off	Movement of water across the soil surface which may carry nutrients from applied manures or fertilisers and with soil particles.
Sand	Soil mineral particles larger than 0.05 mm.
Silt	Soil mineral particles in the 0.002-0.05 mm diameter range.
Slurry	Excreta of livestock (other than poultry), including any bedding, rainwater and washings mixed with it, which can be pumped or discharged by gravity. The liquid fraction of separated slurry is also defined as slurry.
SNS Index	Soil Nitrogen Supply expressed in seven bands or Indices, each associated with a range in kg N/ha.

Soil Index (P, K or Mg)	Concentration of available P, K or Mg, as determined by standard analytical methods, expressed in bands or Indices.
Soil Mineral Nitrogen (SMN)	Ammonium and nitrate nitrogen, measured by the standard analytical method and expressed in kg N/ha.
Soil Nitrogen Supply (SNS)	The amount of nitrogen (kg N/ha) in the soil that becomes available for uptake by the crop in the growing season, taking account of nitrogen losses.
Soil organic matter	Often referred to as humus. Composed of organic compounds ranging from undecomposed plant and animal tissues to fairly stable brown or black material with no trace of the anatomical structure of the material from which it was derived.
Soil texture	Description based on the proportions of sand, silt and clay in the soil.
Soil type	Description based on soil texture, depth, chalk content and organic matter content.
Solid manure	Organic manure which can be stacked in a freestanding heap without slumping.
Target Soil Index	Lowest soil P or K Index at which there is a high probability crop yield will not be limited by phosphorus or potassium supply. See Soil Index (P, K or Mg).
Tillage land	Land that is not being used for grass production and is sown with a crop.
Trace element	See Micronutrient.
Volatilisation	Loss of nitrogen as ammonia from the soil to the atmosphere.
Water-soluble Phosphate	Phosphate, expressed as P_2O_5, that is measured by the statutory method for fertiliser analysis. Not necessarily a measure of available phosphate – high water-solubility indicates high availability but low water-solubility does not necessarily indicate low availability.
Weathering	Breakdown of soil mineral particles by physical or chemical processes. Enhanced by variation in temperature and moisture. A significant mechanism for release of potassium from clay minerals.

Notes

Notes

Notes

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Greenhouse Gas Action Plan:
The industry-wide Greenhouse Gas Action Plan (GHGAP) for agriculture focuses on improving resource use efficiency in order to enhance business performance while reducing GHG emissions from farming.

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Nutrient Management Guide (RB209)

Updated January 2019

Section 2 Organic materials

Using the Nutrient Management Guide (RB209)

This latest revision of RB209 is based on research carried out since the previous edition was published in 2010. The revision includes updated recommendations, including those for additional crops and information on the nutrient content of additional organic materials.

RB209 was first published in 1973 and was the first comprehensive set of fertiliser recommendations from the Ministry of Agriculture, Fisheries and Food (MAFF). RB209 stands for Reference Book 209.

To improve the accessibility of the recommendations and information AHDB's Nutrient Management Guide (RB209) is published as seven sections that will be updated individually.

Further information

The Nutrient Management Guide (RB209) will be updated regularly.

Please email your contact details to AHDB so that we can send you updates when they are published - comms@ahdb.org.uk

RB209: Nutrient Management

Download the app for Apple or Android phones to access the current version of all sections of the guide. With quick and easy access to videos, information and recommendations from the guide, it is practical for use in the field.

Section 1 Principles of nutrient management and fertiliser use

Section 2 Organic materials

Section 3 Grass and forage crops

Section 4 Arable crops

Cereals

Oilseeds

Sugar beet

Peas and beans

Biomass crops

Section 5 Potatoes

Section 6 Vegetables and bulbs

Section 7 Fruit, vines and hops

This section provides guidance on the use of organic materials. For each material, the content of nitrogen (N), phosphate (P_2O_5), potash (K_2O), magnesium (MgO), and sulphur (SO_3) are given in kilograms per tonne (kg/t) or cubic metre (kg/m^3).

Always consider your local conditions and consult a FACTS Qualified Adviser if necessary.

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Summary of main changes from previous edition

1. Overall presentation
   a. Nutrient content of organic materials is now presented as Section 2: Organic materials that incorporates the relevant appendices.
2. Updated nutrient content
   a. The availability of sulphur from organic materials (Table 2.1)
   b. Total nitrogen, sulphur and magnesium content of horse FYM (Table 2.2 and 2.4)
   c. Potash content of cattle FYM (Table 2.4)
   d. Total sulphur and magnesium content of sheep FYM (Table 2.4)
   e. Total magnesium content of duck FYM (Table 2.4)
   f. Nutrient content of poultry manure is presented according to dry matter content (Tables 2.5–7)
   g. Potash content of cattle slurry (Table 2.10)
   h. Phosphate and potash content of pig slurry (Table 2.13)
   i. Dry matter, phosphate, potash and sulphur contents of biosolids (Table 2.16)
   j. Phosphate, potash and sulphur content of compost (Table 2.17)
3. Added materials
   a. Goat FYM
   b. Farm-sourced and food-based anaerobic digestate (page 34)
4. Removed materials
   a. Information on digested liquid biosolids has been removed due to the small volume of material applied to land (less than 1% of total biosolids)

Regulation, codes of practice and assurance schemes

Organic materials applied to agricultural land, such as livestock manures, biosolids, composts, anaerobic digestates and waste derived materials are valuable sources of most major plant nutrients and organic matter. Careful recycling to land allows their nutrient value to be used for the benefit of crops and soil fertility, which can result in large savings in the use of manufactured fertilisers.

However, organic materials can present a considerable environmental risk if not handled carefully. Guidance on avoiding pollution, including manure management planning, is given in **Protecting our Water, Soil and Air: A Code of Good Agricultural Practice for farmers, growers and land managers.**

For all organic materials, it is important to check their use complies with contracts, relevant assurance schemes and animal by-product regulation.

Nitrate Vulnerable Zones (NVZs)

England
www.gov.uk/guidance/nutrient-management-nitrate-vulnerable-zones

Scotland
www.gov.scot/Topics/farmingrural/Agriculture/Environment

Wales
gov.wales/topics/environmentcountryside

Northern Ireland
www.daera-ni.gov.uk/articles/nitrates-directive

Further information

Protecting our Water, Soil and Air: A Code of Good Agricultural Practice for farmers, growers and land managers
www.gov.uk

Sampling livestock manures

For nutrient management planning, it is important to know the nutrient content of manures applied to land. The tables in this section give typical values of the total nutrient content of manures based on the analysis of samples from a wide range of sources.

However, the nutrient content of livestock manures is likely to vary significantly, depending on the source and management of the material. For example, the nutrient content will be influenced by farm-specific feeding and bedding practices, and digestate nutrient content will vary on a site by site basis depending on feedstock used in the digestion process. The livestock manures produced may have a nutrient content that is consistently different from the values given in the tables.

It can, therefore, be worthwhile having the nutrient content of representative manure samples determined by analysis. Rapid on-farm kits (eg Agros, Quantofix) can reliably assess the ammonium-N content of liquid manures (eg cattle slurries and digestates) but laboratory analysis is necessary for other nutrients. Laboratory analyses should include dry matter (DM), organic matter, total nitrogen (N), total phosphate (P_2O_5), total potash (K_2O), total sulphur (SO_3), total magnesium MgO and ammonium-N (NH_4-N).

Additionally, nitrate-N (NO_3-N) should be measured in well-composted farm yard manure (FYM) and poultry manures, and uric acid-N in poultry manures. Hydrometers can be used to measure the dry matter content of liquid manures and, where dry matter varies, adjust previous laboratory results or the typical values in the following tables.

The nutrient content of liquid manures can vary considerably within a store due to settlement and crusting. In particular, pig slurry can ‘settle out’ in storage, with a higher dry matter layer being at the base of the store and a lower dry matter layer occupying the mid/upper, which, during store emptying, can markedly affect slurry dry matter and associated nutrient contents.

Similarly, the composition of solid manure in a heap can vary depending on the amount of bedding and losses of nutrients during storage. If stored materials are to be analysed either in a laboratory or using a rapid on-farm method

Further information
Adding value from pig manures and slurries
pork.ahdb.org.uk/environment-buildings

(eg using Agros or Quantofix slurry-N meters), it is important that the sample taken represents an ‘average’ of what is found in the heap or store.

It is important that sampling is carried out carefully and that representative samples are provided for analysis. The optimum sampling frequency will vary depending on how manures are managed on the farm, but at least two samples per year are recommended, coinciding with the main spreading periods.

Taking a representative sample of a liquid manure

Health & Safety
When sampling enclosed liquid manure stores (pits or tanks) never climb down or lean into the store because of the risk of inhaling toxic gases which can be lethal.

- Collect at least five subsamples of two litres each and pour into a large container
- Thoroughly mix the bulked sample
- On-farm rapid analysis of slurries should be carried out immediately
- If a sample is to be sent to a laboratory 250 ml should be dispatched in a clean, screw topped, plastic container (normally available from the laboratory)
- Leave 2–3 cm of airspace to allow the sample to be shaken in the laboratory
- Label the sample clearly, providing as much information as possible
- As soon as possible, send the sample first class to the laboratory (prepaid envelopes are normally available from the laboratory)

Above ground stores

Ideally, the liquid manure should be fully agitated before sampling. If this is not possible and, provided there is safe access from an operator's platform, the five subsamples can be taken at a range of positions, using a weighted two litre container attached to a rope.

Below ground pit

It may be possible to obtain subsamples at various positions using a weighted container.

Earth-banked lagoons

Do not attempt to sample direct from the lagoon unless there is a secure operator's platform that provides safe access. If the slurry has been well agitated, subsamples can be obtained from the slurry tanker or irrigator. If the tanker is fitted with a suitable valve, it may be possible to take five subsamples from this stationary tanker at intervals during filling or while field spreading is in progress.

How to sample farmyard manure

How to sample slurry

Videos on how to sample farmyard manure and slurry are available at **ahdb.org.uk/rb209**

or

SCAN THE IMAGES WITH THE RB209: NUTRIENT MANAGEMENT APP TO WATCH THE VIDEOS

Taking a representative sample of a solid manure

Health & Safety

You should wear rubber gloves and protective clothing when collecting samples. Remember to wash hands and forearms thoroughly after taking samples and before eating or drinking.

- Take at least 10 subsamples of about 1 kg each as described below
- Place on a clean, dry tray or sheet
- Break up any lumps and thoroughly mix the sample
- Take a representative sample of around 500 g for analysis
- Samples should be dispatched in 500 gauge polythene bags (normally available from the laboratory), expel excess air from the bag before sealing
- Label samples clearly, providing as much information as possible

Manure heaps

- Provided the manure is dry and safe to walk on, identify at least 10 locations which appear to be representative of the heap
- After clearing away any weathered material with a spade or fork, either:
  - dig a hole approximately 0.5 metres deep and take a 1 kg sample from each point
  - use a soil auger to obtain subsamples from at least 50 cm in to the heap
- Alternatively, take subsamples from the face of the heap at various stages during spreading

Weeping wall stores

Do not attempt to take samples before the store is emptied as it is not safe to walk on the surface of the stored material. Subsamples may be taken from the face of the heap once emptying has commenced.

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Calculations and interpretation of laboratory analysis results

Laboratories differ in the way that the analysis results are expressed and conversion of the results is often needed. Analysis results are variously reported:

- On a dry weight (DW or 100% DM) or fresh weight (FW) basis
- In units of grams or milligrams per kilogram (g/kg, mg/kg), grams per 100 grams (g/100 g), percent (%), grams or milligrams per litre (g/l, mg/l), kilograms per tonne (kg/t) or kilograms per cubic metre (kg/m^3)
- As the nutrient element (N, P, K, Mg, S) or the nutrient oxide (P_2O_5, K_2O, MgO, SO_3)

If in doubt about how your results are expressed, as a first step you should confirm with the laboratory.

Use the following conversions if analysis results need to be converted.

Nutrients

To convert nutrient element to nutrient oxide

P	x	2.291	=	P_2O_5
K	x	1.205	=	K_2O
Mg	x	1.658	=	MgO
S	x	2.5	=	SO_3

Solid manures (DM expressed as %)

To convert mg/kg nutrient in DM to kg/t FW: $\frac{\text{mg/kg nutrient}}{1000} \times \frac{\text{\% DM}}{100}$

To convert g/kg nutrient in DM to kg/t FW: $\text{g/kg nutrient} \times \frac{\text{\% DM}}{100}$

To convert g/100g nutrient in DM to kg/t FW: $\text{g/100g nutrient} \times \frac{\text{\% DM}}{10}$

To convert % nutrient in DM to kg/t FW: $\text{\% nutrient} \times \frac{\text{\% DM}}{10}$

Solid manures (DM expressed as g/kg)

To convert mg/kg nutrient in DM to kg/t FW: $\frac{\text{mg/kg nutrient}}{1000} \times \frac{\text{g/kg DM}}{1000}$

To convert g/kg nutrient in DM to kg/t FW: $\text{g/kg nutrient} \times \frac{\text{g/kg DM}}{1000}$

To convert g/100g nutrient in DM to kg/t FW: $\text{g/100g nutrient} \times \frac{\text{g/kg DM}}{100}$

To convert % nutrient in DM to kg/t FW: $\text{\% nutrient} \times \frac{\text{g/kg DM}}{100}$

Liquid manures

To convert mg/l nutrient to kg/m^3: $\frac{\text{mg/l nutrient}}{1000}$

To convert g/l nutrient to kg/m^3: g/l nutrient (no change)

Example 2.1

Digested sludge cake with 27% DM, and 4.0% N and 3.0% P in DM.

$$4.0\%\text{N} \times \frac{27\%\text{ DM}}{10} = 10.8\text{ kg N/t in FW}$$

$$3.0\%\text{P} \times \frac{27\%\text{ DM}}{10} \times 2.29 = 18.6\text{ kg } P_2O_5\text{/t in FW}$$

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Principles of nitrogen supply and losses

Nitrogen is present in organic materials in two main forms:

- Readily available nitrogen (ie ammonium-N as measured by N meters, nitrate-N and uric acid-N) is the nitrogen that is potentially available for rapid crop uptake
- Organic-N is the nitrogen contained in organic forms, which are broken down slowly to become potentially available for crop uptake over a period of months to years

Crop available nitrogen is the readily available-N that remains for crop uptake after accounting for any losses of nitrogen. This also includes nitrogen released from organic forms.

Following the application of organic materials to land, there can be losses of nitrogen as follows:

- Ammonium-N can be volatilised to the atmosphere as ammonia gas
- Following the conversion of ammonium-N to nitrate-N, further losses may occur through nitrate leaching and denitrification of nitrate to nitrous oxide and nitrogen gas under warm and wet soil conditions

To make best use of their nitrogen content, organic materials should be applied at or before times of maximum crop growth – generally during the late winter to summer period.

Ammonia volatilisation

Typically, around 40% of the readily available nitrogen content of organic materials can be lost following surface application to land. Ammonia loss and odour nuisance can be reduced by ensuring that organic materials are rapidly incorporated into soils (within six hours of application for liquid materials and 24 hours for solid materials to tillage land).

For liquid materials, shallow injection and band spreading techniques are effective application methods that reduce ammonia emissions (typically by 30–70%) compared with broadcast application. Band spreading (trailing shoe and trailing hose) and shallow injection application techniques increase the number of spreading days, and cause less sward contamination than surface broadcast applications. These practices will also increase the amount of nitrogen available for crop uptake. Ammonia losses are generally smaller from low dry matter liquid materials, because they more rapidly infiltrate into the soil.

Higher dry matter liquid materials remain on the soil/crop surface for longer, leading to greater losses. Losses are also higher when they are applied to dry soils under warm weather conditions.

Further information

Low emissions – focus on ammonia

ahdb.org.uk/knowledge-library/low-emissions-focus-on-ammonia

Nitrate leaching

The amount of nitrogen leached following land application is mainly related to the soil type, the application rate, the readily available-N content and the amount of rainfall after application. As ammonium-N is rapidly converted in the soil to nitrate-N, organic material applications during the autumn or early winter period should be avoided, as there is likely to be sufficient overwinter rainfall to wash a large proportion of this nitrate out of the soil before the crop can use it.

Delaying applications until late winter or spring will reduce nitrate leaching and increase the efficiency of utilisation of manure nitrogen. This is particularly important for organic materials with a high content of readily available nitrogen.

Release of crop-available nitrogen from organic materials

The organic nitrogen content of organic material is released (mineralised) slowly over a period of months to years. Where the nitrogen mineralised from the material is not taken up by the crop in the season following application, nitrate may be lost by leaching during the following overwinter period or accumulate in soil organic matter, allowing further long-term savings in nitrogen fertiliser inputs. Around 5% of the total nitrogen content of organic material may become available for the second crop following application.

Points to consider

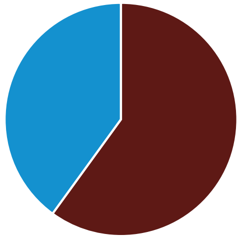
- In NVZs, there are mandatory closed spreading periods for high readily available nitrogen organic materials (eg cattle slurries, poultry manures and digestates), which typically have greater than 30% of their total nitrogen content present as readily available nitrogen

Figure 2.1 Typical proportions of different forms of nitrogen in organic materials

Cattle slurry (6% dry matter)

Organic-N

Ammonium-N

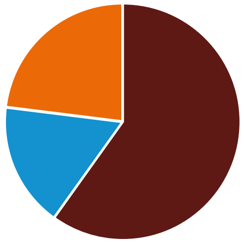


Poultry manure

Organic-N

Ammonium-N

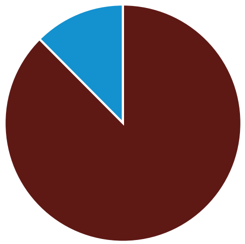
Uric acid-N



Cattle FYM

Organic-N

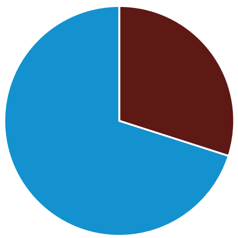
Ammonium-N



Pig slurry (4% dry matter)

Organic-N

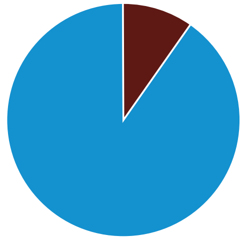
Ammonium-N



Whole digestate

Organic-N

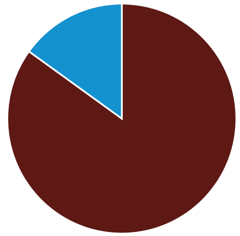
Ammonium-N



Biosolid digested cake

Organic-N

Ammonium-N



The Farm Crap App is a free app that enables you to visually assess manures and slurry applications (rates) and calculate what is being provided in terms of total and crop available nutrients. You can select different seasons, types of manure(s) and crops growing to see what the manure will provide in terms of fertiliser value. The app is available on Apple and Android devices, through the iTunes or Google Play stores.

MANNER-*NPK* is a free practical software tool that provides farmers and advisers with a quick estimate of crop available nitrogen, phosphate and potash supply from applications of organic materials. MANNER-*NPK* is applicable in England, Wales, Scotland and Northern Ireland
www.planet4farmers.co.uk/manner

Phosphate, potash and magnesium

Organic materials are valuable sources of other nutrients as well as nitrogen, although not all of the total nutrient content is available for the next crop. Typical values for the total and available phosphate and potash contents of organic materials are given in this guide.

Nutrients which are not immediately available will mostly become available over a period of years and will usually be accounted for when soil analysis is carried out. The availability of manure phosphate to the next crop grown (typically 50–60%) is lower than from water-soluble phosphate fertilisers. However, around 90% of manure potash is readily available for crop uptake.

Where crop responses to phosphate or potash are expected (eg soil Indices 0 or 1 for combinable crops and grassland) or where responsive crops are grown (eg potatoes or vegetables), the available (not total) phosphate and potash content of the organic material should be used when calculating the nutrient contribution. Soils at Index 0 will particularly benefit from organic material applications.

Where the soil is at target Index (usually Index 2) or above for phosphate or potash, the total phosphate and potash content of the organic material should be used in nutrient balance sheet calculations.

For most arable crops, typical organic material application rates can supply the phosphate and potash requirement. At soil P Index 3 or above, take care to ensure that total phosphate inputs do not exceed the amounts removed in crops during the rotation. This will avoid the soil P Index reaching an unnecessarily high level. It is important to manage organic material applications to ensure phosphate and potash is used through the crop rotation.

Sulphur

Organic materials contain valuable amounts of crop-available sulphur and recent research has quantified sulphur supply from livestock manures and biosolids applications (Table 2.1). Sulphur from autumn applications may be lost via overwinter leaching. The quantity leached will depend on soil type and overwinter rainfall and is likely to be higher on light textured soils in high rainfall areas.

Table 2.1 Sulphur availability from organic materials

Organic material	% total SO_3 available
Autumn applied	
Livestock manures	5–10% [15%]
Biosolids	10–20% [25%]
Spring applied	
Cattle FYM	15%
Pig FYM	25%
Poultry manure	60%
Cattle/pig slurry	45%
Biosolids	35%

[ ] use for grassland and winter oilseed rape cropping

Using organic materials and fertilisers together

You should plan to utilise as much as possible of the nutrient content of organic materials. Not adequately allowing for these nutrients, particularly nitrogen, not only wastes money because of unnecessary fertiliser use but also can reduce crop yields and quality; eg lodging in cereals, poor fermentation in grass silage and low sugar levels in beet.

Step 1 Calculate the quantity of crop available nutrients supplied by each application of organic material.

Step 2 Identify the fields that will benefit most from the application of organic material. This will need to take account of the accessibility and likely soil conditions in individual fields and the application equipment that is available. Crops with a high nitrogen demand should be targeted first. Fields at low soil P or K Indices will benefit more than those at high Indices. Silage fields should be separated in preference to grazing only fields.

Step 3 Plan the application rates for each field taking account of the phosphate content of organic material over the crop rotation to avoid excessive enrichment of soil phosphorus levels. Make sure that plans adhere to NVZ rules. As far as possible, apply organic materials in the late-winter to summer period – this will make best use of the nitrogen content.

Step 4 Aim for the organic material application to supply no more than 50–60% of the total nitrogen requirement of the crop, and use manufactured fertiliser to make up the difference. This approach will minimise the potential impact of variations in nitrogen supply from organic materials on crop yields and quality.

Step 5 Calculate the nutrient requirement of the crop, then deduct the nutrients supplied from organic materials. This will give the balance that needs to be supplied as manufactured fertiliser.

Step 6 Make sure that application equipment is well maintained and suitable for applying the organic material in the most effective way, minimising losses of ammonia-N and soil or crop damage. The equipment should be routinely calibrated for the type of organic material being applied.

Practical aspects of organic material use

Organic materials are commonly applied to arable stubbles in the autumn prior to drilling winter cereals. To make best use of organic material nitrogen and to minimise nitrate leaching losses, materials should, if possible, be applied in the late-winter to summer period.

Band spreaders and shallow injection (5–7 cm deep) equipment allow accurate top-dressing of liquid materials across full tramline widths, without causing crop damage. An additional benefit of these application methods is that odour nuisance and ammonia emissions are reduced by 30–70% compared with conventional ‘splash-plate’ surface application. Herbage contamination is also reduced.

Organic material applications before spring-sown crops (eg root crops, cereals and oilseed rape) should be made from late winter onwards to minimise nitrate leaching losses, particularly where high readily available nitrogen manures are applied.

In NVZs, applications of organic material with a high readily available nitrogen content (eg slurry, poultry manure and digestate) are subject to closed-spreading periods to reduce the risks of nitrate leaching losses. Rapid soil incorporation on tillage land (eg within six hours following surface broadcast application) will minimise ammonia losses and increase crop available nitrogen supply.

Organic material applications to grassland are best made to fields intended for silage or hay production. Cattle slurry and FYM contain large amounts of potash relative to their readily available nitrogen and total phosphate contents, and are ideally suited to this situation. However, take care to ensure that the potash supply does not increase the risk of grass staggers (hypomagnesaemia) in stock through reduced herbage magnesium levels.

Application rates of solid material should be carefully controlled to avoid the risk of sward damage and contamination of conserved grass, which can adversely affect silage quality. To encourage a low pH and good fermentation, grass cuts following solid material or late slurry applications should be wilted before ensiling, or an effective silage additive used.

Where slurry and solid manure applications are made to grazed grassland, the pasture should not be grazed for at least four weeks following application, or until all visible signs of slurry or digestate solids have disappeared. This will minimise the risk of transferring disease to grazing livestock.

Forage crops, particularly forage maize, provide an opportunity to apply organic materials prior to drilling in late spring. Organic material application rates should be carefully controlled and where possible the material should be rapidly incorporated into the soil to minimise ammonia-N emissions and odour nuisance.

Where organic material applications are made before "ready-to-eat crops" (crops that are generally not cooked before eating), relevant industry guidance should be followed to minimise the risks of pathogen transfer (eg The Safe Sludge Matrix or The Renewable Fertiliser Matrix).

Further information

The Safe Sludge Matrix
adlib.everysite.co.uk/resources/000/094/727/SSMatrix.pdf

The Renewable Fertiliser Matrix
www.wrap.org.uk/content/renewable-fertiliser-matrix

Application management

It is important that organic materials are applied evenly and at known application rates. The most important causes of uneven application on farms are the incorrect setting of bout widths and poor attention to machinery maintenance.

For both liquid and solid manures, the evenness of spreading is usually better with rear discharge spreaders than side discharge machines. Top-dressing liquid manures to arable crops in spring can be carried out using tankers or umbilical systems, with boom applicators (fitted with nozzles or trailing-hoses) operating from tramlines.

The aim should be to apply all manure types evenly with a coefficient of variation of less than 25%. This is achievable with commonly used types of manure application equipment, provided they are well maintained and calibrated.

Application rates can be calculated simply from a knowledge of the capacity of the tanker or solid manure spreader (by weighing both full and empty machines on a weighbridge), the number of loads applied per field and the field area. An accurate flow meter should be used to measure the slurry application rate of umbilical and irrigation systems.

Livestock manures

The nutrient content of livestock manures will depend on a number of factors, including the type of livestock, the diet and feeding system, the volume of dirty water and rainwater entering storage facilities, and the amount of bedding used. Consequently, the nutrient content of manures produced on any particular unit may vary significantly from the typical values in the tables.

Therefore, although the following tables provide useful information on the typical nutrient content of livestock manures, it can be worthwhile analysing representative samples (page 6).

Further information

Think Manures
www.nutrientmanagement.org

Managing nutrients for better returns
beefandlamb.ahdb.org.uk

Grass+
dairy.ahdb.org.uk

Adding value from pig manures and slurries
pork.ahdb.org.uk/environment-buildings/nutrient-management

Cattle, pig, sheep, duck, horse and goat farmyard manure (FYM)

Table 2.2 Typical total nitrogen content of FYM (fresh weight basis)

	Dry matter %	Total nitrogen kg N/t[a]
Cattle FYM	25	6.0
Pig FYM	25	7.0
Sheep FYM	25	7.0
Duck FYM	25	6.5
Horse FYM	25	5.0
Goat FYM	40	9.5

a. The crop-available nitrogen supply will depend on the application timing and the delay between application and incorporation.

Duck farmyard manure is included here because the availability of its nitrogen is generally lower than that of other poultry manures.

To convert kg/t to units/ton, multiply by 2.

Table 2.3 Percentage of total nitrogen available to next crop following FYM applications

	Autumn[a] (Aug–Oct, 450 mm rainfall to end March)		Winter[a] (Nov–Jan, 250 mm rainfall to end March)		Spring[a] (Feb–Apr)	Summer[a] use on grassland
	Sandy/ shallow[b]	Medium/ heavy[b]	Sandy/ shallow[b]	Medium/ heavy[b]	All soils	All soils
Surface applied (ie not soil incorporated)						
FYM (old and fresh)	5	10	10	10	10	10
Soil incorporated 24 hours after application[c]						
FYM						
Old[d]	5	10	10	10	10	N/A
Fresh[e]	5	10	10	10	15	N/A

N/A = Not applicable

a. The nitrogen availability estimates assume 450 mm of rainfall (after autumn application) and 250 mm (after winter application) up to the end of soil drainage (end of March). Where rainfall differs from these amounts, intermediate values of nitrogen availability should be used. For spring or summer applications, rainfall is not likely to cause movement of agronomically important amounts of nitrogen to below crop rooting depth.

b. Sandy/shallow = light sand soils and shallow soils. Medium/heavy = medium, deep fertile silt and deep clay soils. Use this category for organic and peaty soils.

c. The values assume incorporation by ploughing. Cultivation using discs or tines is less effective in minimising ammonia losses and intermediate values of nitrogen availability should be used.

d. Old FYM = manure which has been stored for three months or more and has an estimated ammonium-N and nitrate-N content of 10% (cattle and sheep FYM) or 15% (pig and duck FYM) of the total nitrogen.

e. Fresh FYM = manure which has not been stored prior to land application and has an estimated ammonium-N content of 20% (cattle and sheep FYM) or 25% (pig and duck FYM) of total nitrogen.

Table 2.4 FYM – phosphate, potash, magnesium and sulphur (fresh weight basis)

	Dry matter %	Phosphate			Potash[a]			Sulphur[b]	Magnesium
		Total phosphate kg P_2O_5/t	Availability %	Available phosphate kg P_2O_5/t	Total potash kg K_2O/t	Availability %	Available potash kg K_2O/t	Total sulphur kg SO_3/t	Total magnesium kg MgO/t
Cattle FYM	25	3.2	60	1.9	9.4	90	8.5	2.4	1.8
Pig FYM	25	6.0	60	3.6	8.0	90	7.2	3.4	1.8
Sheep FYM	25	3.2	60	1.9	8.0	90	7.2	4.0	2.8
Duck FYM	25	5.5	60	3.3	7.5	90	6.8	2.6	2.4
Horse FYM	25	5.0	60	3.0	6.0	90	5.4	1.6	1.5
Goat FYM	40	4.5	60	2.7	12.0	90	10.8	2.8	1.9

a. Values of potash may be lower for FYM stored for long periods in the open.

b. For crop available sulphur supply refer to Table 2.1 on page 12.

Poultry manure

Table 2.5 Typical total nitrogen content of poultry manure (fresh weight basis)

Dry matter %	Total nitrogen[a] kg N/t
20	9.4
40	19.0
60	28.0
80	37.0

To convert kg/t to units/ton, multiply by 2.

a. Typically, greater than 30% of the total nitrogen content of poultry manure is present as readily available N. As a result, poultry manure is subject to the closed-spreading period in Nitrate Vulnerable Zones. The crop available nitrogen supply will depend on the application timing and the delay between application and incorporation.

Table 2.6. Percentage of total nitrogen available to next crop following poultry manure applications (% of total nitrogen)

	Autumn[a] (Aug–Oct 450 mm to end March)		Winter[a] (Nov–Jan, 250 mm rainfall to end March		Spring[a] (Feb–Apr)	Summer[a] use on grassland
Surface applied (ie not incorporated)	Sandy/Shallow[b]	Medium/heavy[b]	Sandy/shallow[b]	Medium/heavy[b]	All Soils	All Soils
20% DM	15 [20]	25 [30]	25	25	35	35
40% DM	10 [15]	25 [30]	20	25	30	30
60% DM	10 [15]	25 [30]	20	25	30	30
80% DM	10 [15]	25 [30]	20	25	30	30
Soil incorporated 24 hours after application[c]						
20% DM	15 [20]	35 [40]	25	40	50	N/A
40% DM	10 [15]	30 [35]	20	30	40	N/A
60% DM	10 [15]	30 [35]	20	30	40	N/A
80% DM	10 [15]	30 [35]	20	30	40	N/A

N/A = Not applicable

[ ] = use for grassland and winter oilseed rape cropping

a. The nitrogen availability estimates assume 450 mm of rainfall (after autumn application) and 250 mm (after winter application) up to the end of soil drainage (end March). Where rainfall differs from these amounts, intermediate values of nitrogen availability should be used. For spring or summer applications, rainfall is not likely to cause movement of agronomically important amounts of nitrogen to below crop rooting depth.

b. Sandy/shallow = light sand soils and shallow soils. Medium/heavy = medium, deep fertile silt and deep clay soils. Use this category for organic and peaty soils.

c. The values assume incorporation by ploughing. Cultivation using discs or tines is less effective in minimising ammonia losses and intermediate values of nitrogen availability should be used.

Table 2.7 Phosphate, potash, magnesium and sulphur content of poultry manure (fresh weight basis)

Dry matter %	Phosphate			Potash			Sulphur[a]	Magnesium
	Total phosphate kg P_2O_5/t	Availability %	Available phosphate kg P_2O_5/t	Total potash kg K_2O/t	Availability %	Available potash kg K_2O/t	Total sulphur kg SO_3/t	Total magnesium kg MgO/t
20	8.0	60	4.8	8.5	90	7.7	3.0	2.7
40	12	60	7.2	15	90	14	5.6	4.3
60	17	60	10.2	21	90	19	8.2	5.9
80	21	60	12.6	27	90	24	11	7.5

To convert kg/t to units/ton, multiply by 2.

a. For crop-available sulphur supply refer to Table 2.1 on page 12.

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Cattle slurry and dirty water

Table 2.8 Total nitrogen content of cattle slurry and dirty water (fresh weight basis)

	Dry matter %	Total nitrogen[b] kg N/m³ or /t
Slurries/liquids		
Cattle	2	1.6
	6[a]	**2.6**[a]
	10	3.6
Dirty water	0.5	0.5
Separated cattle slurries (liquid portion)		
Strainer box	1.5	1.5
Weeping wall	3	2.0
Mechanical separator	4	3.0
Separated cattle slurry (solid portion)	20	4.0

a. Typical dry matter and nitrogen contents of cattle slurry are shown in bold.

b. Cattle slurry and the liquid portion of separated cattle slurry are high readily available nitrogen manures with typically greater than 30% of their total nitrogen content present as readily available nitrogen and will be subject to closed spreading periods in Nitrate Vulnerable Zones. The crop available nitrogen supply from manures will depend on the application timing, application method and the delay between application and incorporation.

To convert kg/m³ to units/1,000 gallons, multiply by 9.

Table 2.9 Percentage of total nitrogen available to next crop following cattle slurry and dirty water applications (% of total nitrogen)

	Autumn[a] (Aug–Oct, 450 mm rainfall to end March)		Winter[a] (Nov–Jan, 250 mm rainfall to end March)		Spring[a] (Feb–Apr)	Summer[a] use on grassland
	Sandy/ shallow[b]	Medium/ heavy[b]	Sandy/ shallow[b]	Medium/ heavy[b]	All soils	All soils
Cattle slurry – liquid **Surface applied (ie not soil incorporated)**						
2% DM	5 [10]	30 [35]	30	30	45	35
6% DM	**5 [10]**	**25 [30]**	**25**	**25**	**35**	**25**
10% DM	5 [10]	20 [25]	20	20	25	20
Soil incorporated 6 hours after application[c]						
2% DM	5 [10]	35 [50]	25	35	50	N/A
6% DM	**5 [10]**	**30 [35]**	**20**	**30**	**40**	**N/A**
10% DM	5 [10]	25 [30]	15	25	30	N/A
Band spread						
2% DM	5 [10]	30 [35]	30	30	50	40
6% DM	**5 [10]**	**25 [30]**	**25**	**25**	**40**	**30**
10% DM	5 [10]	20 [25]	20	20	30	25
Shallow injected						
2% DM	5 [10]	30 [35]	35	35	55	45
6% DM	**5 [10]**	**25 [30]**	**30**	**30**	**45**	**35**
10% DM	5 [10]	20 [25]	25	25	35	30
Dirty water (surface applied)	10 [15]	35 [40]	35	35	50	30
Separated cattle slurry – solid portion **Surface applied (ie not soil incorporated)**	5	10	10	10	10	10
Soil incorporated 24 hours after application[d]	5	10	10	10	15	N/A

[ ] = use for grassland and winter oilseed rape cropping

N/A = not applicable.

For separated cattle slurry (liquid portion), use the values for 2% dry matter slurry.

a. The nitrogen availability estimates assume 450 mm of rainfall (after autumn application) and 250 mm (after winter application) up to the end of soil drainage (end March). Where rainfall differs from these amounts, intermediate values of nitrogen availability should be used. For spring or summer applications, rainfall is not likely to cause movement of agronomically important amounts of nitrogen to below crop rooting depth.

b. Sandy/shallow = light sand soils and shallow soils. Medium/heavy = medium, deep fertile silt and deep clay soils. Use this category for organic and peaty soils.

c. The values assume incorporation by ploughing. Cultivation using discs or tines is less effective in minimising ammonia. Where slurry has been applied in spring or summer and incorporated more quickly than six hours or has been deep injected, nitrogen availability will be similar to the shallow injected values.

d. The values assume incorporation by ploughing. Cultivation using discs or tines is less effective in minimising ammonia losses and intermediate values of nitrogen availability should be used.

Table 2.10 Phosphate, potash, magnesium and sulphur content of cattle slurry and dirty water (fresh weight basis)

	Dry matter %	Phosphate			Potash			Sulphur[a]	Magnesium
		Total phosphate kg P_2O_5/m^3 or /t	Availability %	Available phosphate kg P_2O_5/m^3 or /t	Total potash kg K_2O/m^3 or /t	Availability %	Available potash kg K_2O/m^3 or/t	Total sulphur kg SO_3/m^3 or /t	Total magnesium kg MgO/m^3
Slurries/liquids									
Cattle	2	0.6	50	0.3	1.7	90	1.5	0.3	0.2
	6[b]	**1.2**	**50**	**0.6**	**2.5**	**90**	**2.3**	**0.7**	**0.6**
	10	1.8	50	0.9	3.4	90	3.0	1.0	0.9
Dirty water	0.5	0.1	50	0.05	1.0	100	1.0	0.1	0.1
Separated cattle slurries (liquid portion)									
Strainer box	1.5	0.3	50	0.15	1.5	90	1.4	ND	ND
Weeping wall	3	0.5	50	0.25	2.3	90	2.1	ND	ND
Mechanical separator	4	1.2	50	0.6	2.8	90	2.5	ND	ND
Separated cattle slurry (solid portion)	20	2.0	50	1.0	3.3	90	3.0	ND	ND

a. For crop-available sulphur supply refer to Table 2.1 on page 12.

b. Typical dry matter and nitrogen contents of cattle slurry are shown in bold.

ND = No data

To convert kg/m^3 to units/1,000 gallons, multiply by 9.

Pig slurry

Table 2.11 Typical total nitrogen content of pig slurry (fresh weight basis)

	Dry matter %	Total nitrogen[b] kg N/m³ or /t
Pig slurry – liquid	2	3.0
	4 [a]	**3.6** [a]
	6	4.4
Separated pig slurry (liquid portion)	3	3.6
Separated pig slurry (solid portion)	20	5.0

a. Typical dry matter and nitrogen contents of pig slurry are shown in bold.

b. Pig slurry and the liquid portion of separated pig slurry are in high readily available N manures with typically greater than 30% of their total nitrogen content present as readily available N and will be subject to closed-spreading periods in Nitrate Vulnerable Zones. The crop available nitrogen supply from manures will depend on the application timing, application method and the delay between application and incorporation.

To convert kg/m³ to units/1000 gallons, multiply by 9.

Table 2.12 Percentage of total nitrogen available to next crop following pig slurry applications (% of total nitrogen)

	Autumn[a] (Aug–Oct, 450 mm rainfall to end March)		Winter[a] (Nov–Jan, 250 mm rainfall to end March)		Spring[a] (Feb–Apr)	Summer[a] use on grassland
	Sandy/ shallow[b]	Medium/ heavy[b]	Sandy/ shallow[b]	Medium/ heavy[b]	All soils	All soils
Pig slurry – liquid Surface applied (ie not soil incorporated)						
2% DM	10 [15]	35 [40]	40	40	55	55
4% DM	**10 [15]**	**30 [35]**	**35**	**35**	**50**	**50**
6% DM	10 [15]	25 [30]	30	30	45	45
Soil incorporated 6 hours after application[c]						
2% DM	10 [15]	40 [45]	35	50	65	N/A
4% DM	**10 [15]**	**40 [45]**	**30**	**45**	**60**	**N/A**
6% DM	10 [15]	40 [45]	25	40	55	N/A
Band spread						
2% DM	10 [15]	35 [40]	40	40	60	60
4% DM	**10 [15]**	**35 [40]**	**35**	**35**	**55**	**55**
6% DM	10 [15]	30 [35]	35	35	50	50
Shallow injected						
2% DM	10 [15]	40 [45]	45	45	65	65
4% DM	**10 [15]**	**35 [40]**	**40**	**40**	**60**	**60**
6% DM	10 [15]	30 [40]	40	40	55	55
Separated pig slurry – solid portion Surface applied (ie not soil incorporated)	5	10	10	10	10	10
Soil incorporated 24 hours after application[d]	5	10	10	10	15	N/A

[ ] = Use for grassland and winter oilseed rape cropping

N/A = Not applicable

a. The nitrogen availability estimates assume 450 mm of rainfall (after autumn application) and 250 mm (after winter application) up to the end of soil drainage (end March). Where rainfall differs from these amounts, intermediate values of nitrogen availability should be used. For spring or summer applications, rainfall is not likely to cause movement of agronomically important amounts of nitrogen to below crop rooting depth.

b. Sandy/shallow = light sand soils and shallow soils. Medium/heavy = medium, deep fertile silt and deep clay soils. Use this category for organic and peaty soils.

c. The values assume incorporation by ploughing. Cultivation using discs or tines is less effective in minimising ammonia losses. Where slurry has been applied in spring or summer and incorporated more quickly than six hours or has been deep injected, nitrogen availability will be similar to the shallow injected values.

d. The values assume incorporation by ploughing. Cultivation using discs or tines is less effective in minimising ammonia losses and intermediate values of nitrogen availability should be used.

For separated pig slurry (liquid portion), use the values for 2% dry matter slurry.

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Table 2.13 Phosphate, potash, magnesium and sulphur content of pig slurry (fresh weight basis)

	Dry matter %	Phosphate			Potash			Sulphur	Magnesium
		Total phosphate kg P_2O_5/m^3 or/t	Availability %	Available phosphate kg P_2O_5/m^3 or/t	Total potash kg K_2O/m^3or/t	Availability %	Available potash kg K_2O/m^3 or/t	Total sulphur[b] kg SO^3/m^3 or /t	Total magnesium kg MgO/m^3
Pig slurry – liquid	2	0.8	50	0.4	1.8	90	1.6	0.4	0.4
	4[a]	**1.5**	**50**	**0.8**	**2.2**	**90**	**2.0**	**0.7**	**0.7**
	6	2.2	50	1.1	2.6	90	2.3	1.0	1.0
Separated pig slurry (liquid portion)	3	1.1	50	0.6	2.0	90	1.8	ND	ND
Separated pig slurry (solid portion)	20	3.7	50	1.9	2.0	90	1.8	ND	ND

a. Typical dry matter and nitrogen contents of pig slurry are shown in bold.

b. For crop-available sulphur supply refer to Table 2.1 on page 12.

ND = no data

To convert kg/m³ to units/1000 gallons, multiply by 9.

Understanding the value of livestock manure applications

Example 2.2

30 m³/ha of cattle slurry (6% dry matter) is surface applied in early spring before first-cut silage. The soil is at P Index 2 and K Index 2-. Where the slurry is surface applied in the spring, the application saves up to £83/ha on manufactured fertiliser costs. This potential saving will be less following autumn or winter application, or where soil P or K Indices are above maintenance levels.

	Nitrogen (N)[e]	Phosphate (P_2O_5)[e]	Potash (K_2O)[e]	Financial saving £/ha
1. Estimated total nutrients in slurry (kg/m³)	2.6	1.2	2.5	
2. Estimated available nutrients in slurry (kg/m³)	0.9[a]	0.6	2.3	
3. Nutrients supplied by slurry that are equivalent to manufactured fertiliser (kg/ha)				
30 m³/ha supplies 78 kg/ha total N and 27 kg/ha crop available N	27	36[b]	75[b]	
Potential saving from manure use				**£83/ha[d]**
4. Nutrient requirements for first-cut silage to produce a yield of 6+ t DM/ha (kg/ha)				
Section 3: Grass and forage crops	120	40[c]	80[c]	
5. Manufactured fertiliser needed for the silage crop (kg/ha)				
Stage 4 minus Stage 3	93	4	5	
Actual saving for silage crop from manure use				**£83/ha**
6. Surplus manure nutrients for subsequent crops that are equivalent to manufactured fertiliser (kg/ha)				
Stage 3 minus Stage 4		NIL	NIL	
Saving for subsequent crops from manure use				**NIL**

a. Crop-available nitrogen is 35% of total nitrogen.

b. Total phosphate and potash content used in calculations to maintain soil Indices.

c. Nutrients required for spring application (soil P Index 2 and K Index 2-).

d. Saving for next crop plus value of surplus manure phosphate and potash which will contribute to the nutrient requirement of future crops.

e. Analyses of representative sample or typical values from Tables 2.8, 2.9 and 2.10 on pages 19–21.

Assumed fertiliser costs: Nitrogen 60 p/kg; phosphate 60 p/kg; potash 60 p/kg.

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Example 2.3

35 t/ha of pig FYM is applied in autumn to a clay soil before drilling winter wheat (8 t/ha grain yield, straw baled). It is NOT rapidly incorporated. The soil is at P Index 2 and K Index 2-. Where the FYM is surface applied in the autumn, the application saves up to £309/ha on manufactured fertiliser costs. This potential saving will be less where soil P or K Indices are above maintenance levels.

	Nitrogen (N)	Phosphate (P_2O_5)	Potash (K_2O)	Financial saving £/ha
1. Estimated total nutrients in FYM (kg/t)				
Analysis of representative sample or typical total values (Table 2.2 and 2.2)	7.0	6.0	8.0	
2. Estimated available nutrients in FYM (kg/t)				
Nitrogen (Table 2.3)	0.7[a]			
Phosphate and potash (Table 2.4)		3.6	7.2	
3. Nutrients supplied by FYM that are equivalent to manufactured fertiliser (kg/ha)				
35 t/ha supplies 245 kg/ha total N and 25 kg/ha crop available N	25	210[b]	280[b]	
Potential saving from manure use				**£309/ha[d]**
4. Nutrient requirements for winter wheat (kg/ha)				
Section 4: Arable crops (Table 4.15 and 4.12)	220	65[c]	85[c]	
5. Manufactured fertiliser needed for the wheat crop (kg/ha)				
Stage 4 minus Stage 3	195	NIL	NIL	
Actual saving for next crop from manure use				**£108/ha**
6. Surplus manure nutrients for subsequent crops that are equivalent to manufactured fertiliser (kg/ha)				
Stage 3 minus Stage 4		140	195	
Saving for subsequent crops from manure use				**£201/ha**

a. Crop-available nitrogen is 10% of total nitrogen.

b. Total phosphate and potash content used in calculations to maintain soil Indices.

c. Nutrients required for maintenance of soil reserves (soil P Index 2 and K Index 2-).

d. Saving for next crop plus value of surplus manure phosphate and potash which will contribute to the nutrient requirement of future crops.

Assumed fertiliser costs: Nitrogen 60 p/kg; phosphate 60 p/kg; potash 60 p/kg

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Biosolids

Biosolids (treated sewage sludge) are valuable fertilisers and soil conditioners, which have undergone processes to create an agriculturally beneficial product. However, applications must comply with several regulations and best practice guidance.

The Biosolids Assurance Scheme (BAS) brings together regulations and best practice to provide food chain and consumer reassurance that BAS Certified Biosolids can be safely and sustainably recycled to agricultural land.

Points to consider

- The Biosolids Nutrient Management Matrix provides a useful overview of regulation and guidance
- Seek support, guidance and nutrient analysis from the biosolids suppliers
- Contract and assurance scheme conditions

Further information

Sewage sludge on farmland: code of practice for England, Wales and Northern Ireland (2017)
www.gov.uk/government/publications/sewage-sludge-in-agriculture-code-of-practice/sewage-sludge-in-agriculture-code-of-practice-for-england-wales-and-northern-ireland

The Sludge (Use in Agriculture) Regulations 1989
www.legislation.gov.uk/

The Sludge (Use in Agriculture) (Amendment) Regulations 1990
www.legislation.gov.uk

The ADAS Safe Sludge Matrix (2001)

Biosolids Nutrient Management Matrix
www.adas.uk

Biosolids Assurance Scheme
www.assuredbiosolids.co.uk

Nutrient content of biosolids

Most biosolid applications apply more phosphate than is taken off by the following crop which may lead to increases in soil phosphate levels. The phosphate supplied by a biosolids application should be considered over the whole crop rotation by managing inputs in relation to crop offtake and soil analysis. On fields receiving biosolid applications, soil sampling every 3–5 years is essential.

Biosolids only contain small amounts of potash but useful quantities of sulphur and magnesium. Lime-stabilised biosolids also have value as liming materials with a neutralising value typically in the range of 2–6% per tonne fresh weight.

Biosolids contain heavy metals such as copper, lead, mercury, nickel or zinc but at lower concentrations than in the past. Heavy metals are elements that are potentially toxic to mammals above critical levels. However, copper, nickel and zinc are required by plants in very small amounts (micronutrients).

Where biosolids are used there is a statutory requirement to analyse topsoil for metals before land spreading to ensure that concentrations are below maximum permissible soil levels, and to control annual additions of metals. Analysis is typically carried out by the supplier. Limits for soil concentrations and permitted rates of addition of heavy metals are given in the Defra Code of Practice for Agricultural Use of Sewage Sludge.

Table 2.14 Typical total nitrogen content of biosolids (fresh weight basis)

	Dry matter %	Total nitrogen kg N/t
Digested cake	25	11
Thermally dried	95	40
Lime stabilised	25	8.5
Composted	40	11

To convert kg/m^3 to units/1,000 gallons, multiply by 9.
To convert kg/t to units/ton, multiply by 2.

Table 2.15 Percentage of total nitrogen available to next crop following biosolid applications (% of total nitrogen)

	Autumn[a] (Aug–Oct, 450 mm rainfall to end March)		Winter[a] (Nov–Jan, 250 mm rainfall to end March)		Spring[a] (Feb–Apr)	Summer[a] use on grassland
	Sandy/ shallow[b]	Medium/ heavy[b]	Sandy/ shallow[b]	Medium/ heavy[b]	All soils	All soils
Surface applied (ie not soil incorporated)						
Digested cake	10	15	15	15	15	15
Thermally dried	10	15	15	15	15	15
Lime stabilised	10	15	15	15	15	15
Composted	10	15	15	15	15	15
Soil incorporated after application – 6 hours for liquids and 24 hours for solids[c]						
Digested cake	10	15	15	15	20	N/A
Thermally dried	10	15	15	15	20	N/A
Lime stabilised	10	15	15	15	20	N/A
Composted	10	15	15	15	15	N/A

N/A = Not applicable

a. The nitrogen availability estimates assume 450 mm of rainfall (after autumn application) and 250 mm (after winter application) up to the end of soil drainage (end March). Where rainfall differs from these amounts, intermediate values of nitrogen availability should be used. For spring or summer applications, rainfall is not likely to cause movement of agronomically important amounts of nitrogen to below crop rooting depth.

b. Sandy/shallow = light sand soils and shallow soils. Medium/heavy = medium, deep fertile silt and deep clay soils. Use this category for organic and peaty soils.

c. The values assume incorporation by ploughing. Cultivation using discs or tines is likely to be less effective in minimising ammonia losses and intermediate values of nitrogen availability should be used.

Table 2.16 Phosphate, potash, magnesium and sulphur content of biosolids (fresh weight basis)

	Dry matter %	Phosphate			Potash			Sulphur[a]	Magnesium
		Total phosphate kg P_2O_5/t	Availability %	Available phosphate kg P_2O_5/t	Total potash kg K_2O/t	Availability %	Available potash kg K_2O/t	Total sulphur kg SO_3/t	Total magnesium kg MgO/t
Digested cake	25	11	50	5.5	0.6	90	0.5	8.2	1.6
Thermally dried	95	55	50	28	2.0	90	1.8	23	6.0
Lime stabilised	25	7	50	3.5	0.8	90	0.7	7.4	2.4
Composted	40	10	50	5.0	3.0	90	2.7	6.1	2.0

a. For crop-available sulphur supply refer to Table 2.1 on page 12.

To convert kg/m^3 to units/1000 gallons, multiply by 9.

To convert kg/t to units/ton, multiply by 2.

Understanding the value of biosolid applications

Example 2.4

20 t/ha of digested cake is applied in autumn before winter wheat (8 t/ha grain yield, straw baled), grown on a medium soil following a previous cereal crop. The sludge is rapidly incorporated. The soil is at P Index 2 and K Index 2-. Where the digested cake is surface applied in the autumn, the application saves up to £243/ha on manufactured fertiliser costs. This potential saving will be less where soil P or K Indices are above maintenance levels.

Stage and calculation procedure	Nitrogen (N)	Phosphate (P_2O_5)	Potash (K_2O)	Financial saving £/ha
1. Estimate total nutrients in digested cake (kg/t)				
Analysis provided by biosolids supplier or typical values from (Table 2.14 and 2.16)	11	11	0.6	
2. Estimate available nutrients in digested cake (kg/t)				
Nitrogen (Table 2.15)	1.7[a]			
Phosphate and potash (Table 2.16)		5.5	0.5	
3. Nutrients supplied by digested cake that are equivalent to manufactured fertiliser (kg/ha)				
20 t/ha supplies 220 kg/ha total nitrogen and 33 kg/ha of crop available N	33	220[b]	12[b]	
Potential saving from biosolids use				**£159/ha[d]**
4. Nutrient requirements for winter wheat (kg/ha)				
Section 4: Arable crops	220	65[c]	85[c]	
5. Manufactured fertiliser needed for the wheat crop (kg/ha)				
Stage 4 minus Stage 3	187	NIL	73	
Actual saving for wheat crop due to biosolids use				**£69/ha**
6. Surplus digested cake phosphate for subsequent crops that is equivalent to manufactured fertiliser (kg/ha)				
Stage 3 minus Stage 4		150	NIL	
Saving for subsequent crops due to biosolid use				**£90/ha**

a. Crop-available nitrogen is 15% of total nitrogen.
b. Total phosphate and potash content used in calculations to maintain soil P and K Indices.
c. Nutrients required for maintenance of soil reserves (soil P Index 2 and K Index 2-)
d. Saving for next crop plus value of surplus biosolids phosphate which will contribute to the nutrient requirement of future crops.

Assumed fertiliser costs: Nitrogen 60 p/kg; phosphate 60 p/kg; potash 60 p/kg.

Compost

Compost is both a soil conditioner and a source of major plant nutrients produced by the controlled biological decomposition of either ‘green waste’ (eg landscaping and garden waste) or from a mix of green waste and food waste, in the presence of oxygen. Compost usually contains little readily available nitrogen but repeated use over time can increase soil organic matter levels, improving workability and water retention properties.

Compost that is certified under the Compost Certification Scheme does not normally need an environmental permit or exemption to be in place for application to land. Non-certified compost is usually applied to land under the Environmental Permitting Regulations. The Compost Certification Scheme sets baseline quality specifications, set by the British Standards Institution Publicly Available Specification 100 (PAS100). While the PAS scheme specifies minimum quality criteria, they also allow customers to specify higher quality thresholds. It is important to check whether customers have any additional quality requirements before compost is applied.

Points to consider

- The nutrient content of compost products will vary depending on the source materials and treatment process
- PAS100 compost should be supplied with specific nutrient content data and other relevant information

Further information
Digestate and compost in agriculture
www.wrap.org.uk

Nutrient supply from compost

The available field experimental data indicate that green compost supplies only very small amounts of crop available nitrogen and that manufactured fertiliser nitrogen application rates should not be changed for the next crop grown. In the case of green/food compost, the available experimental data indicate that around 5% of the total nitrogen applied is available to the next crop grown (irrespective of application timing). Following the repeated use of green and green/food composts, long-term soil nitrogen supply will be increased.

As little work has been done on the availability of compost phosphate to crops, it is appropriate to extrapolate from work on livestock manures and sewage sludge, which suggests that around 50% of the phosphate will be available to the next crop grown, with the remainder released slowly over the crop rotation. Around 80% of compost potash is in a soluble form and is readily available for crop uptake. Composts also supply useful quantities of sulphur and magnesium, although there are no data on availability to the next crop grown.

Table 2.17 Typical total nutrient content of compost (fresh weight basis)

Compost type	Dry matter %	Total nitrogen kg N/t	Total phosphate kg P_2O_5/t	Total potash kg K_2O/t	Total sulphur kg SO_3/t	Total magnesium kg MgO/t
Green	60	7.5	3.0	6.8	3.4	3.4
Green/food	60	11	4.9	8.0	5.1	3.4

Understanding the value of compost applications

Example 2.5

30 t/ha of green compost is applied in autumn to a sandy soil before drilling winter barley (8 t/ha grain yield, straw baled). The soil is at P Index 2 and K Index 2-. Allowing for the green compost nutrient supply saves up to £153/ha. This potential saving will be less where soil P or K Indices are above maintenance levels.

Stage and calculation procedure	Nitrogen (N)	Phosphate (P_2O_5)	Potash (K_2O)	Financial saving £/ha
1. Estimated total nutrients in green compost (kg/t)				
Analysis provided by green compost supplier or typical values from (Table 2.17)	7.5	3.0	6.8	
2. Estimated available nutrients in green compost (kg/t)				
Nitrogen	NIL[a]			
Phosphate and potash (Table 2.17)		1.5	5.4	
3. Nutrients supplied by green compost that are equivalent to manufactured fertiliser (kg/ha)				
30 t/ha supplies 225 kg/ha total nitrogen	NIL[a]	90[b]	204[b]	
Potential saving from green compost use				**£176/ha[d]**
4. Nutrient requirements for barley (kg/ha)				
Section 4: Arable crops	200	65[c]	95[c]	
5. Manufactured fertiliser needed for the barley crop (kg/ha)				
Stage 4 minus Stage 3	200	NIL	NIL	
Actual saving for next crop due to green compost use				**£99/ha**
6. Surplus compost phosphate and potash for subsequent crops that is equivalent to manufactured fertiliser (kg/ha)				
Stage 3 minus Stage 4	NIL	20	109	
Saving for subsequent crops due to green compost use				**£77/ha**

a. Crop available nitrogen is negligible or, for practical purposes, nil.

b. Total phosphate and potash content used in calculations to maintain soil P and K Indices.

c. Nutrients required for maintenance of soil reserves (soil P Index 2 and K Index 2-).

d. Saving for barley crop plus value of surplus compost phosphate and potash which will contribute to the nutrient requirement of future crops.

Assumed fertiliser costs: Nitrogen 60 p/kg; phosphate 60 p/kg; potash 60 p/kg.

Digestate

Digestate is one of the products of anaerobic digestion, which is the controlled biological decomposition of biodegradable materials such as food wastes, animal manures and crops (eg maize and rye) in the absence of oxygen. Digestate is also known as 'biofertiliser' if it meets Biofertiliser Certification Scheme standards.

Digestate that is certified under the Biofertiliser Certification Scheme and farm-sourced digestate does not normally need an environmental permit or exemption to be in place for application to land. Non-certified digestate from non-agricultural sources is usually applied to land under the Environmental Permitting Regulations.

The Biofertiliser Certification Scheme sets baseline quality specifications, set by the British Standards Institution Publicly Available Specification 110 (PAS110). While the PAS scheme specifies minimum quality criteria, they also allow customers to specify higher quality thresholds. It is important to check whether customers have any additional quality requirements before digestate is applied.

Further information

Digestate and compost in agriculture
PAS110
www.wrap.org.uk

Biofertiliser Certification Scheme
www.biofertiliser.org.uk

Digestate is normally produced 'whole' (a slurry-like material with a dry matter content of around 5%), but this can be separated into fibre and liquor fractions. Typically, whole digestate and digestate liquor contain significantly more nitrogen in the readily available form than cattle slurry. Usually 80–90% of the nitrogen in whole and liquor digestate is in the readily available form and applications would be subject to closed-spreading periods in Nitrate Vulnerable Zones.

In separated fibre (typically 25% dry matter), usually less than 30% of the total nitrogen is in the readily available form and applications would not be subject to closed spreading periods in Nitrate Vulnerable Zones, although this should be checked. Separated fibre contains considerably more phosphate than whole and liquor digestate.

The nutrient content of the digestate is controlled by the feedstock used in the digestion process. Food-based digestates will typically have much higher nutrient contents than farm-sourced (eg crop and manure based) digestate. The values in Tables 2.18 and 2.19 are indicative and nutrient contents are likely to vary considerably between sites.

PAS110 digestate will have been sampled and analysed regularly during production and should be supplied with specific nutrient content data. It is recommended that application rates of high readily available nitrogen digestates are carefully controlled to reduce the risk of excessive nitrogen applications.

Points to consider

- The nutrient content of digestate products will vary depending on the source materials and treatment process
- PAS110 digestate should be supplied with specific nutrient content data and other relevant information

Table 2.18 Typical total nutrient contents for food-based digestate

Type	Dry matter %	Total N	Total P_2O_5	Total K_2O	Total MgO	Total SO_3
	kg/m³ or kg/t					
Whole	4.1	4.8[a,b]	1.1	2.4	0.2	0.7
Separated liquor	3.8	4.5[a,b]	1.0	2.8	0.2	1.0
Separated fibre	27.0	8.9[c]	10.2	3.0	2.2	4.1

a. Crop-available nitrogen supply from spring applications is around 55% of total nitrogen applied. Crop-available nitrogen supply following autumn applications to winter cereals is around 15% of total nitrogen applied.

b. For autumn applications to grass or oilseed rape assume a crop-available nitrogen supply of 35% of total nitrogen applied.

c. For autumn applications assume crop-available nitrogen supply of 10% of total nitrogen applied and 15% of total nitrogen applied for spring applications.

Table 2.19 Typical total nutrient contents for farm-sourced digestate

Type	Dry matter %	Total N	Total P_2O_5	Total K_2O	Total MgO	Total SO_3
	kg/m³ or kg/t					
Whole	5.5	3.6[a,b]	1.7	4.4	0.6	0.8
Separated liquor	3.0	1.9[a,b]	0.6	2.5	0.4	<0.1
Separated fibre	24.0	5.6[c]	4.7	6.0	1.8	2.1

a. Crop-available nitrogen supply from spring applications is around 55% of total nitrogen applied. Crop-available nitrogen supply following autumn applications to winter cereals is around 15% of total nitrogen applied.

b. For autumn applications to grass or oilseed rape assume a crop-available nitrogen supply of 35% of total nitrogen applied.

c. For autumn applications assume crop-available nitrogen supply of 10% of total nitrogen applied and 15% of total nitrogen applied for spring applications.

Nutrient supply from digestate

The amount of crop available nitrogen from digestate will depend on how much of the nitrogen applied is lost following application by ammonia emissions and nitrate leaching.

Information from research studies has shown that ammonia emissions from applications of whole and liquid digestate can be greater than from cattle slurries. Ammonia emissions from liquid digestate applications can be reduced by using precision application equipment such as band spreaders or shallow injectors or, where appropriate, be incorporated rapidly into the soil. Precision application equipment allows digestate to be spread evenly, increasing the nutrient use efficiency.

Spring applications are likely to supply more crop available nitrogen than autumn timings as a result of reduced nitrate leaching losses. Data from the DC-Agri project indicate that crop available nitrogen supply from spring applications of food-based digestate to cereal crops was 55% of total nitrogen compared with 10% of total nitrogen applied from autumn applications. The use of precision application is recommended to ensure even application.

As little work has been done on the availability of digestate phosphate and potash to crops, it is appropriate to extrapolate from work on cattle slurries which suggests that around 60% of the phosphate and 90% of potash will be available to the next crop grown, with the remainder released slowly over the crop rotation. Some digestates also supply useful quantities of sulphur and magnesium, although there are no data on availability to the next crop grown.

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Understanding the value of digestate applications

Example 2.6

30 m³/ha of whole food-based digestate is applied using a band spreader in spring to winter wheat on a sandy soil (8 t/ha grain yield, straw baled, previous crop – cereal). The soil is at P Index 2 and K Index 2-. Allowing for the digestate nutrient supply saves £110/ha. This potential saving will be less where soil P or K Indices are above maintenance levels.

Stage and calculation procedure	Nitrogen (N)	Phosphate (P_2O_5)	Potash (K_2O)	Financial saving £/ha
1. Estimated total nutrients in food-based digestate (kg/t)				
Typical values	4.8	1.1	2.4	
2. Estimated available nutrients in food-based digestate (kg/t)				
Nitrogen (assuming 55% availability from spring application)	2.6			
Phosphate and potash		0.7	2.2	
3. Nutrients supplied by digestate that are equivalent to manufactured fertiliser (kg/ha)				
30 m³/ha supplies 145 kg/ha total nitrogen	78	33[a]	72[a]	
Potential saving from whole food-based digestate use				**£110/ha[d]**
4. Nutrient requirements for winter wheat (kg/ha)				
Section 4: Arable crops	180	65[b]	85[b]	
5. Manufactured fertiliser needed for the winter wheat crop (kg/ha)				
Stage 4 minus Stage 3	102	32	13	
Actual saving for winter wheat crop due to whole food-based digestate use				**£110/ha**
6. Surplus digesate phosphate and potash for subsequent crops that is equivalent to manufactured fertiliser (kg/ha)				
Stage 3 minus Stage 4	NIL	NIL	NIL	
Saving for subsequent crops due to digestate compost use				**NIL**

a. Total phosphate and potash content used in calculations to maintain soil P and K Indices.
b. Nutrients required for maintenance of soil reserves (soil P Index 2 and K Index 2-)
c. Saving for current crop.
d. Assumed fertiliser costs: Nitrogen 60 p/kg; phosphate 60 p/kg; potash 60 p/kg.

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Waste-derived materials

The recycling of industrial wastes to agricultural land is controlled by environmental permitting regulations. These regulations allow the spreading of some industrial wastes onto agricultural land under a permit or an exemption provided that certain conditions are met, including demonstration that they provide agricultural benefit or ecological improvement.

The application of such wastes must be registered with the Environment Agency who will supply advice on the regulations and their interpretation. Industrial waste materials are supplied to farmers with specific nutrient content data and advice on how to best manage these materials to the benefit of soils and crops. The typical nutrient content of selected industrial 'waste' materials that are commonly recycled to farmland are summarised below.

Paper crumble

Table 2.20 Typical total nutrient content of paper crumble (fresh weight basis)

	Dry matter %	Total nitrogen kg N/t	Total phosphate kg P_2O_5/t	Total potash kg K_2O/t	Total sulphur kg SO_3/t	Total magnesium kg MgO/t
Chemically/ physically treated	40	2.0	0.4	0.2	0.6	1.4
Biologically treated	30	7.5	3.8	0.4	2.4	1.0

To convert kg/t to units/ton, multiply by 2.

Following the application of chemically/physically treated paper crumble nitrogen, 'lock-up' commonly occurs due to the high carbon:nitrogen ratio of the paper crumble which immobilises soil nitrogen. As a general rule, around 0.8 kg of inorganic nitrogen is required per tonne (fresh weight) of paper crumble applied to compensate for the nitrogen 'lock-up' in the soil. As biologically treated paper crumble has a lower carbon:nitrogen ratio, nitrogen 'lockup' is not usually experienced following land spreading.

Spent mushroom compost

Table 2.21 Typical total nutrient content of spent mushroom compost (fresh weight basis)

	Dry matter %	Total nitrogen kg N/t	Total phosphate kg P_2O_5/t	Total potash kg K_2O/t	Total sulphur kg SO_3/t	Total magnesium kg MgO/t
Spent mushroom compost	35	6.0	5.0	9.0	ND	ND

To convert kg/t to units/ton, multiply by 2.

Further information

Environmental permitting regulation

www.gov.uk/topic/environmental-management/environmental-permits

Water treatment cake

Table 2.22 Typical total nutrient content of water treatment cake (fresh weight basis)

	Dry matter %	Total nitrogen kg N/t	Total phosphate kg P_2O_5/t	Total potash kg K_2O/t	Total sulphur kg SO_3/t	Total magnesium kg MgO/t
Water treatment cake	25	2.4	3.4	0.4	5.5	0.8

To convert kg/t to units/ton, multiply by 2.

Food industry wastes

Table 2.23 Typical total nutrient content of food industry wastes (fresh weight basis)

	Dry matter %	Total nitrogen kg N/t	Total phosphate kg P_2O_5/t	Total potash kg K_2O/t	Total sulphur kg SO_3/t	Total magnesium kg MgO/t
Dairy	4	1.0	0.8	0.2	ND	ND
Soft drinks	4	0.3	0.2	Trace	ND	ND
Brewing	7	2.0	0.8	0.2	ND	ND
General	5	1.6	0.7	0.2	ND	ND

To convert kg/t to units/ton, multiply by 2.

Glossary

Available (nutrient)	Form of a nutrient that can be taken up by a crop immediately or within a short period so acting as an effective source of that nutrient for the crop.
Biosolids	Treated sewage sludge.
Clay	Finely divided inorganic crystalline particles in soils, less than 0.002 mm in diameter.
Coefficient of variation (CV)	Measure of the unevenness of application of fertilisers or manures. CV of 0% indicates perfectly even spreading, unachievable in practice. Correct operation of a well set up spreader should give a CV of 10% for fertilisers and 25% for manures under field conditions.
Compost	Organic material produced by aerobic decomposition of biodegradable organic materials.
Content (nutrient)	Commonly used instead of the more accurate ‘concentration’ to describe nutrients in fertiliser or organic manure. For example, 6 kg N/t often is described as the nitrogen content of a manure.
Crop available nitrogen	The total nitrogen content of organic manure that is available for crop uptake in the growing season in which it is spread on land.
Denitrification	Microbial conversion of nitrate and nitrite in anaerobic soil to nitrogen gas and some nitrous oxide.
Digestate	Organic material produced by anaerobic digestion of biodegradable organic materials. May be separated into liquid and fibre fractions after digestion.
Dirty water	Lightly contaminated run-off from lightly fouled concrete yards or from the dairy/parlour that is collected separately from slurry. It does not include liquids from weeping-wall stores, strainer boxes, slurry separators or silage effluent which are rich in nitrogen and regarded as slurries.
FACTS	UK national certification scheme for advisers on crop nutrition and nutrient management. Membership renewable annually. A FACTS Qualified Adviser has a certificate and an identity card.
Farmyard manure (FYM)	Livestock excreta that is mixed with straw bedding material that can be stacked in a heap without slumping.
Fertiliser	See Manufactured fertiliser.
Incorporation	A technique (discing, rotovating, ploughing or other methods of cultivation) that achieves some mixing between an organic manure and the soil. Helps to minimise loss of nitrogen to the air through volatilisation, and nutrient run-off to surface waters.
Layer manure	Poultry excreta with little or no bedding.

Leaching Process by which soluble materials such as nitrate or sulphate are removed from the soil by drainage water passing through it.

Livestock manure Dung and urine excreted by livestock or a mixture of litter, dung and urine excreted by livestock, even in processed organic form. Includes FYM, slurry, poultry manure, separated manures, and granular or pelletised manures.

Manufactured fertiliser Any fertiliser that is manufactured by an industrial process. Includes conventional straight and NPK products (solid or fluid), organo-mineral fertilisers, rock phosphates, slags, ashed poultry manure, and liming materials that contain nutrients.

Manure See Livestock manure and Organic manure.

Micronutrient Boron, copper, iron, manganese, molybdenum and zinc that are needed in very small amounts by crops. Cobalt and selenium are taken up in small amounts by crops and are needed in human and livestock diets.

Mineralisation Microbial breakdown of organic matter in the soil, releasing nutrients in crop-available, inorganic forms.

Neutralising Value (NV) Percentage calcium oxide (CaO) equivalent in a material. 100 kg of a material with a neutralising value of 52% will have the same neutralising value as 52 kg of pure CaO. NV is determined by a laboratory test.

Nitrate Vulnerable Zones (NVZs) Areas designated by Defra as being at risk from agricultural nitrate pollution.

Nitrous oxide (N_2O) A potent greenhouse gas that is emitted naturally from soils. The amount emitted is related to supply of mineral nitrogen in the soil so increases with application of manures and fertilisers, incorporation of crop residues and growth of legumes. It is greater in organic and peaty soils than in other soils.

Offtake Amount of a nutrient contained in the harvested crop (including straw, tops or haulm) and removed from the field. Usually applied to phosphate and potash.

Organic materials (manure) Livestock manures and all other nitrogen-containing organic materials, such as sewage sludge, composts, food wastes and organic wastes (treated and untreated).

Peaty soil (peat) Soil containing more than 20% organic matter.

Poultry manure Excreta produced by poultry, including bedding material that is mixed with excreta, but excluding duck manure with a readily available nitrogen content of 30% or less.

Prilled fertiliser Fertiliser in which particles (prills) are formed by allowing molten material to fall as droplets in a tower. Droplets solidify during the fall and tend to be more spherical and somewhat smaller than granules.

Readily available nitrogen Nitrogen that is present in livestock and other organic manures at the time of sampling in molecular forms that can be taken up immediately by the crop (ammonium or nitrate, or in poultry manure uric-acid N). High in slurries and poultry manures (typically 35–70% of total N) and low in FYM (typically 10–25%).

Sand Soil mineral particles larger than 0.05 mm.

Silt Soil mineral particles in the 0.002–0.05 mm diameter range.

Slurry Excreta of livestock (other than poultry), including any bedding, rainwater and washings mixed with it, which can be pumped or discharged by gravity. The liquid fraction of separated slurry is also defined as slurry.

Soil Index (P, K or Mg) Concentration of available P, K or Mg, as determined by standard analytical methods, expressed in bands or Indices.

Soil Nitrogen Supply (SNS) The amount of nitrogen (kg N/ha) in the soil that becomes available for uptake by the crop in the growing season, taking account of nitrogen losses.

Soil organic matter Often referred to as humus. Composed of organic compounds ranging from undecomposed plant and animal tissues to fairly stable brown or black material with no trace of the anatomical structure of the material from which it was derived.

Soil type Description based on soil texture, depth, chalk content and organic matter content.

Solid manure Organic manure which can be stacked in a freestanding heap without slumping.

Target Index Lowest soil P or K Index at which there is a high probability crop yield will not be limited by phosphorus or potassium supply. See Soil Index (P, K or Mg).

Tillage land Land that is not being used for grass production and is sown with a crop.

Volatilisation Loss of nitrogen as ammonia from the soil to the atmosphere.

Water-soluble phosphate Phosphate, expressed as P_2O_5, that is measured by the statutory method for fertiliser analysis. Not necessarily a measure of available phosphate – high water solubility indicates high availability but low water solubility does not necessarily indicate low availability.

Notes

Notes

Notes

Acknowledgements

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Greenhouse Gas Action Plan:
The industry-wide Greenhouse Gas Action Plan (GHGAP) for agriculture focuses on improving resource use efficiency in order to enhance business performance whilst reducing GHG emissions from farming.

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Nutrient Management Guide (RB209)

Updated January 2019

Section 3 Grass and forage crops

Using the Nutrient Management Guide (RB209)

This latest revision of RB209 is based on research carried out since the previous edition was published in 2010. The revision includes updated recommendations, including those for additional crops and information on the nutrient content of additional organic materials.

RB209 was first published in 1973 and was the first comprehensive set of fertiliser recommendations from the Ministry of Agriculture, Fisheries and Food (MAFF). RB209 stands for Reference Book 209.

To improve the accessibility of the recommendations and information AHDB's Nutrient Management Guide (RB209) is published as seven sections that will be updated individually.

Further information

The Nutrient Management Guide (RB209) will be updated regularly.

Please email your contact details to AHDB so that we can send you updates when they are published - comms@ahdb.org.uk

RB209: Nutrient Management

Download the app for Apple or Android phones to access the current version of all sections of the guide. With quick and easy access to videos, information and recommendations from the guide, it is practical for use in the field.

Always consider your local conditions and consult a FACTS Qualified Adviser if necessary.

Section 1 Principles of nutrient management and fertiliser use

Section 2 Organic materials

Section 3 Grass and forage crops

Section 4 Arable crops

Cereals

Oilseeds

Sugar beet

Peas and beans

Biomass crops

Section 5 Potatoes

Section 6 Vegetables and bulbs

Section 7 Fruit, vines and hops

This section provides guidance for grass and forage crops (in-situ grazing or ensiling) and should be read in conjunction with Sections 1 and 2. For each crop, recommendations for nitrogen (N), phosphate (P_2O_5) and potash (K_2O) are given in kilograms per hectare (kg/ha). Magnesium (MgO), sulphur (as SO_3) and sodium (as Na_2O) recommendations, also in kg/ha, are given where these nutrients are needed.

Recommendations are given for the rate and timing of nutrient application. The recommendations are based on the nutrient requirements of the crop being grown, while making allowance for the nutrients supplied by the soil.

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Summary of main changes from previous edition

1. Overall presentation

   a. Fertiliser recommendations for grass and forage crops are now presentd in **Section 3: Grass and forage crops** that incorporates the relevant appendices.

2. New and revised recommendations

   a. Grassland recommendations have been revised to cater for different levels of grass production, without linking to particular animal production systems (dairy, beef or sheep), milk yield, stocking rate or concentrate use.

   b. Whole season nitrogen requirements and nitrogen application sequences are provided separately for cutting and grazing situations.

   c. The recommendation tables indicate how it is possible to adjust total nitrogen requirements according to Soil Nitrogen Supply (SNS), Grass Growth Class (GGC) and seasonal rainfall to produce the target amount of home-grown forage.

   d. Recommendations for wholecrop cereals have been added. Information on phosphate and potash in Table 3.27 has been updated and simplified.

   e. Phosphate and potash recommendations for fodder beet have been increased, based on new data on crop demand and offtake.

Further information
AHDB UK Fertiliser Price Series
ahdb.org.uk/fertiliser-information

Introduction

This section provides nutrient recommendations for both grass and forage crops. As with any crop it is important to match nutrient inputs to the demands of the grass sward or forage crop. Doing this will increase nutrient use efficiency, optimise grassland productivity, prevent loss of excess nutrients to the environment, and cut input costs by reducing the need for purchased fertilisers.

For grass and forage crops, there are a number of factors which affect how efficiently nutrients are utilised by the plant. Those applied through fertilisers or manures (especially N) will be used most effectively when there is:

- **Good soil structure – compacted or poorly draining soils will hinder plant nutrient uptake and can increase gaseous release of N**
- **Balanced soil fertility – nutrient efficiency (particularly N) is higher when soils have optimal levels of phosphate, potash, magnesium and sulphur**
- **Moderate soil temperatures – at low temperatures, nutrient uptake by the plant will diminish leading to a higher risk of leaching. North-facing slopes and higher altitude fields will have lower soil temperatures**
- **Sufficient soil moisture – too much moisture will increase the risk of leaching losses, too little will curb plant growth and reduce nutrient uptake**
- **Optimum soil pH – very low or high soil pH will reduce the amount of nutrients available to the plant. Optimum soil pH for grassland is 6.0 for mineral soils, 5.7 for intermediate organic soils and 5.3 for peaty soils. Aim to raise pH to 0.2 units above the optimum**
- **Good sward composition – more productive sward species, eg perennial ryegrass and timothy, will be more responsive to fertiliser inputs**

It is important to plan the amount of grass and forage crop production that needs to be achieved in each field, remembering that nutrient applications may need to be adjusted for seasonal and weather conditions.

Checklist for decision making

Before applying fertilisers to grassland or forage crops it is important to:

1. Carry out a soil test (page 8).
2. Understand if the field is within a nitrate vulnerable zone (NVZ) and check the rules for application rates and timing for organic materials and fertilisers.
3. Assess soil structure.
4. Ensure drainage systems are maintained and functioning correctly.
5. Calibrate the fertiliser spreader.
6. Calculate any nutrient available for additions of organic materials **(Section 2: Organic materials)**
7. Consider the environmental risks that fertiliser or organic manure use could impact eg connectivity of field to water or proximity of sensitive habitat.
8. Keep good records of organic materials and fertiliser applications across the farm.

Further information

AHDB Field drainage guide
ahdb.org.uk/knowledge-library/field-drainage-guide

Beef and sheep manual 7: Managing nutrients for Better Returns
beefandlamb.ahdb.org.uk/returns/nutrition-and-forage

Healthy grassland soils – Four quick steps to assess soil structure
www.healthygrasslandsoils.co.uk

Think soils
ahdb.org.uk/knowledge-library/thinksoils

Grass and forage requirements

Well-managed grass remains the cheapest feed available to livestock farms. However, to make the most of this resource, it is important to know:

- How much grass the farm is capable of producing
- How much grass needs to be produced to meet livestock requirements

The recommendations presented in this guide use target dry matter yield to help determine the amount of nutrient required.

Further information

Beef and sheep manual 8: Planning grazing strategies for Better Returns
beefandlamb.ahdb.org.uk/returns/nutrition-and-forage

Grass+
dairy.ahdb.org.uk/technical-information

Points to consider

- Nitrogen response occurs in two stages: firstly, nitrogen is taken up rapidly and secondly, dry matter yield increases
- Nitrogen uptake is more rapid than yield increase and is less affected by some adverse conditions, such as short day length. It is necessary, therefore, to distinguish greening of grass (associated with nitrogen uptake) from actual growth

Measuring grass yield

Measuring on farm grass production in terms of dry matter yield is an essential component of any efficient livestock system. It can also be a useful tool in deciding the target grass dry matter yield which, in turn, will help identify the appropriate nitrogen recommendation. A range of methods exist to measure dry matter yield production across a season.

For grazed fields, these include:

- Rising plate meter
- Sward stick
- Cut and weight (quadrat measurements)

For silage fields, cuts can be used to determine grass dry matter yield using trailer-mounted weigh cells, weigh bridges or a small quadrat, or record total weight of bales from the field. It may be necessary to send off sub-samples to measure dry matter percentage.

Further information

Visit ahdb.org.uk/RB209
to view videos on how to use plate meters and sward sticks.

Calculating target dry matter yield from livestock forage requirement

Aiming to optimise the amount of meat or milk produced from home-grown forages should help reduce the requirement for purchased concentrates and reduce cost of production. To maximise meat and milk production from grass and forage, efficient production and utilisation is needed and it is important to match supply to demand to avoid oversupply of nutrients to crops and poor utilisation.

Further information

Beef and sheep manual 1: Improving pasture for Better Returns
Beef and sheep manual 4: Managing clover for Better Returns
Beef and sheep manual 5: Making grass silage for Better Returns
Beef manual 7: Feeding growing and finishing cattle for Better Returns
Sheep manual 12: Improving ewe nutrition for Better Returns
beefandlamb.ahdb.org.uk/returns/nutrition-and-forage

Feeding+
Grass+ Factsheet 2: Rising plate meter
dairy.ahdb.org.uk/technical-information

British Grassland Society
www.britishgrassland.com/page/fact-sheets

Tried & Tested: Feed planning for cattle and sheep
Tried & Tested: Think Manures – a guide to manure managements
www.nutrientmanagement.org

Sampling for soil pH, phosphorus, potassium and magnesium

Current phosphate, potash and magnesium recommendations are based on achieving and maintaining target soil Indices for each nutrient in the soil throughout the crop rotation. Soil analysis should be done every 3–5 years. The use of soil analysis as a basis for making nutrient decisions and the procedure for taking soil samples is described below.

Taking soil samples for pH, phosphate, potassium and magnesium

Soil sampling must be done accurately to avoid misleading results and expensive mistakes.

- The soil in each field should be sampled every 3–5 years
- Collect samples at the same point in the rotation and well before growing a sensitive crop eg sugar beet
- For arable and forage crops, aim to sample immediately after the harvest of the previous crop
- Do not sample within six months of a lime or fertiliser application (except nitrogen) or six weeks of last organic manure application in autumn, and avoid sampling when the soil is very dry
- Do not take samples where muck heaps or feeders have been, in headlands, or in the immediate vicinity of hedges, trees or other unusual features
- The soil sample must be representative of the area sampled. Areas of land known to differ in some important respects (eg soil type, previous cropping, applications of manure, fertiliser or lime) should be sampled separately. Small areas known to differ from the majority of a field should be excluded from the sample
- Ideally the sampled area should be no larger than four hectares
- Clean tools before starting and before sampling a new area
- Walk a 'W' pattern across the sampling area, stopping at least 25 times
- At each point, collect a subsample (core) using a gouge corer or screw auger
  - Sample to 7.5 cm depth in long-term grassland fields
  - Sample to 15 cm depth in arable fields, short-term (<5 year) leys or grassland about to be ploughed and re-seeded
- The subsamples should be bulked to form a representative sample and sent to the laboratory for analysis
- Use appropriate packaging (normally available from the laboratory) and label samples clearly, providing as much information about the field and crop as possible

For soils prone to acidity, more frequent testing may be needed than the cycle used for phosphate, potash and magnesium. Since acidity can occur in patches, spot testing with a soil indicator across the field is often useful. Soil indicator tests can also be useful on soils which contain fragments of free lime, since these can give a misleadingly high pH when analysed following grinding in the laboratory.

PAAG
Professional Agricultural Analysis Group

Most UK laboratories are members of the PAAG that offers farmers and advisers confidence in laboratory analysis.

- Proficiency Tests (often called ring tests) carried out by Wageningen University, guaranteeing that analysis from any member can be trusted.
  www.wepal.nl
- List of UK laboratories
  www.nutrientmanagement.org/what-we-do/support-and-advice/find-a-laboratory
- Sampling guidelines
  www.nutrientmanagement.org/library/sampling

Classification of soil analysis results into Indices

The laboratory soil analysis results for P, K and Mg (in mg/kg dry soil) can be converted into soil Indices using Table 3.1.

Table 3.1 Classification of soil P, K and Mg analysis results into Indices

Index	Phosphorus (P)		Potassium (K)	Magnesium (Mg)
	Olsen P	Resin P	Ammonium nitrate extract	
	mg/litre			
0	0–9	0–19	0–60	0–25
1	10–15	20–30	61–120	26–50
2	16–25	31–49	121–180 (2-) 181–240 (2+)	51–100
3	26–45	50–85	241–400	101–175
4	46–70	86–132	401–600	176–250
5	71–100	>132	601–900	251–350
6	101–140		901–1,500	351–600
7	141–200		1,501–2,400	601–1,000
8	201–280		2,401–3,600	1,001–1,500
9	Over 280		Over 3,600	Over 1,500

Further information

Beef and sheep manual 3: Improving soils for Better Returns
beefandlamb.ahdb.org.uk/returns/nutrition-and-forage

Healthy Grassland Soils
www.healthygrasslandsoils.co.uk

Grassland recommendations

Phosphate and potash recommendations

For phosphate and potash recommendations, the results of a recent soil analysis showing the soil Index will be needed. The use of soil analysis as a basis for making nutrient decisions is described on page 10, 11 and 18.

Recommendations are given in the tables as phosphate (P_2O_5) and potash (K_2O). Conversion tables are given on page 35.

- Recommendations for soils at target Indices (2 for phosphate and 2- for potash) are maintenance dressings intended to meet crop requirements and maintain soil reserves to prevent depletion of soil fertility
- Recommendations at Indices lower than target include an allowance for building up soil reserves over several years, as well as meeting immediate crop requirement
- All recommendations are given for the mid-point of each Index (mid-point of 2- for potash)
- Herbage or forage analysis can be useful to assess the adequacy of recent phosphate and potash applications and as a basis for adjusting nutrient use for future cuts. Samples uncontaminated with slurry or soil should be taken. Phosphorus (P) deficiency is indicated if the P concentration is below 0.35% P. Potassium (K) deficiency is indicated if the herbage potassium concentration is below 2.5% potasssium (in dry matter) or the nitrogen:potassium ratio of the herbage is above 1:1.3
- In the first season after autumn or spring sowing, deduct the amounts of phosphate and potash applied to the seedbed from the recommendations
- Phosphate and potash applications should be adjusted where yields are likely to be greater or smaller than those shown in the tables in this section. Table 3.2 provides typical values of the phosphate and potash content in crop material per tonne of yield. For example, the offtake for a 10t cut of 30% DM grass silage would be 21 kg of phosphate and 72 kg of potash

Phosphate and potash in crop material

Table 3.2 Phosphate and potash in crop material

		Phosphate	Potash
		kg/t of fresh material	
Grass	Fresh grass (15–20% DM)	1.4	4.8
	Silage (25% DM)	1.7	6.0
	Silage (30% DM)	2.1	7.2
	Hay (86% DM)	5.9	18.0
	Haylage (45% DM)	3.2	10.5
Wholecrop cereals		1.8	5.4
Kale		1.2	5.0
Maize	Silage (30% DM)	1.4	4.4
Swedes	Roots only	0.7	2.4
Fodder beet	Roots only	0.7	4.0

The offtake values are based on herbage or forage concentrations of 0.3% phosphorus (P) and 2.0% potassium (K) (on a DM basis). Large data sets of forage analyses show the five-year average (2012–16) concentrations are 0.33% P and 2.75% K. Offtake values should be adjusted based on actual figures from analyses.

Phosphate and potash for grass silage

Where yields are likely to be greater or smaller than shown in Table 3.3, phosphate and potash applications should be adjusted accordingly (see Table 3.2).

At soil K Indices 2+ or below, extra potash is needed after cutting as follows:

- In one or two cut systems, apply an extra 60 kg potash per ha after the last cut or by the autumn. Where grazing follows cutting, this may be applied as an extra 30 kg potash per ha per grazing for up to two grazings
- In three cut systems, apply an extra 30 kg potash per ha after cutting
- In four cut systems, no extra potash is needed

Table 3.3 Phosphate and potash recommendations for grass silage

	P or K Index				
	0	1	2	3	4 and higher
	kg/ha				
First cut (23t FW/ha)					
Phosphate[a]	100	70	40M	20	0
Potash[b] – previous autumn – spring	 60 80	 30 80	 0 80M (2-) 60 (2+)	 0 30	 0 0
Second cut (15 t FW/ha)					
Phosphate[a]	25	25	25M	0	0
Potash[b]	120	100	90M (2-) 60 (2+)	40	0
Third cut (9 t FW/ha)					
Phosphate[a]	15	15	15M	0	0
Potash[b]	80	80	80M (2-) 40 (2+)	20	0
Fourth cut (7 t FW/ha)					
Phosphate[a]	10	10	10M	0	0
Potash[b]	70	70	70M (2-) 40 (2+)	20	0

a. At soil phosphate Index 2 or above, the whole of the total phosphate requirement may be applied in the spring. At phosphate Index 0 and 1, the phosphate recommendation for the third and fourth cuts may be added to the 2nd cut recommendation and applied in one dressing.

b. To minimise luxury uptake of potash, no more than 80–90kg potash per ha should be applied in the spring for the first cut. The balance of the recommended rate should be applied in the previous autumn.

The yields are based on wilted silage at 25% dry matter content as removed from the field.

FW = fresh weight. M = maintenance level

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Phosphate and potash for grazing

Table 3.4 Phosphate and potash recommendations for grazed swards

	P or K Index			
	0	1	2	3
	kg/ha			
Phosphate[a]	80	50	20	0
Potash[b]	60	30	0	0

a. Phosphate may be applied in several small applications during the season, though there may be a small response if it is all applied in early spring for the first grazing.

b. Potash may either be applied in one application in June or July, or in several small applications during the season. At Index 0, apply 30 kg potash per ha for the first grazing. Where there is a known risk of hypomagnesaemia, application of potash in spring should be avoided.

Point to consider

- Tables contain the total nutrient required, remember to deduct nutrients applied as organic materials **(Section 2: Organic materials)**

Example 3.1

A field with a P Index of 1 and K Index of 1 is having one cut of silage removed.

The recommendations would be 70 kg/ha of phosphate. For potash, 30 kg/ha would be needed as an autumn dressing, 80 kg in the spring and 60 kg after the cut or by the autumn. 30m^3/ha of 6% cattle slurry in the spring would supply around 18 kg of phosphate and 69 kg of potash per ha, plus 23 kg of N.

Phosphate and potash for hay

Table 3.5 Phosphate and potash recommendations for hay

	P or K Index				
	0	1	2	3	Over 3
	kg/ha				
Phosphate	80	55	30M	0	0
Potash	140	115	90M (2-) 65 (2+)	20[a]	0

a. Potash may be unnecessary in upper half of Index   M = maintenance level

Newly sown swards

In the first season after autumn or spring sowing, deduct the amounts of phosphate and potash applied to the seedbed.

Phosphate and potash recommendations for legume swards

Apply phosphate, potash and magnesium as recommended for pure grass swards. Clover may benefit from a small application of potash at Index 2-, as clover is more responsive to potash than grass.

Example 3.2

Phosphate and potash recommendations for a field with one cut of silage and grazing

The field has a P Index of 1 and a K Index of 1. It would require 70 kg of phosphate for the first cut. It would require 30 kg of potash the previous autumn and 80 kg in the spring. There would be a need for additional potash due to a cut being taken. This can be met by applying 30 kg of potash per ha up to twice during the grazing season.

If the field was only being grazed it would require 30 kg of potash, which could be applied in June or July or in several small applications during the season.

Sulphur recommendations

Sulphur is an essential nutrient in maximising dry matter yield protein levels in both grazed and conserved grass. Sulphur deficiency is common in grassland, especially in later cuts or where high rates of nitrogen are used.

The symptoms of sulphur deficiency are indicated by a yellowing of the sward. In contrast to nitrogen deficiency where the older leaves are most affected, sulphur deficiency can be identified by yellowing of the youngest leaves. Analysis of uncontaminated herbage sampled just before cutting is a useful indicator of deficiency. The information can be used to assess the need for sulphur for future cuts. The critical level is 0.25% total sulphur or an N:S ratio greater than 13:1.

Some soils are more at risk of sulphur deficiency than others. Apply sulphur as mineral fertiliser or livestock manures, to all grass grown on:

- Sandy and shallow soils, eg chalk and limestone
- Loamy and coarse silty soils in areas with >200 mm rainfall between November and February
- Clay, fine silty or peat soils in areas with >400 mm rainfall between November and February

On soils at risk of sulphur deficiency, apply:

- Silage – 40 kg SO_3/ha before each cut
- Grazing – 20–30 kg SO_3/ha when up to 100 kg N/ha is applied and an additional 20–30 kg SO_3/ha for each additional 100 kg N/ha applied

All sulphur recommendations are given as SO_3 and not S; conversion tables (metric–imperial, oxide–element) are given on page 35.

Point to consider

- In drought conditions SO_3 uptake will be limited. Application rates should be reduced or delayed accordingly

Nitrogen recommendations

The nitrogen requirements for grassland can be calculated in four simple steps:

Step 1:
Select the correct Soil Nitrogen Supply (high, moderate or low)
Page 13

↓

Step 2:
Select the correct Grass Growth Class (poor, average, good)
Page 14

↓

Step 3:
Select the target yield

↓

Step 4:

Establishment	Grazing	Silage	Hay
Select the correct N recommendations for SNS and GGC [a b] Page 18	Select the correct N recommendations for target yield, SNS and GGC [a b] Page 16	Select the correct N recommendations for target yield, SNS and GGC [a b] Page 15	Select the correct N recommendations for SNS and GGC [b] Page 16

a. For grass-clover swards see page 17.

b. Nutrients applied as organic materials can be subtracted from the recommendations at this stage.

SNS = Soil Nutrient Supply, GGC = Grass Growth Class

Adjusting nitrogen use throughout the season

Nitrogen requirement and uptake can be heavily influenced by weather conditions, so it is important to continually re-evaluate nitrogen fertiliser requirements throughout the season.

- **As nitrogen is more likely to be lost from the soil, aim to target fertiliser timing to meet crop nitrogen demand**
- **Most nitrogen should be applied in spring or early summer, when sward demand is greatest**
- **If grass growth is restricted due to drought, reduce the use of N once growth restarts following rain. As a guide, if grass does not grow for two weeks in June or July, the yield will be reduced by about 1t DM/ha, leaving 40 kg/ha of unused N in the soil. This should be taken into account in following applications**

Assessing the Soil Nitrogen Supply status

The nitrogen recommendations presented in this guide are based on the requirement of the crop, which is adjusted for, the amount of nitrogen available from the soil, known as the Soil Nitrogen Supply (SNS).

The method used to assess SNS in grassland systems is different from that used in arable or vegetable cropping systems. Three levels of SNS status are recognised: low, moderate and high. Fields with a low SNS need more additional nitrogen than fields with a moderate or high status.

Nitrogen fertiliser, organic manure use and management history in the last one to three years are of most importance for determining the SNS status.

Nitrogen returns

In cattle and sheep systems, around 70% of the nitrogen ingested as conserved grass or feed, is excreted. During grazing, this nitrogen is returned to the soil and, in intensive systems, will result in the soil having a moderate or high SNS status.

Likewise, silage fields that receive regular average applications of manure will usually have a moderate or high SNS status. Fields which are regularly cut for silage and receive little or no manure are likely to have a low SNS status. Adjustments upwards to higher rates of nitrogen may be needed for these fields.

The nutrient recommendations take account of past manure applications, because these influence assessment of the SNS status of a field. The crop available nitrogen supply from manures applied for the current season's growth (ie previous September applications onwards) must be assessed using the information in **Section 2: Organic materials** and deducted from the recommendation.

Table 3.6 Determining the Soil Nitrogen Supply status of grassland

Previous management		Previous nitrogen use (kg/ha/yr)[a]	SNS status
Long-term grass. Includes: • Grass reseeded after grass or after one year of arable • Grass ley in second or later year		Over 250	High
		100–250 or high clover content	Moderate[b]
		Up to 100	Low
First year ley after two or more years of arable with previous crop:	Potatoes, oilseed rape, peas or beans, NOT on light sand soil		Moderate[b]
	Cereals, sugar beet, linseed or any crop on a light sand soil		Low

a. Refers to typical fertiliser and available manure nitrogen used per year in the last 2–3 years

b. The nitrogen values in the recommendation tables assume a moderate Soil Nitrogen Supply (SNS) status and so adjustments need to be made for high or low SNS: increase total fertiliser nitrogen input by 30 kg/ha in a low SNS situation; decrease total fertiliser nitrogen input by 30 kg/ha in a high SNS situation.

Increase SNS status by one class if more than 150 kg/ha of total nitrogen has been regularly applied as organic manure for several years. Reduce SNS status by one class if grass was cut for silage and less than 150 kg/ha of total nitrogen as organic manure has been applied on average in previous years.

Assessing Grass Growth Class

Grass Growth Class (GGC) describes the ability of a site to respond to nitrogen depending on soil type and rainfall. The better the GGC, the greater the efficiency of nitrogen use and the greater the dry matter yield response (Figure 3.1).

On good/very good GGC sites, swards dominated by productive grass species typically respond strongly to increasing nitrogen supply as soil drainage, temperature and water supply are conducive to growth.

On poor/very poor GGC sites, grass does not respond as well to N applications due to factors such as poor drainage (ie wetness) or cooler temperatures (due to aspect or altitude). Applying high rates of N fertiliser to these sites can be costly due to inefficient N use and has a high risk of nutrient loss to the environment.

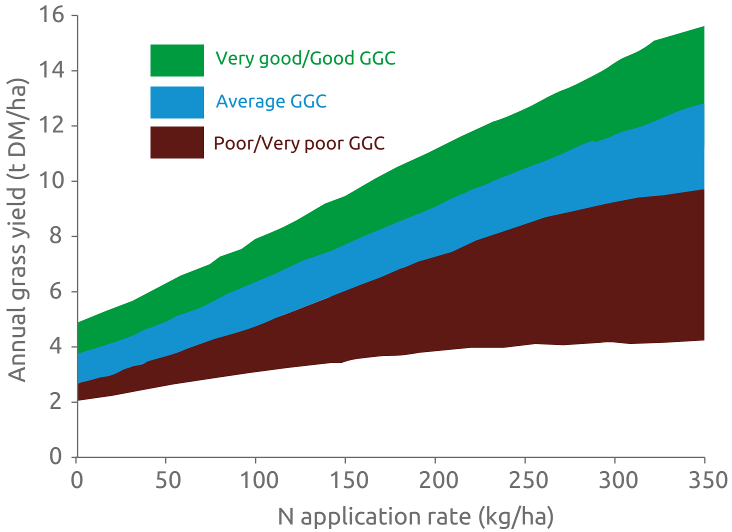

Figure 3.1 Indicative grass dry matter yield by Grass Growth Class (GGC)

Grass swards greater than three years old with minimal clover and low to moderate soil nitrogen supply (SNS).

Similarly, grass growth will be restricted where summer rainfall and the moisture stored in the soil (the soil available water) are inadequate to meet the grass water demand. Although there can be wide variations in summer rainfall between years, Table 3.7 gives an indication of the grass growth potential in an average season, based on the risk of summer drought.

Table 3.7 Determining Grass Growth Class

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

a. See Table 3.13 for soil descriptions.

b. Mean summer rainfall (April to September) is usually about half of annual rainfall.

For sites above 300 m altitude where lower temperatures restrict growth, move down one GGC, eg good becomes average.

Nitrogen recommendations for grass silage

Table 3.8 provides nitrogen recommendations for grass silage production for a range of target in-field dry matter yields (t DM/ha).

- The recommendations are applicable to grass swards with low clover content in a very good/good GGC and moderate SNS situation
- Target DM yield will be different for individual farms dependent on GGC and livestock requirements
- Good/very good GGC sites with 2–10 year old swards are likely to achieve target DM yield values at the higher end of the range. New leys with modern varieties may exceed the upper DM yield range by 10–20%
- Poor/very poor GGC sites are likely to achieve DM yield levels towards the lower end of the range in most years

Table 3.8 Nitrogen recommendations for grass silage

Target annual DM yield[a] (t/ha)	N application rate (kg N/ha)				Total N applied[b] (kg N/ha)
	First cut	Second cut	Third cut	Fourth cut	
5–7	70	-	-	-	**70**
7–9	80	50	-	-	**130**
9–12	100	75	75[c]	-	**250**
12–15+	120	90	70[c]	30[c]	**310[d]**

a. DM yield as harvested in the field for all cuts combined. Does not include spoilage in the clamp. Fresh yield is four times these values if the silage is 25% DM.

b. As manufactured fertiliser and crop available nitrogen from organic materials.

c. If previous growth has been severely restricted by drought, reduce or omit this application.

d. This total N could be applied to a 3-cut system (yielding around 15 t DM/ha) with the fourth cut recommendation of 30 kg N/ha being split between the second and third cuts.

For haylage, in the absence of detailed research use similar rates to silage in Table 3.8.

- To adjust for high SNS sites, apply 10 kg N/ha less for first cut, and 20 kg N/ha less for second cut
- To adjust for low SNS sites, apply 10 kg N/ha more for first cut, and 20 kg N/ha more for second cut
- Following early spring grazing, reduce the first cut recommendation by 25 kg/ha
- For first cut rates over 80 kg N/ha, split application: 40 kg N/ha in mid-February to early March with the remainder in late March to early April and at least six weeks before cutting
- Applications for second and subsequent cuts should be made as soon as possible after the previous cut

Example 3.3

Nitrogen recommendations for a field with one cut of silage and grazing. The target yield is 9–12 tonnes of dry matter per hectare and the site has a good GGC and low SNS situation.

The recommendation for the first cut would be 110 kg N per ha, which could be applied as 40 kg in late February and 70 kg in late March.

The field should be available for grazing in June. 40 kg of N would be applied soon after the cut (May) and an additional two applications of 40 kg of N could be applied for July and August, due to SNS adjustment. This would mean a total of 230 kg of N would be applied across the season.

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Nitrogen recommendations for grazing

Table 3.9 provides N recommendations for grazing for a range of target in-field dry matter yields (t DM/ha).

- The recommendations are applicable to grass swards with low clover content in a very good/good GGC and moderate SNS situation
- Target dry matter yield will be different for individual farms dependent on grass growth class and livestock requirements
- Good/very good GGC sites with 2–10 year old swards are likely to achieve target dry matter yield values at the higher end of the range. New leys with modern varieties may exceed the upper dry matter yield range by 10–20%
- Poor/very poor GGC sites are likely to achieve dry matter yield levels towards the lower end of the range in most years

Table 3.9 Nitrogen recommendations for grazed swards

Nitrogen application rate (kg N/ha) per grazing rotation and approximate application date								
Indicative DM yield[a] (t/ha)	Jan/ Feb	Mar	Apr	May	Jun	Jul[c]	Aug[c]	Total N applied
4–5		30						**30**
5–7		30		20				**50**
6–8		30		30		20		**80**
7–9		40		30	30	30		**130**
9–12		30	30	30	30	30	30	**180**
10–13	30[b]	40	40	30	30	30	30	**230**
12–15+	30[b]	40	50	50	40	30	30	**270**

- For high SNS sites, apply 30 kg N/ha less across the season
- For low SNS sites, apply 30 kg N/ha more across the season
- Rates should be adjusted through the season according to grass growth, summer rainfall and livestock requirements.

Nitrogen recommendations for hay

Table 3.10 Nitrogen recommendations for grass hay production

	Soil Nitrogen Supply		
	Low	Moderate	High
	kg N/ha		
Each hay cut	100	70	40

Point to consider

- Tables contain the total nutrient required, remember to deduct nutrients applied as organic materials **(Section 2: Organic materials)**

a. The recommendations take account of nitrogen recycled at grazing.

b. Only applicable to areas with a long grass growing season; the first nitrogen application could be applied as early as mid to late January, with the second application in early March.

c. If previous growth has been severely restricted by drought, reduce or omit this application.

Applications of N after August are not usually productive due to supply of N from soil organic matter at that time. Check nitrate vulnerable zones (NVZ) rules for guidance on timing.

Nitrogen recommendations for grass and clover

Generally, little fertiliser nitrogen is needed on swards with an appreciable clover content. On average, a good grass and clover sward (30–40% of dry matter of clover) will give annual dry matter yields equivalent to that produced from about 180 kg N/ha applied to a pure grass sward.

It is often difficult to decide how much nitrogen will be supplied as the clover content can be very changeable from year to year and within a given season. The photographs indicate how to estimate clover content and assess nitrogen supply.

These figures should be used as rough guides only as full clover development does not normally take place until late spring onwards.

Lucerne and red clover crops have no requirement for N fertiliser apart from that needed for establishment in low SNS soils (up to 50 kg N/ha).

For red clover and grass swards, there may be some advantage in applying a small amount of nitrogen (up to 50 kg N/ha) in the early spring if the grass appears to be nitrogen deficient.

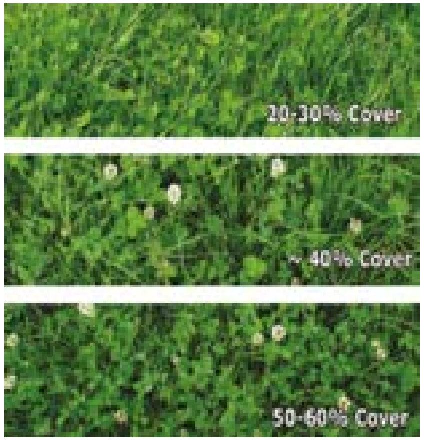
Percentage cover from clover

Potential nitrogen supply

180 kg N/ha

240 kg N/ha

300 kg N/ha



Grazing grass and clover swards

Applications of fertiliser nitrogen to grass/clover swards should be made with caution as any form of mineral nitrogen inhibits nitrogen fixation by rhizobia in the clover nodules. There is also a risk of the grass responding to the nitrogen and shading out the clover, which can reduce the percentage of clover in the sward.

However, some nitrogen may need to be applied to grass/clover swards to encourage early spring or late autumn growth:

- Apply up to 50 kg N/ha in mid-February to early March if early grass growth is required
- Apply up to 50 kg N/ha in late July or August if autumn grass is required

Establishment

Clover is particularly sensitive to nitrogen application during establishment. No nitrogen should be used during this period.

Cutting grass-clover, red clover or lucerne swards

- Do not apply high levels of nitrogen if a silage crop is taken from a grass/clover sward where the clover content needs to be maintained
- Do not apply any fertiliser nitrogen for red clover or lucerne conservation

Point to consider

- The rate and timing of nitrogen applications in fertiliser and organic materials are subject to limits under nitrate vulnerable zones (NVZ) rules. For further information see www.gov.uk

Nutrient recommendations for grass establishment

Correct nutrition is important to ensure successful establishment of a new sward. The phosphate, potash and nitrogen recommendations will differ from existing swards. New leys have a greater requirement for phosphate to help with root development and a lower requirement for nitrogen.

Table 3.11 Phosphate and potash recommendations for grass establishment

	P or K Index				
	0	1	2	3	4 and higher
	kg/ha				
Phosphate	120	80	50	30	0
Potash	120	80	60 (2-) 40 (2+)	0	0

- **The amount of phosphate and potash applied for establishment may be deducted from the first season's grazing or silage/hay requirement.**

Application of nitrogen

Table 3.12 Nitrogen recommendations for grass establishment

	Soil Nitrogen Supply		
	Low	Moderate	High
	kg N/ha		
Spring sown (April–June)	60	60	60
Summer or Autumn sown (July–mid-October)	30–50[a]	0–30[a]	0
Grass and clover swards	0	0	0

a. Nitrogen is important when rapid grass growth is needed, eg when seedbed conditions are sub-optimal or seed is sown late. Nitrogen should not be applied where it will stimulate weed growth (eg in weedy stubbles) or seedling competition (eg direct-drilled into an existing sward). Be aware of NVZ closed periods.

- **For spring sown swards, deduct the amount of nitrogen applied for establishment from the first season's grazing or silage/hay requirement**

Magnesium, sodium and micronutrient recommendations

Magnesium

Grass swards must contain a sufficiently high level of magnesium if the risk of hypomagnesaemia (grass staggers) is to be reduced. At soil magnesium Index 0, apply 50 to 100 kg magnesium oxide (MgO) per ha every three or four years.

However, the uptake of herbage magnesium decreases as nitrogen and potash increase; consequently hypomagnesaemia can occur when soil magnesium appears adequate (Index 1). If there is a risk of hypomagnesaemia, 100 kg/ha MgO may be justified to maintain soil magnesium at Index 2. Direct treatment of livestock may also be needed to avoid hypomagnesaemia.

Where liming is also needed, use of magnesian limestone may be most cost effective **(Section 1: Principles of nutrient management and fertiliser use)**.

Magnesium recommendations are given as kg/ha of MgO not as Mg.

Herbage or forage analysis is a useful indicator of the need for additional magnesium and for assessing the risk of hypomagnesaemia. Maintain magnesium concentrations above 0.20% (dry matter basis) and ensure the K:Mg ratio does not exceed 20:1.

Conversion tables are given on page 35.

Further information

Grassland reseeding guide

beefandlamb.ahdb.org.uk/returns/nutrition-and-forage

Sodium

Sodium will not have any effect on grass growth but a minimum level of 0.15% (dry matter basis) in the diet is essential for livestock health. Research has demonstrated that sodium can improve the palatability of grass and therefore increase dry matter intake.

Herbage or forage analysis is useful to assess the sodium status of grass and its balance with potassium. Where sodium levels are low (below 0.15%) or the K:Na ratio is higher that 20:1, mineral supplements may be required for some classes of stock or a sodium containing fertiliser may be used.

Apply sodium in fertiliser at 140 kg/ha Na_2O in early spring, either in a single or split application, to improve herbage mineral balances. To improve pasture palatability, apply regular dressings of 10 kg/ha Na_2O throughout the season.

Herbage or forage analysis can be useful to assess nutrient requirements and balances.

- **Magnesium (Mg) deficiency is indicated if the Mg concentration is below 0.20% (dry matter basis) or the K:Mg ratio is above 20:1**
- **Sodium (Na) deficiency is indicated if the Na concentration is below 0.15% (dry matter basis) or the K:Na ratio is above 20:1**

Herbage or forage analysis is a useful indicator of the need for additional magnesium and for assessing the risk of hypomagnesaemia. Maintain magnesium concentrations above 0.20% (dry matter basis) and ensure the K:Mg ratio does not exceed 20:1.

The K:Na and K:Mg ratios are key indicators of nutritional quality of forage and reducing the risk of tetany

Micronutrients (trace elements)

Liming fields above pH 7 should be avoided as it can induce deficiencies of trace elements such as copper, cobalt and selenium which can adversely affect livestock growth but will not affect grass growth. Too few micronutrients in the overall diet can lead to deficiency in some animals; and cobalt deficiency can impact nitrogen fixation by clover.

The aim should be only to use micronutrient supplementation where deficiency has been diagnosed. Where a deficiency does occur, treatment of the animal with the appropriate trace element is usually the most effective means of control, though application of cobalt and selenium to grazing pastures can be effective. If deficiencies are identified, consult an accredited feed adviser, preferably one on the Feed Adviser Register (FAR), to decide on an appropriate course of action.

More information on the use of lime is given in **Section 1: Principles of nutrient management and fertiliser use**.

Further information

Dairy cow mineral intake on commercial farms
dairy.ahdb.org.uk/resources-library/research-development/nutrition/minerals-report/#.XDy2jrp2uUI

Trace element supplementation of beef cattle and sheep
beefandlamb.ahdb.org.uk/returns/nutrition-and-forage

Potash Development Agency Leaflet 6: Potash, Magnesium & Sodium – Fertilisers for Grass
www.pda.org.uk/leaflet-type/grass-and-forage

Forage crop recommendations

Calculating Soil Nitrogen Supply (SNS)

Fields vary widely in the amount of nitrogen available to a crop before any fertiliser or manure is applied. This variation must be taken into account to avoid inadequate or excessive applications of nitrogen.

The Soil Nitrogen Supply (SNS) system (Index 0 to 6) indicates the likely extent of this 'background' SNS. Once the Index is identified, it can be used to select the appropriate nitrogen recommendation to achieve optimum yield.

The system used to estimate SNS in cultivated fields is different from the system used in grass fields. The SNS Index for each field used to grow a forage or arable crop can be arrived at either by the:

- **Field Assessment Method** An estimation of SNS based on soil type, previous cropping and winter rainfall
- **Measurement Method** A soil sample is collected and sent to a laboratory for analysis

The Field Assessment Method is most commonly used by livestock farmers and is described in this section. If you wish to use the Measurement Method it is described in **Section 1: Principles of nutrient management and fertiliser use**.

Field Assessment Method

There are five essential steps to follow to identify the appropriate SNS Index:

Step 1. Identify the soil type for the field
Step 2. Identify the previous crop
Step 3. Select the rainfall range for the field
Step 4. Identify the provisional SNS Index using the appropriate table
Step 5. Make any necessary adjustments to the SNS Index

Point to consider

- **The field assessment method does not take account of the nitrogen that will become available to a crop from any organic materials applied since harvest of the previous crop. These should be deducted from the fertiliser nitrogen application rates shown in the recommendation tables**
- **The Measurement Method is not suitable for organic and peaty soils as SNS (due to mineralisation of soil organic matter) is very unpredictable**

Step 1. Identify the soil type for the field

Careful identification of the soil type in each field is very important. The whole soil profile should be assessed to one metre depth for forage crops. Where the soil varies, and nitrogen is to be applied uniformly, select the soil type that occupies the largest part of the field.

The soil type can be identified using Figure 3.2 that categorises soils on their ability to supply and retain mineral nitrogen. The initial selection can then be checked using Table 3.13. Carefully assess the soil organic matter content when deciding if the soil is organic (10% to 20% organic matter for the purposes of this guide) or peaty (more than 20% organic matter). If necessary, seek professional advice on soil type assessments, remembering this will need to be done only once.

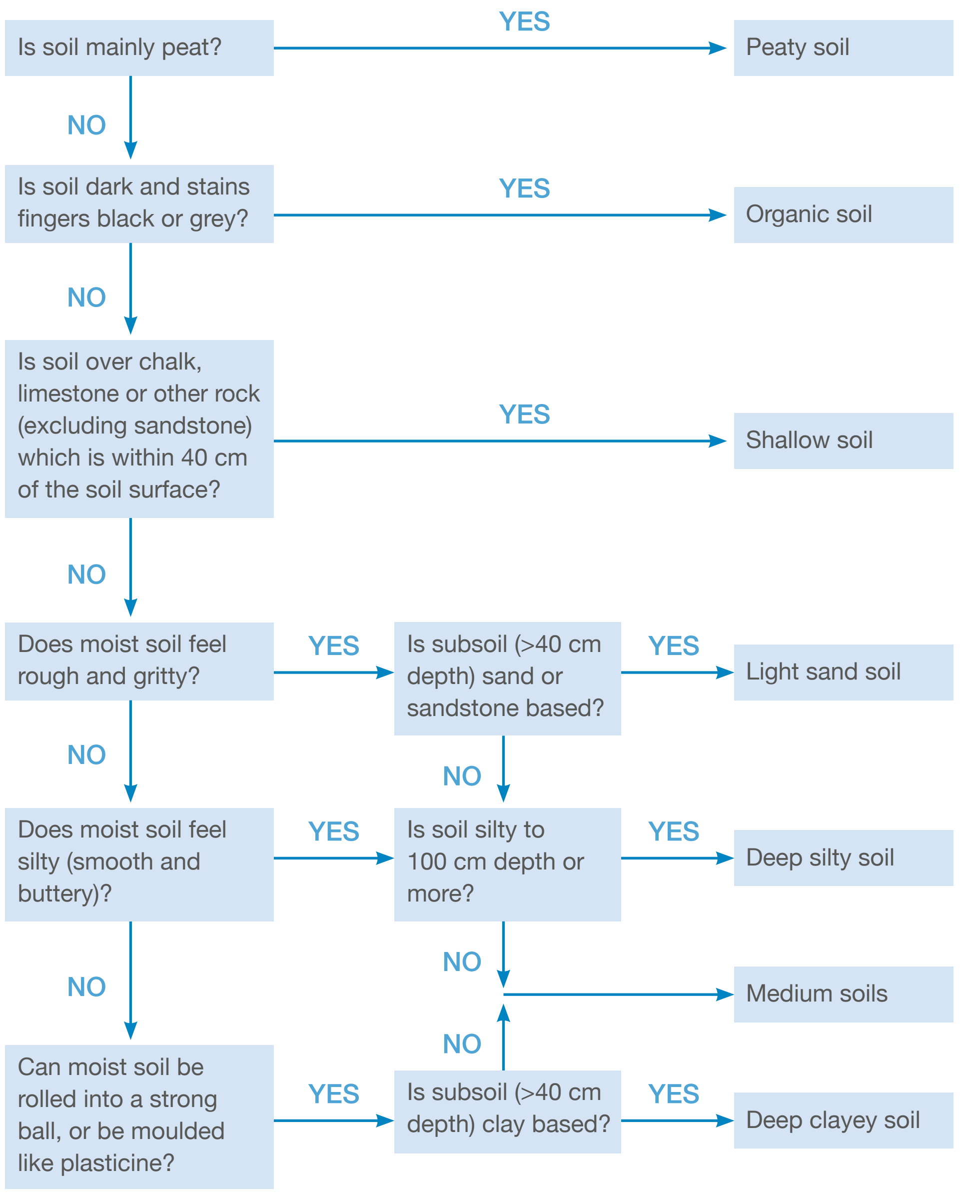


Figure 3.2 Soil category assessment

Table 3.13 Soil category assessment

Soil category	Description of soil types within category	Properties
Light sand soils	Soils which are sand, loamy sand or sandy loam to 40 cm depth and are sand or loamy sand between 40– 80 cm, or over sandstone rock.	Soils in this category have poor water holding capacity and retain little nitrogen.
Shallow soils	Soils over impermeable subsoils and those where the parent rock (chalk, limestone or other rock) is within 40 cm of the soil surface. Sandy soils developed over sandstone rock should be regarded as light sand soils.	Soils in this category are less able to retain or supply nitrogen at depth.
Medium soils	Mostly medium-textured mineral soils that do not fall into any other soil category. This includes sandy loams over clay, deep loams, and silty or clayey topsoils that have sandy or loamy subsoils.	Soils in this category have moderate ability to retain nitrogen and allow average rooting depth.
Deep clayey soils	Soils with predominantly sandy clay loam, silty clay loam, clay loam, sandy clay, silty clay or clay topsoil overlying clay subsoil to more than 40 cm depth. Deep clayey soils normally need artificial field drainage.	Soils in this category are able to retain more nitrogen than lighter soils.
Deep silty soils	Soils of sandy silt loam, silt loam or silty clay loam textures to 100 cm depth or more. Silt soils formed on marine alluvium, warp soils (river alluvium) and brickearth soils are in this category. Silty clays of low fertility should be regarded as other mineral soils.	Soils in this category are able to retain more nitrogen than lighter soils and allow rooting to greater depth.
Organic soils	Soils that are predominantly mineral but with between 10–20% organic matter to depth. These can be distinguished by darker colouring that stains the fingers black or grey.	Soils in this category are able to retain more nitrogen than lighter soils and have higher nitrogen mineralisation potential.
Peat soils	Soils that contain more than 20% organic matter derived from sedge or similar peat material.	Soils in this category have very high nitrogen mineralisation potential.

Step 2. Identify previous crop
Usually, this is straightforward but sometimes clarification may be needed:

High residual nitrogen vegetables ('high N vegetables') are leafy, nitrogen-rich Brassica crops such as calabrese, Brussels sprouts and some crops of cauliflower, where significant amounts of crop debris are returned to the soil, especially in rotations where an earlier Brassica crop has been grown within the previous twelve months. To be available for crop uptake, this organic nitrogen must have had time to mineralise but the nitrate produced must not have been at risk to loss by leaching.

Medium residual nitrogen vegetables ('medium N vegetables') are crops such as lettuce, leeks and long season Brassicas such as Dutch white cabbage, where a moderate amount of crop debris is returned to the soil.

Low residual nitrogen vegetables ('low N vegetables') are crops such as carrots, onions, radish, swedes or turnips, where the amount of crop residue is relatively small.

Step 3. Select low, moderate or high rainfall
The appropriate rainfall category should be identified, based on either annual rainfall or excess winter rainfall. Ideally, an estimate of excess winter rainfall is required because this is closely related to drainage by which nitrate is lost through leaching. Figure 3.3 shows long-term (1981–2010) average excess winter rainfall, which in an average year can be used to select the rainfall category (Table 3.14).

Figure 3.3 Excess winter rainfall (mm)

Table 3.14 Rainfall categories

Rainfall category	Excess winter rainfall (mm)	Annual rainfall (mm)
Low	Less than 150	Less than 600
Moderate	150–250	600–700
High	250 or more	700 or more

Step 4. Identify the provisional SNS Index
Tables 3.15 (low rainfall), 3.16 (moderate rainfall) and 3.17 (high rainfall) should be used where the field has not been in grass within the past three years. Take account of the footnotes to the tables.

Higher than typical Indices can occur where there has been a history of grassland or frequent applications of organic materials. The Measurement Method is recommended in these situations **(Section 4: Arable crops)**.

If grass has been grown in the previous three years, also look at Table 3.18. Select the higher of the Index levels based on the last crop grown (from Table 3.15, 3.16 or 3.17 and that based on the grass history (from Table 3.18).

Table 3.15 SNS Indices for low rainfall (500–600 mm annual rainfall, up to 150 mm excess winter rainfall) – based on the last crop grown

Previous crop	Soil type					
	Light sand soils or shallow soils over sandstone	Medium soils or shallow soils not over sandstone	Deep clayey soils	Deep silty soils	Organic soils	Peat soils
Beans	1	2	3	3	All crops in SNS Index 3, 4, 5 or 6. Consult a FACTS Qualified Adviser.	All crops in SNS Index 4, 5 or 6. Consult a FACTS Qualified Adviser.
Cereals	0	1	2	2		
Forage crops (cut)	0	1	2	2		
Oilseed rape	1	2	3	3		
Peas	1	2	3	3		
Potatoes	1	2	3	3		
Sugar beet	1	1	2	2		
Uncropped land	1	2	3	3		
Vegetables (low N)[b]	0	1	2	2		
Vegetables (medium N)[b]	1	3	3[a]	3[a]		
Vegetables (high N)[b]	2	4[a]	4[a]	4[a]		

a. Index may need to be increased by up to 1 where significantly larger amounts of leafy residues are incorporated (Step 5). Where there is uncertainty, soil sampling for SMN may be appropriate.

b. Refer to Step 2.

Table 3.16 SNS Indices for moderate rainfall (600–700 mm annual rainfall, or 150–250 mm excess winter rainfall) – based on the last crop grown

Previous crop	Soil type					
	Light sand soils or shallow soils over sandstone	Medium soils or shallow soils not over sandstone	Deep clayey soils	Deep silty soils	Organic soils	Peat soils
Beans	1	2	2	3	All crops in SNS Index 3, 4, 5 or 6. Consult a FACTS Qualified Adviser.	All crops in SNS Index 4, 5 or 6. Consult a FACTS Qualified Adviser.
Cereals	0	1	1	1		
Forage crops (cut)	0	1	1	1		
Oilseed rape	0	2	2	2		
Peas	1	2	2	3		
Potatoes	0	2	2	2		
Sugar beet	0	1	1	1		
Uncropped land	1	2	2	2		
Vegetables (low N)[b]	0	1	1	1		
Vegetables (medium N)[b]	0	2	3	3		
Vegetables (high N)[b]	1	3	4	4		

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Table 3.17 SNS Indices for high rainfall (over 700 mm annual rainfall, or over 250 mm excess winter rainfall) – based on the last crop grown

Previous crop	Soil type					
	Light sand soils or shallow soils over sandstone	Medium soils or shallow soils not over sandstone	Deep clayey soils	Deep silty soils	Organic soils	Peat soils
Beans	0	1	2	2	All crops in SNS Index 3, 4, 5 or 6. Consult a FACTS Qualified Adviser.	All crops in SNS Index 4, 5 or 6. Consult a FACTS Qualified Adviser.
Cereals	0	1	1	1		
Forage crops (cut)	0	1	1	1		
Oilseed rape	0	1	1	2		
Peas	0	1	2	2		
Potatoes	0	1	1	2		
Sugar beet	0	1	1	1		
Uncropped land	0	1	1	2		
Vegetables (low N)[b]	0	1	1	1		
Vegetables (medium N)[b]	0	1	1	2		
Vegetables (high N)[b]	1[a]	2	2	3		

a. Index may need to be lowered by 1 where residues incorporated in the autumn and not followed immediately by an autumn-sown crop.

b. Refer to Step 2.

Table 3.18 SNS Indices following ploughing out of grass leys

	SNS Index		
Light sands or shallow soils over sandstone – all rainfall areas	**Year 1**	**Year 2**	**Year 3**
All leys with 2 or more cuts annually receiving little or no manure 1–2 year leys, low N 1–2 year leys, 1 or more cuts 3–5 year leys, low N, 1 or more cuts	0	0	0
1–2 year leys, high N, grazed 3–5 year leys, low N, grazed 3–5 year leys, high N, 1 cut then grazed	1	2	1
3–5 year leys, high N, grazed	3	2	1
Other medium soils and shallow soils – not over sandstone – all rainfall areas			
All leys with 2 or more cuts annually receiving little or no manure 1–2 year leys, low N 1–2 year leys, 1 or more cuts 3–5 year leys, low N, 1 or more cuts	1	1	1
1–2 year leys, high N, grazed 3–5 year leys, low N, grazed 3–5 year leys, high N, 1 cut then grazed	2	2	1
3–5 year leys, high N, grazed	3	3	2
Deep clayey soils and deep silty soils in low rainfall areas (500–600 mm annual rainfall)			
All leys with 2 or more cuts annually receiving little or no manure 1–2 year leys, low N 1–2 year leys, 1 or more cuts 3–5 year leys, low N, 1 or more cuts	2	2	2
1–2 year leys, high N, grazed 3–5 year leys, low N, grazed 3–5 year leys, high N, 1 cut then grazed	3	3	2
3–5 year leys, high N, grazed	5	4	3
Deep clayey soils and deep silty soils in moderate (600–700 mm annual rainfall) or high (over 700 mm annual rainfall) rainfall areas			
All leys with 2 or more cuts annually receiving little or no manure 1–2 year leys, low N 1–2 year leys, 1 or more cuts 3–5 year leys, low N, 1 or more cuts	1	1	1
1–2 year leys, high N, grazed 3–5 year leys, low N, grazed 3–5 year leys, high N, 1 cut then grazed	3	2	1
3–5 year leys, high N, grazed	4	3	2

The Indices shown in Table 3.18 assume that little or no organic materials have been applied. Where silage fields have received the organic manures produced by livestock that have eaten the silage and the manure has been applied in spring, they should be regarded as containing nitrogen residues equivalent to a previous grazing history.

'Low N' grassland means average annual inputs of less than 250 kg N/ha in fertiliser plus crop available nitrogen in organic materials used in the last two years, or swards with little clover.

'High N' grassland means average annual applications of more than 250 kg N/ha in the last two years, clover-rich swards or lucerne.

Step 5. Make any necessary adjustment to the SNS Index for certain conditions

When using the field assessment method, it is not necessary to estimate the amount of nitrogen taken up by the crop over winter. This is already taken into account in the tables.

Manure history: Where regular applications of organic manures have been made to previous crops in the rotation, increase the Index value by one or two levels, depending on manure type, application rate and frequency of application. The nitrogen contribution from manures applied after harvest of the previous crop should not be considered when deciding the SNS Index. This contribution should be deducted from the recommended nitrogen application rate using the information in **Section 2: Organic materials**.

Fertiliser residues from previous crop: The Index assessments assume that the previous crop grew normally and that it received the recommended rate of nitrogen applied as fertiliser and/or organic manures. The Index should be increased if there is reason to believe nitrogen residues are likely to be greater than normal and these residues will not be lost by leaching. This could occur where a cover crop was sown in autumn and grew well over winter. Similarly the Index may need to be adjusted downwards if there is reason to believe nitrogen residues are likely to be smaller than usual.

Example 3.4

Maize is to be sown following over-wintered barley stubbles after a long-term arable rotation with limited use of organic manures. The soil is a light sand in a high rainfall area.

Using Table 3.17, the SNS Index would be 0. Using Table 3.19, the nitrogen recommendation would be 150 kg N/ha.

Example 3.5

Winter wheat is to be sown following a 3-year pure grass ley, which has been managed in the last two years using 280 kg N/ha/year as fertiliser plus crop available nitrogen in manure. An application of slurry has been applied in early spring each year before taking one cut of silage followed by grazing.

The soil is a medium soil in a moderate rainfall area.

The previous grass management is classed as 'high N'. Using Table 3.18 for medium soils, select the category '3–5 year leys, high N, grazed', which gives an SNS Index of 3 in year 1. Regular applications of slurry in previous years could increase the SNS Index by one level, but account should be taken of the application rate and N content of the slurry.

Cereals

For phosphate, potash and magnesium recommendations, the results of a recent soil analysis will be needed showing the soil Index (page 9). The use of soil analysis as a basis for making nutrient decisions is described in **Section 1: Principles of nutrient management and fertiliser use**.

Recommendations are given in the tables as phosphate (P_2O_5) and potash (K_2O). Conversion tables are given on page 35.

- **Recommendations at target Indices (2 for phosphate and 2- for potash) are maintenance dressings intended to meet crop requirements and maintain soil reserves to prevent depletion of soil fertility**
- **Recommendations at Indices lower than target include an allowance for building up soil reserves over several years (typically 10–15 years to raise one soil index) as well as meeting immediate crop requirement**
- **All recommendations are given for the mid-point of each Index (mid-point of 2- for potash). Where the soil analysis value is close to the range of an adjacent Index, the recommendation may be reduced or increased**
- **Recommendations are based on a typical yield. Adjustments can be made for higher or lower yields by estimating crop offtake using Table 3.2**

Further information

Cereal growth stages – a guide for crop treatments
cereals.ahdb.org.uk/publications

AHDB Beef & Lamb Cereals Directory
beefandlamb.ahdb.org.uk/returns/nutrition-and-forage

Forage maize – nitrogen, phosphate and potash

Table 3.19 Nitrogen, phosphate and potash recommendations for forage maize

	SNS, P or K Index				
	0	1	2	3	4 and higher
	kg N/ha				
Nitrogen	150	100	50	20	0
Phosphate[a]	115	85	55	20	0
Potash[a]	235	205	175 (2-) 145 (2+)	110	0

a. Estimates based on a 40 t/ha fresh weight yield. Use Table 3.2 to adjust for higher or lower yields.

Evidence is being gathered by the Maize Growers Association (MGA) that forage maize could respond to higher levels of nitrogen. Currently there is not enough data to justify changing the recommendations but it is area of further work. Discuss with a FACTS Qualified Adviser and use MGA's nitrogen predictor form.

- **To encourage rapid early growth, all of the phosphate requirement and up to 10–15 kg/ha of the nitrogen requirement may be placed below the seed at drilling. The remainder of the nitrogen requirement should be top-dressed as soon as the crop has emerged. Potash should be applied before seedbed preparation and thoroughly worked in**
- **Where sugar beet or potatoes do not feature in the rotation, magnesium fertiliser is only justified at soil Index 0 when 50 to 100 kg MgO/ha should be applied every three or four years**

Wholecrop wheat, winter sown – nitrogen

Nitrogen recommendations for wholecrop wheat are the same as wheat grown for grain with no adjustments made to account for harvest date. Fermented wholecrop is generally cut at soft dough stage (GS85), with high dry matter wholecrop cut closer to fully ripe (GS87–89).

Table 3.20 Nitrogen for winter sown wholecrop wheat

	SNS Index						
	0	1	2	3	4	5	6
	kg N/ha						
Light sand soils	180	150	120	90	60	0-60	0–40
Shallow soils	280[a]	240[a]	210	180	140	80	0–40
Medium soils	250[a]	220	190	160	120	60	0–40
Deep clay soils	250[a]	220	190	160	120	60	0–40
Deep silty soils	240[a]	210	170	130	100	40	0–40
Organic soils				120	80	40–80	0–40
Peat						0–60	

a. The N recommendation exceeds the N max limit of 220 kg for winter-sown wheat. The N max limit is calculated for the whole of the area of a crop type grown on farm and not for individual fields. For more details see **www.gov.uk/nitrate-vulnerable-zones**

Timing of application

There is no requirement for seedbed nitrogen. Depending on the total nitrogen requirement and crop development, it will often be appropriate to apply nitrogen at the following timings.

- **Less than 120 kg N/ha:** Apply all the recommended amount as a single dressing by early stem extension but not before early April
- **120 kg N/ha or more:** Apply about 40 kg N/ha between mid-February and mid-March except where:
  - There is a low risk of take-all, and
  - Shoot numbers are very high. Well-tillered crops do not need nitrogen at this stage. Crops with too many tillers will be prone to lodging and higher disease levels

The balance of the application should be applied in one or two dressings during early stem extension. Where more than 120 kg N/ha remains to be applied, half should be applied at the start of stem extension (not before April), and half at least 2 weeks later (not after early May).

Don't forget

- Tables contain the total nutrient required – remember to deduct nutrients applied as organic materials **(Section 2: Organic materials)**

Wholecrop wheat, spring sown – nitrogen

Table 3.21 Nitrogen for spring sown wholecrop wheat

	SNS Index						
	0	1	2	3	4	5	6
	kg N/ha						
Light sand soils	160	130	100	70	40	0–40	0
All other mineral soils	210[a]	180	150	120	70	40	0–40
Organic soils				120	70	40	0–40
Peaty soils						0–40	

a. The N recommendation exceeds the N max limit of 180 kg for spring-sown wheat. The N max limit is calculated for the whole of the area of a crop type grown on farm and not for individual fields. For more details see **www.gov.uk/nitrate-vulnerable-zones**

Timing of application

For crops drilled before March, apply nitrogen at early stem extension but not before early April or after early May. For amounts greater than 70 kg N/ha, apply the first 40 kg N/ha of the total in the seedbed except on light sand soils. On these soils apply 40 kg N/ha at the 3-leaf stage but not before March.

For late-drilled crops, all the nitrogen can be applied in the seedbed except on light sand soils where amounts greater than 70 kg N/ha should be split with 40 kg N/ha in the seedbed and the remainder by the 3-leaf stage.

Wholecrop barley, winter sown – nitrogen

Table 3.22 Nitrogen for winter-sown wholecrop barley

	SNS Index						
	0	1	2	3	4	5	6
	kg N/ha						
Light sand soils	170	140	110	80	60	0–40	0
Shallow soils	220[a]	190	150	120	60	20–60	0–20
Medium and deep clay soils	190[a]	170	140	110	60	20–60	0–20
Deep fertile silty soils	170	150	120	80	40	0–30	0
Organic soils				110	60	0–40	0
Peaty soils						0–40	

a. The N recommendation exceeds the N max limit of 180 kg for winter-sown barley. The N max limit is calculated for the whole of the area of a crop type grown on farm and not for individual fields. For more details see **www.gov.uk/nitrate-vulnerable-zones**

Timing of application

There is no requirement for seedbed nitrogen. Depending on the total nitrogen requirement and crop development, it will often be appropriate to apply nitrogen at the following timings.

- **Less than 100kg N/ha:** Apply this amount as a single dressing by early stem extension (GS30–31)
- **Between 100 and 200 kg N/ha:** Split the dressing with 50% during late tillering in mid-February/early March and 50% at GS30–31
- **200 kg N/ha or more:** Apply three splits with 40% during late tillering in mid-February/early March, 40% at GS30–31 and 20% at GS32

These recommendations assume appropriate measures are taken to control lodging (eg choice of variety, use of plant growth regulator). Reduce the recommendation by 25 kg N/ha if the lodging risk is high.

Wholecrop barley, spring sown – nitrogen

Table 3.23 Nitrogen for spring sown wholecrop barley

	SNS Index						
	0	1	2	3	4	5	6
	kg N/ha						
Light sand soils	140	110	70	50	0–40	0	0
Other mineral soils	160[a]	140	110	70	30	0–30	0
Organic soils				70	30	0–30	0
Peaty soils						0–30	

a. The N recommendation exceeds the N max limit of 150 kg for spring-sown barley. The N max limit is calculated for the whole of the area of a crop type grown on farm and not for individual fields. For more details see **www.gov.uk/nitrate-vulnerable-zones**

Research has shown that the economically optimal rate of N fertiliser increases with yield, assuming all limiting factors are managed. Where previous experience of growing spring barley indicates that grain yields above 5.5 t/ha can be realistically expected, the recommended rate should be increased by 10 kg N/ha for each 0.5 t/ha additional yield, up to a maximum yield of 10 t/ha. Similarly, for low yielding crops, the recommended rate should be reduced by 10 kg N/ha for each 0.5 t/ha reduction in expected yield.

Timing of application

For crops drilled before March, apply nitrogen at early stem extension but not before early April or after early May. For amounts greater than 70 kg N/ha, apply 40 kg N/ha of the total in the seedbed except on light sand soils. On these soils apply 40 kg N/ha at the 3-leaf stage but not before March.

For late-drilled crops, all the nitrogen can be applied in the seedbed except on light sand soils where amounts greater than 70 kg N/ha should be split with 40 kg N/ha in the seedbed and the remainder by the 3-leaf stage.

Forage triticale, winter sown – nitrogen

The nitrogen requirements of triticale are the same as those of wheat in most situations. However, forage triticale is generally harvested earlier than winter wheat or triticale grown for grain; typically at early milky development (GS71; mid–end June). Nitrogen recommendations are therefore 50 kg N/ha lower than for winter wheat grown for grain.

Triticale has a greater lodging risk than wheat, so less nitrogen may be required in situations of high lodging risk.

Table 3.24 Nitrogen for winter sown forage triticale

	SNS Index						
	0	1	2	3	4	5	6
	kg N/ha						
Light sand soils	130	100	70	40	0–30	0	0
Shallow soils	230	190	160	130	90	30	0
Medium soils	200	170	140	110	70	0–30	0
Deep clay soils	200	170	140	110	70	0–30	0
Deep silty soils	190	160	120	80	50	0–30	0
Organic soils				70	30	0–30	0
Peaty soils						0–30	

Timing of application

There is no requirement for seedbed nitrogen. Depending on the total nitrogen requirement and crop development, it will often be appropriate to apply nitrogen at the following timings.

- **Less than 120 kg N/ha:** Apply all the recommended amount as a single dressing by early stem extension but not before early April
- **120kg N/ha or more:** Apply about 40 kg N/ha between mid-February and mid-March except where there is a low risk of take-all and shoot numbers are very high. Well-tillered crops do not need nitrogen at this stage. Crops with too many tillers will be prone to lodging and higher disease levels

The balance of the application should be applied in one or two dressings during early stem extension. Where more than 120 kg N/ha remains to be applied, half should be applied at the start of stem extension (not before April), and half at least 2 weeks later (not after early May).

Oats and rye, winter sown – nitrogen

Table 3.25 Nitrogen for winter sown oats and rye

	SNS Index						
	0	1	2	3	4	5	6
	kg N/ha						
Oats							
Light sand soils	150	110	80	20–60	0–40	0	0
All other mineral soils	190	160	130	100	70	0–40	0
Organic soils				100	70	0–40	0
Peaty soils						0–40	
Rye							
Light sand soils	110	70	20–50	0–20	0	0	
All other mineral soils	150	120	90	60	30	0–20	
Organic soils				60	30	0–20	
Peaty soils						0–20	

Timing of application

Depending on the total nitrogen requirement and crop development, it will often be appropriate to apply nitrogen at the following timings.

- **Less than 100 kg N/ha:** Apply as a single dressing by early stem extension, but not before late March
- **100 kg N/ha or more:** Split the dressing with 40 kg N/ha in mid-February early-March and:
  - If the remaining nitrogen is less than 100 kg N/ha then apply the rest by early stem extension, but not before late March
  - If the remaining nitrogen is 100 kg N/ha or more then apply in two dressings, half at early stem extension (not before late March), and half at least two weeks later

These recommendations assume appropriate measures are taken to control lodging (eg choice of variety, use of plant growth regulator). Reduce the recommended rate by 40 kg N/ha for oats or 25 kg N/ha for rye if lodging risk is high.

Wholecrop silage from bi-crops

Crops, such as cereals and legumes, are grown together as specialist wholecrop silages. It is difficult to provide recommendations for the range of crops that are being used by the industry, so it is best to assess the proportion of each crop within the mix and use the relevant tables, alongside knowledge of SNS Index, to produce an appropriate recommendation.

Wholecrop cereals grown for silage with legumes (eg peas, beans, vetch or lupins) do not require any nitrogen but will benefit from sulphur, phosphate, potash and magnesium as for cereals grown as a single crop.

Oats, rye and triticale, spring sown – nitrogen

Table 3.26 Nitrogen for spring sown oats, rye and triticale

	SNS Index						
	0	1	2	3	4	5	6
	kg N/ha						
Light sand soils	90	60	30	0–30	0	0	0
All other mineral soils	140	110	70	40	0–30	0	0
Organic soils				40	0–30	0	0
Peaty soils						0	

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All wholecrop cereals – phosphate and potash

Table 3.27 Phosphate and potash for all wholecrop cereals

	P or K Index				
	0	1	2	3	4 and higher
	kg/ha				
Expected yield 30 t FW/ha					
Phosphate	115	85	55	0	0
Potash	220	190	160	100	0

The amounts of phosphate and potash are appropriate to the fresh weight yield shown. Table 3.2 can be used to calculate offtake if wholecrop yields are known to be different, for example a spring-sown crop yielding 25 t FW/ha.

At Index 2, phosphate and potash can be applied when convenient during the year but, at Index 0 and 1, they should be applied and worked into the seedbed. To avoid damage to germinating seedlings, do not use more than 150 kg/ha of nitrogen plus potash on sandy soils.

All wholecrop cereals – magnesium

At Mg Index 0, magnesium fertiliser should be applied every 3–4 years at 50 to 100 kg MgO/ha.

All wholecrop cereals – sulphur

Not all cereal crops will respond to sulphur. Use Table 3.28 to assess the risk of deficiency. Where deficiency has been recognised or is expected, apply 25–50 kg/ha SO_3 as a sulphate-containing fertiliser in early spring, before the start of stem extension.

Table 3.28 Sulphur deficiency risk

<table>
<tr><th></th><th colspan="3">Winter rainfall (Nov–Feb)</th></tr>
<tr><th>Soil texture</th><th>Low
(<175 mm)</th><th>Medium
(175–375 mm)</th><th>High
(>375 mm)</th></tr>
<tr><td>Sandy</td><td colspan="3">High</td></tr>
<tr><td>Loamy and coarse silty</td><td>Low</td><td colspan="2">High</td></tr>
<tr><td>Clay, fine silty or peaty</td><td colspan="2">Low</td><td>High</td></tr>
</table>

Example 3.6

Wholecrop winter wheat is to be sown on land at P and K Index 0. The crop is expected to yield 30 t FW/ha.

Offtake for a wholecrop cereal is 1.8 kg P_2O_5/t and 5.4 K_2O/t (Table 3.2). The recommendations at Index 0 would be 114 kg P_2O_5/ha and 222 kg K_2O/ha. Both these values are arrived at by (expected yield, ie 30 x offtake) + 60 to build up the soil Index over 10–15 years (Table 1.6, Section 1).

Swedes, turnips, fodder beet, rape and kale

Table 3.29 Nitrogen, phosphate and potash for forage swedes, turnips, fodder beet, rape and kale

	SNS, P or K Index						
	0	1	2	3	4	5	6
	kg/ha						
Forage swedes and turnips (65t/ha roots lifted)							
Nitrogen	100	80	60	40	0–40	0	0
Phosphate	105	75	45	0	0	0	0
Potash	215	185	155 (2-) 125 (2+)	80	0	0	0
Fodder beet (85t/ha roots lifted)							
Nitrogen	130	120	110	90	60	0–40	0
Phosphate	120	90	60	0	0	0	0
Potash	400	370	340 (2-) 310 (2+)	190*	0	0	0
Forage rape, swedes and stubble turnips (grazed)							
Nitrogen	100[a]	80[a]	60	40	0–40	0	0
Phosphate	85	55	25	0	0	0	0
Potash	110	80	50 (2-) 20 (2+)	0	0	0	0
Kale (grazed)							
Nitrogen	130	120	110	90	60	0–40	0
Phosphate	80	50	20	0	0	0	0
Potash	200	170	140 (2-) 70 (2+)	70	0	0	0

Recommendations are based on typical yields. Adjustments can be made for higher or lower yields by estimating crop offtake using Table 3.2.
The recommendations for grazed crops are assuming that all the manures are returned. For hybrid brassicas, use the recommendations for forage rape, swedes or stubble turnips.
a. Forage rape and stubble turnips, apply no more than 75 kg N/ha at Index 0 or 1. Further reductions may be made if the soil is moist and has been cultivated.
*Updated January 2019

Phosphate and potash

Phosphate and potash need only be applied to the seedbed at Index 0 or 1. In crops where roots are removed (forage swedes, turnips and fodder beet) and the tops are also carted off, potash applications may need to be increased by up to 150 kg/ha.

Magnesium

Where sugar beet or potatoes do not feature in the rotation, magnesium fertiliser is only justified at soil Index 0, where 50 to 100 kg MgO /ha should be applied every three or four years. The exception is fodder beet which should be treated as sugar beet with a Mg recommendation at Index 1 **(Section 4: Arable crops)**.

Sodium

For fodder beet, sodium is recommended on all soils except Fen silts and peats. Apply 400 kg/ha of agricultural salt (200 kg Na_2O /ha) well before drilling. If sodium is recommended but not applied, increase potash by 100 kg K_2O/ha.

Boron

A boron application may be needed. Soil and plant analysis are useful guides to assess the need for boron.

Sulphur

25 kg/ha SO_3 is needed on soils at risk of deficiency (Table 3.28).

Point to consider

- Tables contain the total nutrient required – remember to deduct nutrients applied as organic materials **(Section 2: Organic materials)**

Ryegrass grown for seed

Phosphate and potash

Phosphate and potash can be applied at any convenient time except at Index 0 and 1 when the dressing should be applied in the spring of the harvest year.

Table 3.30 Nitrogen, phosphate and potash for ryegrass grown for seed

	SNS, P or K Index						
	0	1	2	3	4	5	6 and higher
	kg N/ha						
Nitrogen							
Light sand soils	160	110	60	0–40	0	0	0
All other mineral soils		160	110	60	0–40	0	0
Organic soils				60	0–40	0	0
Peaty soils						0–40	
Phosphate	90	60	30	0	0	0	0
Potash	150	120	90 (2-) 60 (2+)	0	0	0	0

Requirements are based on a seed and hay yield of 5 t/ha. If the hay is chopped and returned, much less phosphate and potash is required.

Nitrogen

Nitrogen rates are for crops where there is a low risk of crop lodging either due to field characteristics or use of a growth regulator. A lower nitrogen rate will be appropriate for crops with a higher risk of lodging. Higher rates may be needed in the second cropping year or where amenity varieties are grown.

Depending on the total nitrogen requirement and crop development, it will often be appropriate to apply nitrogen at the following timings.

- **Less than 100 kg N/ha:** Apply the whole application in early April
- **100 kg N/ha or more:** Apply 40 kg N/ha in early-mid March and the balance of the application in early April

Where a crop of Italian ryegrass seed is to be grown following a silage crop, apply 60 kg N/ha immediately following the silage crop.

Example 3.7

Fodder beet is to be sown on land at P and K Index 1. The crop is expected to yield 85 t/ha (roots lifted).

Offtake for fodder beet is 0.7 kg P_2O_5/t and 4.0 K_2O/t (Table 3.2). The recommendations at Index 1 would be 90 kg P_2O_5/ha and 370 kg K_2O/ha. Both these values are arrived at by (expected yield, ie 85 x offtake) + 30 to build up the soil Index over 10–15 years (Table 1.6, Section 1).

Conversion tables

Metric to imperial

1 tonne/ha	0.4 tons/acre
100 kg/ha	80 units/acre
1 kg/tonne	2 units/ton
10 cm	4 inches
1 m^3	220 gallons
1 m^3/ha	90 gallons/acre
1 kg/m^3	9 units/1000 gallons
1 kg	2 units

Note: a 'unit' is 1% of 1 hundredweight, or 1.12lbs.

Imperial to metric

1 ton/acre	2.5 tonnes/ha
100 units/acre	125 kg/ha
1 unit/ton	0.5 kg/tonne
1 inch	2.5 cm
1,000 gallons	4.5 m^3
1,000 gallons/acre	11 m^3/ha
1 unit	0.5 kg

Element to oxide

P to P_2O_5	Multiply by 2.291
K to K_2O	Multiply by 1.205
Mg to MgO	Multiply by 1.658
S to SO_3	Multiply by 2.500
Na to Na_2O	Multiply by 1.348
Na to salt	Multiply by 2.542

Oxide to element

P_2O_5 to P	Multiply by 0.436
K_2O to K	Multiply by 0.830
MgO to Mg	Multiply by 0.603
SO_3 to S	Multiply by 0.400
Na_2O to Na	Multiply by 0.742
Salt to Na	Multiply by 0.393

Further information

Conversion calculators

cereals.ahdb.org.uk/tools/agronomy-calculators

Fluid fertiliser

kg/tonne (w/w basis) to kg/m^3	Multiply by specific gravity (w/v basis)

Analysis of fertilisers and liming materials

The materials listed below are used individually and some are used as components of compound or multi-nutrient fertilisers. The chemical and physical forms of nutrient sources, as well as growing conditions, can influence the effectiveness of fertilisers. A FACTS Qualified Adviser can give advice on appropriate forms for different soil and crop conditions.

The reactivity, or fineness of grinding, of liming materials determines their speed of action. However, the amount of lime needed is determined mainly by its neutralising value.

Nitrogen fertilisers	Typical % nutrient content
Ammonium nitrate	33.5–34.5% N
Liquid nitrogen solutions	18–30% N (w/w)
Calcium ammonium nitrate (CAN)	26–28% N
Ammonium sulphate	21% N, 60% SO_3
Urea	46% N
Urea + Urease Inhibitor:	46% N + NBPT
Urea + Nitrification Inhibitor:	46% N + DCD
Calcium nitrate	15.5% N, 26% CaO

Phosphate fertilisers	
Single superphosphate (SSP)	18–21% P_2O_5, typically 30% SO_3
Triple superphosphate (TSP)	45–46% P_2O_5
Di-ammonium phosphate (DAP)	18% N, 46% P_2O_5
Mono-ammonium phosphate (MAP)	12% N, 52% P_2O_5
Rock phosphate (eg Gafsa)	27–33% P_2O_5

Potash, magnesium and sodium fertilisers	
Muriate of potash (MOP)	60% K_2O
Sulphate of potash (SOP)	50% K_2O, 45% SO_3
Potassium nitrate	13% N, 45% K_2O
Kainit	11% K_2O, 5% MgO, 26% Na_2O, 10% SO_3
Sylvinite	Minimum 16% K_2O, typically 32% Na_2O
Kieserite (magnesium sulphate)	25% MgO, 50% SO_3
Calcined magnesite	Typically 80% MgO
Epsom salts (magnesium sulphate)	16% MgO, 33% SO_3
Agricultural salt	50% Na_2O

Sulphur fertilisers	
Ammonium sulphate	21% N, 60% SO_3
Epsom salts (magnesium sulphate)	16% MgO, 33% SO_3
Elemental sulphur	Typically 200–225% SO_3 (80–90% S)
Quarried gypsum (calcium sulphate)	40% SO_3
Polyhalite (eg Polysulphate)	Minimum 48% SO_3, 14% K_2O, 6% MgO, 17% CaO.

Liming materials	Neutralising Value (NV)
Ground chalk or limestone	50–55
Magnesian limestone	50–55, over 15% MgO
Hydrated lime	c.70
Burnt lime	c.80
Sugar beet lime	22–32 + typically 7–10 kg P_2O_5, 5–7 kg MgO, 3–5 kg SO_3/tonne

Glossary

Available (nutrient)	Form of a nutrient that can be taken up by a crop immediately or within a short period so acting as an effective source of that nutrient for the crop.
Clay	Finely divided inorganic crystalline particles in soils, less than 0.002 mm in diameter.
Content	Commonly used instead of the more accurate 'concentration' to describe nutrients in fertiliser or organic manure. For example, 6 kg N/t often is described as the nitrogen content of a manure.
Cover crop	A crop sown primarily for the purpose of taking up nitrogen from the soil and which is not harvested. Also called green manure.
Crop available nitrogen	The total nitrogen content of organic manure that is available for crop uptake in the growing season in which it is spread on land.
Crop nitrogen requirement	The amount of crop available nitrogen that must be applied to achieve the economically optimum yield.
Economic optimum	Rate of nitrogen application that achieves the greatest (nitrogen rate) economic return from a crop, taking account of crop value and nitrogen cost.
FACTS	UK national certification scheme for advisers on crop nutrition and nutrient management. Membership renewable annually. A FACTS Qualified Adviser has a certificate and an identity card.
Farm yard manure (FYM)	Livestock excreta that is mixed with straw bedding material that can be stacked in a heap without slumping.
Fertiliser	See Manufactured fertiliser.
Fluid fertiliser	Pumpable fertiliser in which nutrients are dissolved in water (solutions) or held partly as very finely divided particles in suspension (suspensions).
Grassland	Land on which the vegetation consists predominantly of grass species.
Grass Growth Class (GGC)	Ability of a site to respond to nitrogen fertiliser application depending soil type and rainfall.
Leaching	Process by which soluble materials such as nitrate or sulphate are removed from the soil by drainage water passing through it.
Ley	Temporary grass, usually ploughed up one to five years (sometimes longer) after sowing.
Lime requirement	Amount of standard limestone needed in tonnes/ha to increase soil pH from the measured value to a higher specified value (often 6.5 for arable crops). Can be determined by a laboratory test or inferred from soil pH.

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Liquid fertiliser	See Fluid fertiliser.
Livestock manure	Dung and urine excreted by livestock or a mixture of litter, dung and urine excreted by livestock, even in processed organic form. Includes FYM, slurry, poultry litter, poultry manure, separated manures and granular or pelletised manures.
Maintenance application	Amount of phosphate or potash that must be applied to replace (phosphate or potash) the amount removed from a field at harvest (including that in any straw, tops or haulm removed).
Major nutrient	Nitrogen, phosphorus and potassium that are needed in relatively large amounts by crops.
Manufactured fertiliser	Any fertiliser that is manufactured by an industrial process. Includes conventional straight and NPK products (solid or fluid), organo-mineral fertilisers, rock phosphates, slags, ashed poultry manure and liming materials that contain nutrients.
Manure	See Livestock manure and Organic manure.
Micronutrient	Boron, copper, iron, manganese, molybdenum, zinc that are needed in very small amounts by crops (see also Major nutrients and Micronutrients). Cobalt and selenium are taken up in small amounts by crops and are needed in human and livestock diets.
Mineral nitrogen	Nitrogen in ammonium (NH_4) and nitrate (NO_3) forms.
Mineralisation	Microbial breakdown of organic matter in the soil, releasing nutrients in crop-available, inorganic forms.
Neutralizing value (NV)	Percentage calcium oxide (CaO) equivalent in a material. 100 kg of a material with a neutralising value of 52% will have the same neutralising value as 52 kg of pure CaO. NV is determined by a laboratory test.
Nitrate vulnerable zones (NVZs)	Areas designated by Defra as being at risk from agricultural nitrate pollution.
Offtake	Amount of a nutrient contained in the harvested crop (including straw, tops or haulm) and removed from the field. Usually applied to phosphate and potash.
Olsen P	Concentration of available P in soil determined by a standard method (developed by Olsen) involving extraction with sodium bicarbonate solution at pH 8.5. The main method used in the England, Wales and Northern Ireland and the basis for the Soil Index for P.

Organic manure	Any bulky organic nitrogen source of livestock, human or plant origin, including livestock manures.
Organic soil	Soil containing between 10% and 20% organic matter (in this Manual). Elsewhere, sometimes refers to soils with between 6% and 20% organic matter.
Peaty soil (peat)	Soil containing more than 20% organic matter.
Poultry manure	Excreta produced by poultry, including bedding material that is mixed with excreta, but excluding duck manure, with a readily available nitrogen content of 30% or less.
Sand	Soil mineral particles larger than 0.05 mm.
Silt	Soil mineral particles in the 0.002–0.05 mm diameter range.
Slurry	Excreta of livestock (other than poultry), including any bedding, rainwater and washings mixed with it, which can be pumped or discharged by gravity. The liquid fraction of separated slurry is also defined as slurry.
SNS Index	Soil Nitrogen Supply expressed in seven bands or Indices, each associated with a range in kg N/ha.
Soil Index (P, K or Mg)	Concentration of available P, K or Mg, as determined by standard analytical methods, expressed in bands or Indices.
Soil Nitrogen Supply (SNS)	The amount of nitrogen (kg N/ha) in the soil that becomes available for uptake by the crop in the growing season, taking account of nitrogen losses.
Soil texture	Description based on the proportions of sand, silt and clay in the soil.
Soil type	Description based on soil texture, depth, chalk content and organic matter content.
Trace element	See Micronutrient.

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The industry-wide Greenhouse Gas Action Plan (GHGAP) for agriculture focuses on improving resource use efficiency in order to enhance business performance whilst reducing GHG emissions from farming.

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Nutrient Management Guide (RB209)

Updated January 2019

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Section 4 Arable crops

Using the Nutrient Management Guide (RB209)

This latest revision of RB209 is based on research carried out since the previous edition was published in 2010. The revision includes updated recommendations, including those for additional crops and information on the nutrient content of additional organic materials.

RB209 was first published in 1973 and was the first comprehensive set of fertiliser recommendations from the Ministry of Agriculture, Fisheries and Food (MAFF). RB209 stands for Reference Book 209.

To improve the accessibility of the recommendations and information AHDB's Nutrient Management Guide (RB209) is published as seven sections that will be updated individually.

Further information

The Nutrient Management Guide (RB209) will be updated regularly.

Please email your contact details to AHDB so that we can send you updates when they are published - **comms@ahdb.org.uk**

RB209: Nutrient Management
Download the app for Apple or Android phones to access the current version of all sections of the guide. With quick and easy access to videos, information and recommendations from the guide, it is practical for use in the field.

Section 1	Principles of nutrient management and fertiliser use
Section 2	Organic materials
Section 3	Grass and forage crops
Section 4	Arable crops
	Cereals
	Oilseeds
	Sugar beet
	Peas and beans
	Biomass crops
Section 5	Potatoes
Section 6	Vegetables and bulbs
Section 7	Fruit, vines and hops

This section provides guidance for arable crops and should be read in conjunction with Sections 1 and 2. For each crop, recommendations for nitrogen (N), phosphate (P_2O_5) and potash (K_2O) are given in kilograms per hectare (kg/ha). Magnesium (as MgO), sulphur (as SO_3) and sodium (as Na_2O) recommendations, also in kg/ha, are given where these nutrients are needed.

Recommendations are given for the rate and timing of nutrient application. The recommendations are based on the nutrient requirements of the crop being grown, while making allowance for the nutrients supplied by the soil.

Always consider your local conditions and consult a FACTS Qualified Adviser if necessary.

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Summary of main changes from previous edition

1. Overall presentation

   a. Fertiliser recommendations for arable crops are now presented in **Section 4: Arable crops** that incorporates the relevant appendices.

2. New and revised recommendations

   a. The revised recommendations allow the crop nitrogen requirement to be adjusted for expected yield for winter wheat, winter barley and spring barley.

   b. Updated nitrogen recommendations for winter wheat, winter triticale, winter oats, winter barley and spring barley.

   c. Updated guidance on nitrogen fertiliser application timing for winter barley and winter oilseed rape.

   d. The guidance on assessing Soil Nitrogen Supply (SNS) has been revised to include guidance on when Soil Mineral Nitrogen (SMN) sampling can be most useful and interpretation of SMN analysis results.

   e. The guidance on soil sampling for P, K Mg and pH analysis has been updated.

   f. Recommendations for sunflower have been included.

   g. An error was corrected on page 29. To increase grain protein content by 1.1% in wheat for bread-making, an application of up to 40 kg N/ha could be made, not 60 kg N/ha as published in May 2017.

   h. Figures on the effect of economic changes on nitrogen rates for oilseed rape have been updated (page 40, Table 4.27).

Checklist for decision making

Individual decisions for fertiliser use must be made separately for every field. Where more than one crop is grown in a field, these areas must be considered individually.

1. Confirm the crop to be grown and the intended market. Identify any crop quality requirements for this market. For the purposes of this guide, winter sown is defined as sown before 1 February and spring sown as in February or after.

2. Identify the dominant soil type in the cropped area **(Section 1: Principles of nutrient management and fertiliser use)**.

3. Assess soil structure and take action to remove soil compaction if necessary. Poor soil structure can restrict crop growth and results in poor nutrient use efficiency.

Further information

Think soils
ahdb.org.uk/knowledge-library/thinksoils

AHDB Field drainage guide
ahdb.org.uk/knowledge-library/field-drainage-guide

4. Carry out soil analysis for pH, P, K and Mg every 3–5 years (page 19). Target values to maintain in arable rotations are:
   - Soil pH 6.5 (5.8 on peat soils)
   - Soil P Index 2
   - Soil K lower Index 2 (2-)
   - Soil Mg Index 2

5. Identify the Soil Nitrogen Supply (SNS) Index of the field, either by using the Field Assessment Method (page 6) or the Measurement Method (page 13).
6. Calculate the total and crop available nutrients from organic materials that have been applied since harvest of the previous crop, or which will be applied to the crop being grown **(Section 2: Organic materials)**. Deduct these nutrients from the recommended rates given in the tables.
7. Decide on the strategy for phosphate and potash use. This will be building up, maintaining or running down the soil Index **(Section 1: Principles for nutrient management and fertiliser use)**. Allow for any surplus or deficit of phosphate or potash applied to previous crops in the rotation.
8. Calculate the amount of phosphate and potash removed in the harvested crop according to targeted crop yield (Table 4.11). This is the amount of these nutrients that must be replaced in order to maintain the soil at the current Index. Remember that some of these nutrients will also be removed in straw.
9. Using the tables, decide on the required rate of each nutrient. Decide on the optimum timings for fertiliser application, then find the best match for these applications using available fertilisers.
10. Check that the fertiliser spreader or sprayer is in good working order and has been recently calibrated **(Section 1: Principles of nutrient management and fertiliser use)**.
11. Keep an accurate record of the fertilisers and organic materials applied.

Calculating Soil Nitrogen Supply

Fields vary widely in the amount of nitrogen available to a crop before any fertiliser or manure is applied. This variation must be taken into account to avoid inadequate or excessive applications of nitrogen.

The Soil Nitrogen Supply (SNS) system assigns an Index of 0 to 6 to indicate the likely extent of this background nitrogen supply (Table 4.6). The Index is used in the recommendation tables to select the amount of nitrogen, as manufactured fertiliser, manure or a combination of both, that typically would need to be applied to ensure optimum yield.

The SNS Index for each field can be estimated either by the Field Assessment Method using records of soil type, previous cropping and winter rainfall or by the Measurement Method. This uses measurements of Soil Mineral Nitrogen (SMN) plus estimates of nitrogen already in the crop (at the time of soil sampling) and of available nitrogen from the mineralisation of soil organic matter and crop debris during the period of active crop growth.

Field Assessment Method

The Field Assessment Method does not take account of the nitrogen that will become available to a crop from any organic manures applied since harvest of the previous crop. The available nitrogen from organic materials applied since harvest of the previous crop, or those that will be applied to the current crop, should be calculated separately using the information in **Section 2: Organic materials**, and deducted from the fertiliser nitrogen application rates shown in the recommendation tables.

There are five essential steps to follow to identify the appropriate SNS Index:

Step 1. Identify the soil type for the field
Step 2. Identify the previous crop
Step 3. Select the rainfall range for the field
Step 4. Identify the provisional SNS Index using the appropriate table
Step 5. Make any necessary adjustments to the SNS Index

In detail, these steps are:

Step 1. Identify soil type for the field
Careful identification of the soil type in each field is very important. The whole soil profile should be assessed to one metre depth for arable crops. Where the soil varies, and nitrogen is to be applied uniformly, select the soil type that occupies the largest part of the field.

The soil type can be identified using Figure 4.1 which categorises soils on their ability to supply and retain mineral nitrogen. The initial selection can then be checked using Table 4.1. Carefully assess the soil organic matter content when deciding if the soil is organic (10% to 20% organic matter for the purposes of this guide) or peaty (more than 20% organic matter). If necessary, seek professional advice on soil type assessments, remembering this will need to be done only once.

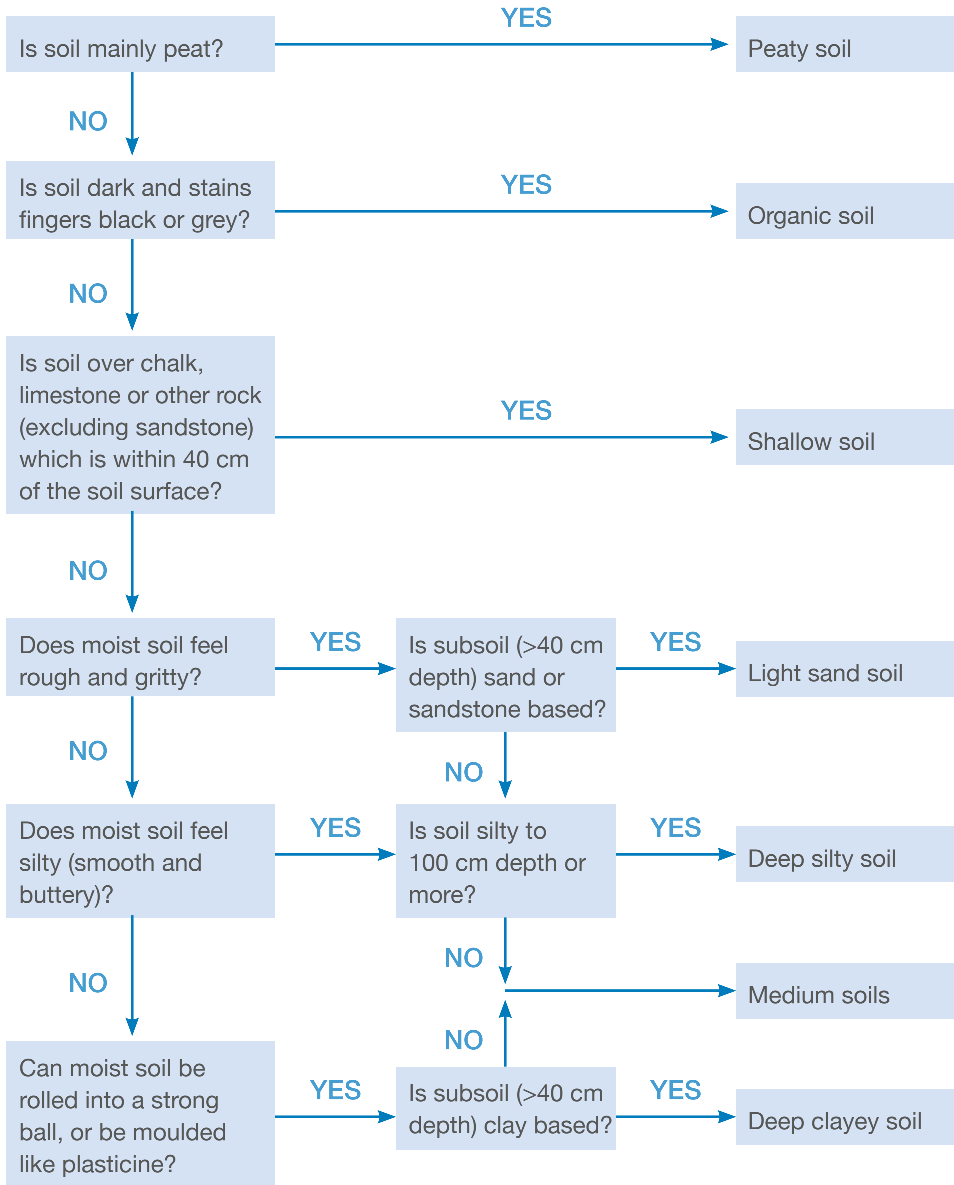

Figure 4.1 Soil category assessment

Table 4.1 Soil category assessment

Soil category	Description of soil types within category	Properties
Light sand soils	Soils which are sand, loamy sand or sandy loam to 40 cm depth and are sand or loamy sand between 40– 80 cm, or over sandstone rock.	Soils in this category have poor water holding capacity and retain little nitrogen.
Shallow soils	Soils over impermeable subsoils and those where the parent rock (chalk, limestone or other rock) is within 40 cm of the soil surface. Sandy soils developed over sandstone rock should be regarded as light sand soils.	Soils in this category are less able to retain or supply nitrogen at depth.
Medium soils	Mostly medium-textured mineral soils that do not fall into any other soil category. This includes sandy loams over clay, deep loams, and silty or clayey topsoils that have sandy or loamy subsoils.	Soils in this category have moderate ability to retain nitrogen and allow average rooting depth.
Deep clayey soils	Soils with predominantly sandy clay loam, silty clay loam, clay loam, sandy clay, silty clay or clay topsoil overlying clay subsoil to more than 40 cm depth. Deep clayey soils normally need artificial field drainage.	Soils in this category are able to retain more nitrogen than lighter soils.
Deep silt soils	Soils of sandy silt loam, silt loam or silt clay loam textures to 100 cm depth or more. Silt soils formed on marine alluvium, warp soils (river alluvium) and brickearth soils are in this category. Silt clays of low fertility should be regarded as other mineral soils.	Soils in this category are able to retain more nitrogen than lighter soils and allow rooting to greater depth.
Organic soils	Soils that are predominantly mineral but with between 10–20% organic matter to depth. These can be distinguished by darker colouring that stains the fingers black or grey.	Soils in this category are able to retain more nitrogen than lighter soils and have higher nitrogen mineralisation potential.
Peat soils	Soils that contain more than 20% organic matter derived from sedge or similar peat material.	Soils in this category have very high nitrogen mineralisation potential.

Step 2. Identify previous crop
Usually, this is straightforward but sometimes clarification may be needed:

High residual nitrogen vegetables ('high N vegetables') are leafy, nitrogen-rich Brassica crops such as calabrese, Brussels sprouts and some crops of cauliflower where significant amounts of crop debris are returned to the soil, especially in rotations where an earlier Brassica crop has been grown within the previous twelve months. To be available for crop uptake, this organic nitrogen must have had time to mineralise but the nitrate produced must not have been at risk to loss by leaching.

Medium residual nitrogen vegetables ('medium N vegetables') are crops such as lettuce, leeks and long-season Brassicas, eg Dutch white cabbage, where a moderate amount of crop debris is returned to the soil.

Low residual nitrogen vegetables ('low N vegetables') are crops such as carrots, onions, radish, swedes or turnips where the amount of crop residue is relatively small.

Step 3. Select low, moderate or high rainfall
The appropriate rainfall category should be identified, based on either annual rainfall or excess winter rainfall. Ideally, an estimate of excess winter rainfall is required because this is closely related to drainage by which nitrate will be lost through leaching. Figure 4.2 shows long-term (1981–2010) average excess winter rainfall which, in an average year, can be used to select the rainfall category.

There are three SNS Index tables representing 'low rainfall' (annual rainfall less than 600 mm, or less than 150 mm excess winter rainfall), 'moderate rainfall' (between 600–700 mm annual rainfall, or 150–250 mm excess winter rainfall), and 'high rainfall' areas (over 700 mm annual rainfall, over 250 mm excess winter rainfall).

Further information
AHDB provides Excess Winter Rainfall (EWR) data for the current season
cereals.ahdb.org.uk/ewr

Figure 4.2 Excess winter rainfall (mm)

Step 4. Identify the provisional SNS Index
Tables 4.2 (low rainfall), 4.3 (moderate rainfall) and 4.4 (high rainfall) should be used where the field has not been in grass within the past three years. Select one of these tables according to rainfall for the field. Take account of the footnotes to the tables.

Higher than typical Indices can occur where there has been a history of grassland or frequent applications of organic manures. The Measurement Method is recommended in these situations (page 13).

If grass has been grown in the previous three years, also look at Table 4.5. Select the higher of the Index levels based on the last crop grown (from Table 4.2, 4.3 or 4.4) and on the grass history (from Table 4.5).

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Table 4.2. Soil Nitrogen Supply (SNS) Indices for low rainfall (500–600 mm annual rainfall, up to 150 mm excess winter rainfall) – based on the last crop grown

Previous crop	Soil type					
	Light sand soils or shallow soils over sandstone	Medium soils or shallow soils not over sandstone	Deep clayey soils	Deep silty soils	Organic soils	Peat soils
Beans	1	2	3	3	All crops in SNS Index 3, 4, 5 or 6. Consult a FACTS Qualified Adviser.	All crops in SNS Index 4, 5 or 6. Consult a FACTS Qualified Adviser.
Cereals	0	1	2	2		
Forage crops (cut)	0	1	2	2		
Oilseed rape	1	2	3	3		
Peas	1	2	3	3		
Potatoes	1	2	3	3		
Sugar beet	1	1	2	2		
Uncropped land	1	2	3	3		
Vegetables (low N)[b]	0	1	2	2		
Vegetables (medium N)[b]	1	3	3[a]	3[a]		
Vegetables (high N)[b]	2	4[a]	4[a]	4[a]		

a. Index may need to be increased by up to 1 where significantly larger amounts of leafy residues are incorporated (see Step 5). Where there is uncertainty, soil sampling for SMN may be appropriate.

b. Refer to Step 2.

Table 4.3. Soil Nitrogen Supply (SNS) Indices for moderate rainfall (600–700 mm annual rainfall, or 150–250 mm excess winter rainfall) – based on the last crop grown

Previous crop	Soil type					
	Light sand soils or shallow soils over sandstone	Medium soils or shallow soils not over sandstone	Deep clayey soils	Deep silty soils	Organic soils	Peat soils
Beans	1	2	2	3	All crops in SNS Index 3, 4, 5 or 6. Consult a FACTS Qualified Adviser.	All crops in SNS Index 4, 5 or 6. Consult a FACTS Qualified Adviser.
Cereals	0	1	1	1		
Forage crops (cut)	0	1	1	1		
Oilseed rape	0	2	2	2		
Peas	1	2	2	3		
Potatoes	0	2	2	2		
Sugar beet	0	1	1	1		
Uncropped land	1	2	2	2		
Vegetables (low N)[b]	0	1	1	1		
Vegetables (medium N)[b]	0	2	3	3		
Vegetables (high N)[b]	1	3	4	4		

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Table 4.4. Soil Nitrogen Supply (SNS) Indices for high rainfall (over 700 mm annual rainfall, or over 250 mm excess winter rainfall) – based on the last crop grown

Previous crop	Soil type					
	Light sand soils or shallow soils over sandstone	Medium soils or shallow soils not over sandstone	Deep clayey soils	Deep silty soils	Organic soils	Peat soils
Beans	0	1	2	2	All crops in SNS Index 3, 4, 5 or 6. Consult a FACTS Qualified Adviser.	All crops in SNS Index 4, 5 or 6. Consult a FACTS Qualified Adviser.
Cereals	0	1	1	1		
Forage crops (cut)	0	1	1	1		
Oilseed rape	0	1	1	2		
Peas	0	1	2	2		
Potatoes	0	1	1	2		
Sugar beet	0	1	1	1		
Uncropped land	0	1	1	2		
Vegetables (low N)[b]	0	1	1	1		
Vegetables (medium N)[b]	0	1	1	2		
Vegetables (high N)[b]	1[a]	2	2	3		

a. Index may need to be lowered by 1 where residues incorporated in the autumn and not followed immediately by an autumn-sown crop.

b. Refer to Step 2.

Table 4.5. Soil Nitrogen Supply (SNS) Indices following ploughing out of grass leys

	SNS Index		
Light sands or shallow soils over sandstone – all rainfall areas	Year 1	Year 2	Year 3
All leys with 2 or more cuts annually receiving little or no manure 1–2 year leys, low N 1–2 year leys, 1 or more cuts 3–5 year leys, low N, 1 or more cuts	0	0	0
1–2 year leys, high N, grazed 3–5 year leys, low N, grazed 3–5 year leys, high N, 1 cut then grazed	1	2	1
3–5 year leys, high N, grazed	3	2	1
Other medium soils and shallow soils – not over sandstone – all rainfall areas			
All leys with 2 or more cuts annually receiving little or no manure 1–2 year leys, low N 1–2 year leys, 1 or more cuts 3–5 year leys, low N, 1 or more cuts	1	1	1
1–2 year leys, high N, grazed 3–5 year leys, low N, grazed 3–5 year leys, high N, 1 cut then grazed	2	2	1
3–5 year leys, high N, grazed	3	3	2
Deep clayey soils and deep silty soils in low rainfall areas (500–600 mm annual rainfall)			
All leys with 2 or more cuts annually receiving little or no manure 1–2 year leys, low N 1–2 year leys, 1 or more cuts 3–5 year leys, low N, 1 or more cuts	2	2	2
1–2 year leys, high N, grazed 3–5 year leys, low N, grazed 3–5 year leys, high N, 1 cut then grazed	3	3	2
3–5 year leys, high N, grazed	5	4	3
Deep clayey soils and deep silty soils in moderate (600–700 mm annual rainfall) or high (over 700 mm annual rainfall) rainfall areas			
All leys with 2 or more cuts annually receiving little or no manure 1–2 year leys, low N 1–2 year leys, 1 or more cuts 3–5 year leys, low N, 1 or more cuts	1	1	1
1–2 year leys, high N, grazed 3–5 year leys, low N, grazed 3–5 year leys, high N, 1 cut then grazed	3	2	1
3–5 year leys, high N, grazed	4	3	2

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The Indices shown in Table 4.5 assume that little or no organic manure has been applied. Where silage fields have received the organic manures produced by livestock that have eaten the silage and the manure has been applied in spring, such fields should be regarded as containing nitrogen residues equivalent to a previous grazing history.

'Low N' grassland means average annual inputs of less than 250 kg N/ha in fertiliser plus crop available nitrogen in manure used in the last two years, or swards with little clover.

'High N' grassland means average annual applications of more than 250 kg N/ha in fertiliser plus crop available nitrogen in manure used in the last two years, or clover-rich swards or lucerne.

Step 5. Make any necessary adjustment to the SNS Index for certain conditions

When using the Field Assessment Method, it is not necessary to estimate the amount of nitrogen taken up by the crop over winter. This is already taken into account in the tables.

Manure history: Where regular applications of organic manures have been made to previous crops in the rotation, increase the Index value by one or two levels depending on manure type, application rate and frequency of application.

Point to consider

- The nitrogen contribution from manures applied after harvest of the previous crop should not be considered when deciding the SNS Index; this contribution should be deducted from the recommended nitrogen application rate using the information in Section 2: Organic Materials

Field vegetables as previous crop: On medium, deep silty or deep clayey soils, nitrogen residues in predominantly vegetable rotations can persist for several years especially in the drier parts of the country. This is likely to be especially evident following 'high or medium N vegetables'. The SNS tables make some allowance for this long persistency of nitrogen residues but the Index level may need to be adjusted upwards, particularly where:

- Winter rainfall is low
- Where the history of vegetable cropping is longer than one year
- In circumstances where larger than average amounts of crop residue or unused fertiliser are left behind (see Footnote to Table 4.2)

In rotations where vegetable crops are grown infrequently and when there is uncertainty, soil sampling for SMN may be appropriate.

Fertiliser residues from previous crop: The Index assessments assume that the previous crop grew normally and that it received the recommended rate of nitrogen applied as fertiliser and/or organic manures. The Index should be increased if there is reason to believe nitrogen residues are likely to be greater than normal and these residues will not be lost by leaching. This could occur where a cover crop was sown in autumn and grew well over winter. The Index may need to be adjusted downwards if there is reason to believe nitrogen residues are likely to be smaller than usual.

After any adjustment, the SNS Index can be used in the recommendation tables.

Measurement Method

This method is particularly appropriate where the SNS is likely to be large and uncertain. This includes:

- **Fields with a history of organic manure application and vegetable rotations where the timing of residue incorporation can strongly affect Soil Mineral Nitrogen (SMN) for the following crop**
- **Fields where long leys or permanent pasture have been recently ploughed out (but not in the first year after ploughing out)**
- **Fields where there have been problems such as regular lodging of cereals, very high grain protein or nitrogen contents, or previous crop failure (for example due to drought or disease)**
- **Fields where there is significant variation in soil texture and/or large amounts of crop residues are incorporated; nitrogen residues also can be large following outdoor pigs**

The SNS Index can be identified using the results of direct measurement of SMN to 90 cm depth in spring, 60 cm depth in autumn/early winter, or to maximum rooting depth in shallow soils over rock. The crop nitrogen content (at the time of soil sampling) and an estimate of net mineralisable nitrogen must be added to the SMN result when calculating the SNS.

SNS is likely to be low on light sand and shallow soils that have not received regular additions of organic manure or crop residues, particularly in moderate to high rainfall areas. In this scenario prediction of SNS using the Field Assessment Method is advised.

The Measurement Method is not recommended for peat soils, or in the first season after ploughing out long leys or permanent pasture, where net mineralisation can be very large and uncertain and the measured SMN may be a relatively small component of SNS. For these soils, the Field Assessment Method or local experience will be better guides to SNS.

Points to consider

- **Do not confuse Soil Nitrogen Supply (SNS) and Soil Mineral Nitrogen (SMN)**
- **SMN is the measured amount of mineral nitrogen (nitrate-N plus ammonium-N) in the soil profile**
- **The Measurement Method is not suitable for organic and peaty soils as SNS (due to mineralisation of soil organic matter) is unpredictable**
- **SNS = an estimate of crop N (at time of sampling) + a measurement of SMN + an estimate of subsequent N mineralisation**

The Measurement Method does not take account of the available nitrogen supplied from organic materials applied after the date of soil sampling for SMN. The available nitrogen from materials applied after sampling should be calculated separately using the information in **Section 2: Organic materials**, and deducted from the nitrogen rate shown in the appropriate recommendation table.

The nitrogen contribution from materials applied before sampling for SMN will be largely taken account of in the measured value and should not be calculated separately.

When using the Measurement Method there are four steps to follow:

Step 1. Measure Soil Mineral Nitrogen (SMN)
Step 2. Estimate nitrogen already in the crop
Step 3. Make an allowance for net mineralisable nitrogen
Step 4. Identify Soil Nitrogen Supply (SNS) Index

In detail these four steps are:

Step 1. Measure Soil Mineral Nitrogen (SMN)
Soil sampling must be done well to avoid misleading results and expensive mistakes.

Guidance on how to collect a SMN sample

- In most situations, sampling in late winter or early spring before nitrogen fertiliser is applied gives slightly better predictions of SNS than sampling in the autumn, because overwinter leaching is accounted for, especially in high rainfall areas or on shallow or light sand soils. On soils less prone to leaching, sampling in autumn or early spring is equally effective
- Avoid sampling within two to three months after application of nitrogen fertiliser or organic manures, or within a month after sowing
- Areas of land known to differ in some important respects (eg soil type, previous cropping, manure or nitrogen fertiliser application) should be sampled separately
- Do not sample unrepresentative areas, such as ex-manure heaps or headlands
- Avoid collecting and sending samples immediately before the weekend or a public holiday
- Samples must be taken to be representative of the area sampled. A minimum of 10–15 soil cores should be taken following a ‘W’ pattern across each field/area to be sampled
- In larger fields (10–20 ha), increase the number of cores to 15–20 unless the soil type is not uniform, in which case more than one sample should be taken. This can be done by dividing the field into smaller blocks from each of which 10–15 soil cores are taken
- Each position should be sampled at three depths in the spring: 0–30 cm, 30–60 cm and 60–90 cm. Sampling to 60 cm is adequate in the autumn
- Samples from each depth should be bulked to form a representative sample of that depth. If the bulk sample is too big, take a representative subsample to send to the laboratory; do not stir the sample excessively
- Use appropriate packaging (normally available from the laboratory) and label samples clearly, providing as much information about the field and crop as possible
- Samples should be analysed within three days of sampling. Samples must be kept cool (2–4˚C) but not frozen during storage or transport

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.

Analysis in the laboratory
Samples should be analysed for nitrate-N and ammonium-N. Analytical results in mg N/kg should be converted to kg/ha, taking into account the dry bulk density of the soil, then summed to give a value for the whole soil profile. For the majority of mineral soils a ‘standard’ bulk density of 1.33 g/ml can be used and the calculation can be simplified to:

SMN (kg N/ha) = mg N/kg x 2 (for each 15 cm layer of soil)

SMN (kg N/ha) = mg N/kg x 4 (for each 30 cm layer of soil)

SMN (kg N/ha) = mg N/kg x 8 (for each 60 cm layer of soil)

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Step 2. Estimate nitrogen already in the crop
Where a crop is present when SMN is measured, the amount of nitrogen already taken up must be estimated. For cereals, this is often a small though important component of the SNS, but for oilseed rape it can be large.

The crop nitrogen content in cereals can be estimated according to the number of shoots present (main shoots and tillers), as follows:

Table 4.6 Estimating cereal crop N using shoot number

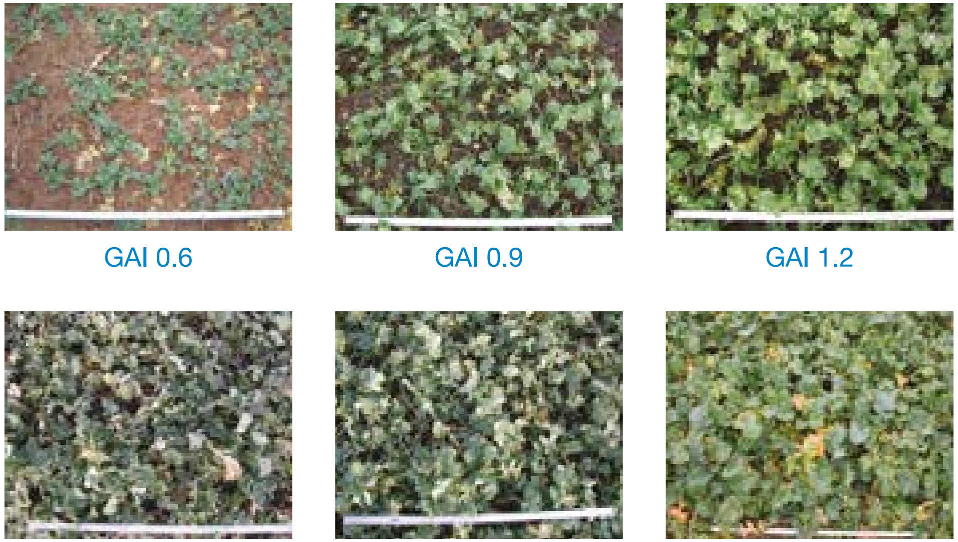
Shoot number/m²	Crop nitrogen content (kg N/ha)	
	Autumn	Spring
500	5	15
1,000	15	30
1,500	25	50

Large oilseed rape canopies can contain substantial amounts of nitrogen by the spring (in excess of 100 kg N/ha). Research has shown that even for large canopies all of the N in the crop can be treated as contributing to the SNS.

In oilseed rape, the crop contains around 50 kg N/ha for every unit of Green Area Index (GAI, Table 4.7). For larger canopies (GAI of 2 or more) the crop may contain closer to 40 kg N/ha per unit of GAI. Use Figure 4.3 as a guide for estimating GAI.

Table 4.7 Estimating oilseed rape crop N using GAI

Oilseed rape GAI	Crop N (kg/ha)
0.5	25
1.0	50
2.0	80–100



GAI 0.6 GAI 0.9 GAI 1.2

GAI 1.6 GAI 2.2 GAI 2.8

Figure 4.3 Estimating the GAI of an oilseed rape crop

Alternatively, the nitrogen content of an average density crop can be estimated by measuring the average crop height. This may not be appropriate for semi-dwarf varieties and should not be used on crops that have been flattened by snow.

Table 4.8 Estimating crop N using crop height

Crop height (cm)	Crop nitrogen content (kg N/ha)	
	Autumn	Spring
10	35	45
15	55	65
20	75	85

Add the estimate of crop N to the measurement of SMN.

Step 3. Make an adjustment for net mineralisable nitrogen
Nitrogen mineralised from soil organic matter and crop debris after soil sampling is a potentially important source of nitrogen for crop uptake. However, in mineral soils of low to average organic matter content (<4% in England and Wales or <10% in Scotland and Northern Ireland), the amount of net mineralisable nitrogen will be relatively small and, for practical purposes, no further adjustment is needed when using the recommendations in this guide. The only exception being after cold winters, when an estimate of around 20 kg N/ha may be appropriate.

An adjustment may be needed where soil organic matter content is above average or where there has been a history of regular manure applications. In these situations, a commercial measurement of Additionally Available N (AAN) gives the most useful prediction of mineralisation.

As a guide, where measurement is not done, for every 1% organic matter above 4%, a topsoil may release an additional 10 kg N/ha. Therefore, a soil that has a topsoil organic matter content of 10% may release around 60 kg/ha more Soil Mineral Nitrogen than an equivalent soil with 4% organic matter content.

However, some soils with an organic matter content above 4% may release little nitrogen and local knowledge must be used when estimating mineralisable nitrogen. Therefore, it is not possible to specify a routine amount by which to adjust SNS based on soil organic matter level.

Add any adjustment for net mineralisable nitrogen to the total of SMN and nitrogen in the crop to give SNS.

Step 4. Identify the SNS Index

Table 4.9 Soil Nitrogen Supply (SNS) Indices

SNS (kg N/ha)	SNS Index	SNS (kg N/ha)	SNS Index
Less than 60	0	121–160	4
61–80	1	161–240	5
81–100	2	More than 240	6
101–120	3		

Adopting changes to nitrogen use
Large SMN measurements can overestimate SNS and small SMN measurements can underestimate SNS. Uptake of soil N by crops is rarely less than 50 kg N/ha, so SNS estimates less than this should be treated as 50 kg N/ha and no less.

Unless high SNS results (>160 kg N/ha) are confidently expected, they should also be treated with caution. If SNS estimates indicate that large changes (either increases or decreases) in nitrogen fertiliser use are required, crops should be monitored closely through spring for signs of nitrogen deficiency or excess and the planned nitrogen strategy should be adjusted, if necessary. It may be best for changes in nitrogen use to be introduced gradually over a few seasons so that the effect on crop performance can be monitored.

Example 4.1

Spring barley (feed) is to be grown on a light sand soil following sugar beet. Annual rainfall is 650 mm. There have been no organic manures applied or grass grown in the last five years.

Select Table 4.3 (SNS Indices for moderate rainfall areas). On a light sand soil following sugar beet, the SNS Index is 0. Refer to the spring barley recommendation (Table 4.19, page 32) which gives a recommendation of 140 kg N/ha.

Example 4.2

Sugar beet is grown on a medium soil after winter wheat. 30 m^3/ha of pig slurry (4% DM) was applied in February and incorporated into the soil within six hours. Although the average annual rainfall is 650 mm, in an unusually dry winter the excess winter rainfall was found to be 100 mm.

Since the winter was dry, select Table 4.2 (SNS Indices for low rainfall areas). On a medium soil after winter wheat, the SNS Index is 1. Refer to the sugar beet recommendation (Table 4.29, page 41) which gives a recommendation of 120 kg N/ha.

Since the pig slurry was applied after harvest of the last crop, its nitrogen contribution must be calculated separately. This manure application provides 65 kg/ha of available nitrogen that is equivalent to manufactured nitrogen fertiliser **(Section 2: Organic materials)**

120 – 65 = 55 kg N/ha as fertiliser should be applied.

Example 4.3

Winter wheat is grown on a medium textured, low organic matter soil after potatoes, which received some FYM. Annual rainfall is 750 mm. The soil is sampled in early February and analysed for SMN.

The analysis report shows that the SMN (0–90 cm) is 115 kg N/ha and the crop nitrogen content is estimated to be 25 kg N/ha. Because the soil contains little organic matter, no extra allowance is made for net mineralisable nitrogen. The SNS is therefore 140 kg N/ha. Refer to Table 4.9 that shows the SNS Index is 4. Refer to the winter wheat recommendation (Table 4.15, page 28) which gives a recommendation of 120 kg N/ha for a medium soil.

Example 4.4

Winter barley is to be sown following a 3-year pure grass ley which has been managed in the last two years using 280 kg/ha/year nitrogen as manufactured fertiliser and crop-available N from manures. An average application of slurry has been applied in early spring each year, before taking one cut of silage followed by grazing.

The soil is a medium soil in a moderate rainfall area.

The previous grass management is classed as 'high N'. Using Table 4.5 for medium soils, select the category '3–5 year leys, high N, grazed'. The SNS Index appropriate for the winter barley crop is Index 3. If regular applications of bulky organic manures had been applied in previous years, the Index value could be increased by one or two levels. In this case slurry was applied. The SNS Indices for the next two crops following the winter barley are Index 3 and Index 2, respectively.

Example 4.5

Winter wheat is to be sown following spring barley that followed a 2-year grazed ley which has been managed using 300 kg/ha/year nitrogen as manufactured fertiliser and crop available N from manures. The soil is a deep clay in a high rainfall area.

Using Table 4.4, the SNS Index would be 1. Using Table 4.5, the previous grass management is classed as 'high N, grazed'. The SNS Index from this Table is 2. The higher of these two Indices from Tables 4.4 and 4.5 is 2 and this should be used for the recommendation tables.

Phosphate, potash and magnesium recommendations

Current phosphate, potash and magnesium recommendations are based on achieving and maintaining target soil Indices for each nutrient in the soil throughout the crop rotation. Soil analysis should be done every 3–5 years. The use of soil analysis as a basis for making fertiliser decisions and the procedure for taking soil samples is described on page 19.

The phosphate and potash recommendations shown at Index 2 and 2-, respectively, are those required to replace the offtake and maintain target soil Indices. The larger recommended applications for soils at Index 0 and 1 will bring the soil to Index 2 over a number of years. By not applying fertiliser at Index 3 or above, soil will run down over a number of years to the target Index.

Phosphate and potash recommendations shown in this guide are those required to replace the offtake of the yield shown. The recommendation should be increased or decreased where yields are expected to be substantially more or less than this. The amount to apply can be calculated using the targeted yield and values for the offtake of phosphate and potash per tonne of yield given in Table 4.11.

Recommendations are appropriate where the phosphate or potash balance for preceding crops have been close to neutral. Adjustments can be made where the balance for the preceding crop was significantly positive or negative. This might occur where actual yields were substantially different from those expected, or where there was a change of plan on straw removal. A phosphate or potash ‘holiday’ can result in a need for greater than normally recommended amounts for following crops.

Points to consider

- Recommendations assume good soil structure, water supply, and pest and disease control
- Recommendations are given as phosphate (P_2O_5), potash (K_2O) and magnesium oxide (MgO). Conversion tables (metric-imperial, oxide-element) are given on page 46
- Organic materials supply phosphate and potash which contribute to crop requirements. Don’t forget to make allowance for the phosphate and potash applied in organic materials **(Section 2: Organic materials)**
- All recommendations are given for the mid-point of each Index. For some crops, there are different recommendations depending on whether the soil is in the lower half (2-) or upper half (2+) of K Index 2
- Where a soil analysis value (as given by the laboratory) is close to the range of an adjacent Index, the recommendation may be reduced or increased slightly, taking account of the recommendation given for the adjacent Index. Small adjustments of less than 10 kg/ha are generally not justified
- Where more or less phosphate and potash are applied than suggested in the tables, adjustments can be made later in the rotation

PAAG

Professional Agricultural Analysis Group

Most UK laboratories are members of the PAAG that offers farmers and advisers confidence in laboratory analysis.

- Proficiency tests (often called ring tests) carried out by Wageningen University, guarantee that analysis from any member can be trusted **www.wepal.nl**
- List of UK laboratories **www.nutrientmanagement.org/what-we-do/support-and-advice/find-a-laboratory**
- Sampling guidelines **www.nutrientmanagement.org/library/sampling**

Taking soil samples for phosphorus, potassium and magnesium

Soil sampling must be done accurately to avoid misleading results and expensive mistakes.

- The soil in each field should be sampled every 3–5 years
- Collect samples at the same point in the rotation and well before growing a sensitive crop eg sugar beet
- Ideally, sample immediately after the harvest of the previous crop
- Do not sample within six months of a lime or fertiliser application (except nitrogen) and avoid sampling when the soil is very dry
- Do not take samples in headlands, or in the immediate vicinity of hedges, trees or other unusual features
- The soil sample must be representative of the area sampled. Areas of land known to differ in some important respects (eg soil type, previous cropping, applications of manure, fertiliser or lime) should be sampled separately. Small areas known to differ from the majority of a field should be excluded from the sample.
- Ideally, the sampled area should be no larger than four hectares
- Clean tools before starting and before sampling a new area
- Walk a 'W' pattern across the sampling area, stopping at least 25 times
- At each point, collect a subsample (core) to 15 cm depth using a gouge corer or screw auger. However, if the land is min-tilled, phosphate and potash will tend to accumulate near the soil surface and a 15 cm sample will overestimate nutrient concentrations to normal plough depth. In this case, samples are better taken to about 23 cm
- The subsamples should be bulked to form a representative sample and sent to the laboratory for analysis
- Use appropriate packaging (normally available from the laboratory) and label samples clearly, providing as much information about the field and crop as possible

On soils where acidity is known to occur, more frequent testing may be needed than the four-year cycle used for phosphate, potash and magnesium. Since acidity can occur in patches, spot testing with a soil indicator test across the field is often useful. Soil indicator tests can be useful on soils which contain fragments of free lime, since these can give a misleadingly high pH when analysed following grinding in the laboratory.

Classification of soil analysis results into Indices

The laboratory soil analysis results for P, K and Mg (in mg/kg dry soil) can be converted into soil Indices using Table 4.10.

Table 4.10 Classification of soil P, K and Mg analysis results into Indices

Index	Phosphorus (P)	Potassium (K)	Magnesium (Mg)
	Olsen P	Ammonium nitrate extract	
	mg/litre		
0	0–9	0–60	0–25
1	10–15	61–120	26–50
2	16–25	121–180 (2-) 181–240 (2+)	51–100
3	26–45	241–400	101–175
4	46–70	401–600	176–250
5	71–100	601–900	251–350
6	101–140	901–1,500	351–600
7	141–200	1,501–2,400	601–1,000
8	201–280	2,401–3,600	1,001–1,500
9	Over 280	Over 3,600	Over 1,500

Phosphate and potash in crop material

Table 4.11 Typical values of phosphate and potash in crop materials

		Phosphate (P_2O_5)	Potash(K_2O)
		kg/t of fresh material	
Cereals	Grain only (all cereals)	7.8	5.6
	Grain and straw		
	Winter wheat/barley [a]	8.4	10.4
	Spring wheat/barley [a]	8.6	11.8
	Winter/spring oats [a]	8.8	16.7
Oilseed rape	Seed only	14.0	11.0
	Seed and straw [a]	15.1	17.5
Peas	Dried	8.8	10.0
	Vining	1.7	3.2
Field beans		11.0	12.0
Straw[b]	Winter wheat, winter barley	1.2	9.5
	Spring wheat, spring barley	1.5	12.5
	Oilseed rape	2.2	13.0
	Beans	2.5	16.0
	Peas	3.9	16.0
Sugar beet	Roots only	0.8	1.7
	Roots and tops	1.9	7.5

a. Values are per tonne of grain or seed removed but include nutrients in straw when this also is removed without weighing.

b. These values to be used only when straw weight is known. Potash content of straw can vary substantially – higher than average rainfall between crop maturity and baling straw will reduce straw potash content. There is less information on phosphate and potash contents in the non-cereals so the values above should be treated as guides only.

Example 4.6

Winter wheat yields 10t/ha of grain. The straw is baled and removed from the field.

Phosphate offtake	= 10 x 8.4	= 84 kg P_2O_5/ha
Potash offtake	= 10 x 10.4	= 104 kg K_2O /ha

Example 4.7

Spring barley straw is baled and 5 t/ha removed from the field.

Phosphate offtake	= 5 x 1.5	= 7.5 kg P_2O_5/ha
Potash offtake	= 5 x 12.5	= 62 kg K_2O /ha

Crop phosphate and potash requirements at different Indices

Soil P and K status is best monitored through soil analysis which should be used alongside crop requirements to generate P and K recommendations. Recommendations in Table 4.12, are based around P and K offtake in the harvested crop. If the crop yield is above average, it will remove more P and K which must be replaced.

If the soil is at target Index (2 for P and 2- for K), only maintenance applications should be made to replace offtake (Table 4.11). If the soil is above the target Index, phosphate or potash application can be reduced or omitted to allow crop offtake to lower the Index over the years. However, yield responses are likely where the soil Index is lower than target. In such cases, soil P and K Indices can be built up through application of more phosphate or potash than crop offtake, further information on building up or running down soil P and K Indices can be found in **Section 1: Principles of nutrient management and fertiliser use**.

If the soil analysis shows that a particular field is on the border line between two Indices, P and K rates can be fine-tuned by interpolation, for example by averaging recommendations for Indices 0 and 1.

Sulphur and sodium recommendations

Sulphur and sodium recommendations are given for each crop, where appropriate, because they are not required by all crops or in all parts of England and Wales. Farmers are advised to monitor the sulphur requirements of their crops because the risk of sulphur deficiency is increasing as atmospheric deposition of sulphur declines. Organic manures can supply useful amounts of sulphur **(Section 2: Organic materials)**.

All sulphur recommendations are given as SO_3 and sodium recommendations as Na_2O. Conversion tables (metric–imperial, oxide–element) are given on page 46. If applying liquid fertilisers, manufacturers can supply tables which convert kg/ha of nutrient to litres/ha of product.

Leaf analysis

Suspected nutrient deficiencies based on the appearance of symptoms can be confirmed by leaf nutrient analysis. In such cases, the leaf nutrient concentrations will usually be well below the normal range and there should, therefore, be little doubt about the diagnosis.

Interpretation of laboratory results is possible by comparison with normal levels expected for the crop. Values presented in this guide are based on the best information available.

Guidance on how to collect a leaf tissue sample

It is essential to collect leaf samples that accurately reflect the nutritional status of the crop submitted for analysis. Therefore, to adequately represent any field or smaller area of crop, the following sampling procedure should be followed:

- If possible, collect samples early in the season at stem extension rather than after symptoms become visible
- It is recommended to take two tissue samples approximately two weeks apart to help distinguish between permanent and transient sulphur deficiency
- Samples should not be taken from crops that have recently been sprayed with nutrients or fungicides
- Avoid collecting and sending samples immediately before the weekend or a public holiday
- If areas of fields differ significantly, sample each separately
- Walk a ‘W’ pattern across the sampling area, stopping at least 25 times
- At each point, collect the youngest fully expanded leaf from 2–3 plants
- Ensure there is no soil contamination
- Do not sample diseased or dead plants, those damaged by insects and mechanical equipment or stressed by extremes of cold, heat or moisture
- Dry any wet leaves and immediately send to a laboratory between sheets of paper towel
- Use appropriate packaging (normally available from the laboratory) and label samples clearly, providing as much information about the field and crop as possible
- Do not post fresh material in an airtight container
- Send by overnight courier or deliver directly to the analytical laboratory

Selecting the most appropriate fertiliser

For a single nutrient, the recommended amount can be applied using a straight fertiliser. Where more than one nutrient is required, a compound or blended fertiliser can be used. In this case, the compound or blend selected will depend on the ratio of the nutrients in the fertiliser and the amount applied should give as near the recommended amount of each nutrient as possible.

Often it will not be possible to exactly match the recommendations with available fertilisers. In most cases, the first priority is to get the amount of nitrogen correct, because crops respond most to nitrogen.

Slight variation in the rates of phosphate or potash will have less effect on yield, especially on Index 2 soils, and any discrepancy can be corrected in fertiliser applications to future crops. The approximate nutrient content of commonly used fertilisers is described on page 47.

Example 4.8

Winter wheat grown on a P Index 2, K Index 1 soil and expected to yield 8 t/ha grain requires 220 kg N/ha, 65 kg P_2O_5/ha and 115 kg K_2O/ha.

A 20:10:10 fertiliser is available and 100 kg contains 20 kg N, 10 kg P_2O_5 and 10 kg K_2O. Applied at 1,100 kg/ha, this fertiliser will supply 220 kg N/ha, 110 kg P_2O_5/ha and 110 kg K_2O/ha.

The surplus 45 kg P_2O_5/ha can be allowed for later in the rotation. The deficit of 5 kg K_2O/ha can be ignored.

Metric to imperial conversion tables are given on page 46. If applying liquid fertilisers, manufacturers can supply tables which convert kg/ha of nutrient to litres/ha of product.

Cereals

All Cereals – phosphate, potash, magnesium and sulphur

Phosphate and potash

The amounts of phosphate and potash needed to replace offtake and maintain the soil at the target Index (P Index 2 and K Index 2-) are shown in Table 4.12. The upper half of the table shows the maintenance applications for each crop when straw is incorporated. The lower half of the table shows the maintenance applications when straw is removed (and with straw yield assumed to be 50% of grain yield).

The amounts of phosphate and potash are appropriate to the grain yields shown for each crop in the table. The phosphate and potash recommendations can be adjusted if yields are likely to be larger or smaller than those shown.

To adjust the amounts, multiply the difference in expected grain yield by the phosphate and potash content per tonne of grain yield using the appropriate value for where straw is either incorporated or removed, as given in Table 4.11. Then add this value to (for larger yields) or subtract from (for smaller yields) the amounts in Table 4.12.

For example, at P Index 1, the phosphate recommendation for wheat with an expected yield of 10 t/ha where straw is incorporated is 90 + (2 x 7.8) = 106 kg/ha.

Where the weight of straw to be removed can be estimated separately, use the amounts of phosphate and potash per tonne of straw shown in Table 4.11 to calculate the amounts removed in the straw. Add these to the appropriate amounts for grain yield in order to calculate the overall amounts removed.

Crops grown on soil at Index 0 and 1 would be expected to respond to the higher amounts of phosphate and potash shown in the table. Over a number of years, these extra amounts of fertiliser will help to raise most soils, except light sands, to Index 2. At Index 3 and above, no phosphate and potash need to be applied but analyse soil regularly.

Table 4.12 Phosphate and potash for all cereals

	P or K Index			
	0	1	2	3 and higher
	kg/ha			
Straw ploughed in/incorporated				
Winter wheat, winter barley (8 t/ha)				
Phosphate (P_2O_5)	120	90	60	0
Potash (K_2O)	105	75	45 (2-) 20 (2+)	0
Spring wheat, spring barley, rye, triticale (6 t/ha)				
Phosphate (P_2O_5)	105	75	45	0
Potash (K_2O)	95	65	35 (2-) 0 (2+)	0
Winter and spring oats (6 t/ha)				
Phosphate (P_2O_5)	105	75	45	0
Potash (K_2O)	95	65	35 (2-) 0 (2+)	0
Straw removed				
Winter wheat, winter barley (8 t/ha)				
Phosphate (P_2O_5)	125	95	65	0
Potash (K_2O)	145	115	85 (2-) 55 (2+)	0
Spring wheat, spring barley, rye, triticale (6 t/ha)				
Phosphate (P_2O_5)	110	80	50	0
Potash (K_2O)	130	100	70 (2-) 40 (2+)	0
Winter and spring oats (6 t/ha)				
Phosphate (P_2O_5)	115	85	55	0
Potash (K_2O)	165	135	105 (2-) 75 (2+)	0

At Index 2, phosphate and potash can be applied when convenient during the year but at Index 0 and 1, they should be applied and worked into the seedbed.

To avoid damage to germinating seedlings, do not combine drill more than 150 kg/ha of nitrogen plus potash on sandy soils.

Magnesium

At Mg Index 0, magnesium fertiliser should be applied every 3–4 years at 50–100 kg MgO/ha.

Sulphur

Not all cereal crops will require sulphur and the responsiveness of a crop to the application of sulphur is dependent on soil texture and winter rainfall.

Figure 4.4 The youngest leaves of sulphur-deficient cereals are often yellow

Use Table 4.13 to assess the risk of deficiency. If deficiency is suspected, tissue and grain analysis can be used to make a diagnosis and, if necessary, the deficiency should be treated.

There are a number of laboratory analyses that can be used to detect sulphur deficiency in leaf tissue but AHDB trials have shown that the malate:sulphate test is the most reliable.

Where deficiency has been recognised or is expected in winter or spring-sown cereals, apply 25–50 kg/ha SO_3 as a sulphate-containing fertiliser in early March to early May for wheat and for barley between mid-March and mid-April.

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Using sulphur to maximise quality

Further clarity on application rates has been provided by AHDB trials that have shown that acrylamide formation can be minimised by applying 50 kg SO_3/ha to sulphur-deficient wheat grown for flour milling or cereal foods.

Acrylamide is a processing contaminant that has been found in cooked foods. It can form during high-temperature cooking and processing of wheat. Acrylamide formation in wheat-based products is linked to the levels of the amino acid, asparagine. AHDB trials have shown that asparagine levels, and hence acrylamide formation, can increase if wheat is sulphur-deficient. Processors have modified their methods to minimise the formation of acrylamide but growers can also minimise formation by applying sulphur where deficiency is likely.

In addition to reducing acrylamide formation, AHDB trials have shown that loaf volume and malting quality of wheat can be improved by correctly fertilising with sulphur.

Table 4.13 Estimating the risk of sulphur deficiency for cereal crops

Soil texture	Winter rainfall (Nov-Feb)		
	Low (<175 mm)	Medium (175-375 mm)	High (>375 mm)
Sandy	High		
Loamy and coarse silty	Low	High	
Clay, fine silty or peaty	Low		High

All cereals – micronutrients

AHDB research has shown that the most common micronutrient deficiencies limiting productivity of cereals crops are copper (Cu), manganese (Mn) and zinc (Zn, Table 4.14). More information is provided in **Section 1: Principles of nutrient management and fertiliser use**.

Visual symptoms are usually the first sign of a deficiency (Figure 4.5), however, they can be short-lived, easily confused and, by the time symptoms appear, it can be too late to correct the deficiency.

Points to consider

- **The amounts of phosphate and potash are appropriate to the grain yields shown**
- **Make allowance for nutrients applied in organic manures (Section 2: Organic materials)**
- **Ensure the phosphate and potash offtake is balanced by application on Index 2 soils**
- **Check that the soil is maintained at Index 2 by soil sampling every 3–5 years**
- **Drought, frost and herbicide damage can be mistaken for visual symptoms of nutrient deficiencies. It can be difficult to make a definitive diagnosis but if a deficiency is suspected, it is important to consider:**
  - Which nutrient deficiencies can commonly affect the crop species being grown
  - The soil type, condition and pH
  - The results of soil and tissue analysis

Table 4.14 Micronutrient deficiency risk factors and interpretation of soil and leaf analysis

Micronutrient	Soil risk factor	Soil analysis	Leaf analysis
Manganese (Mn)	Under-consolidated seedbeds; low soil temperature; low rainfall; over-liming; any soil with pH above 7.5; sandy soils with pH above 6.5; organic, peaty or marshland soil with pH above 6.0	Not reliable	Deficiency is more likely below 20 mg Mn/kg
Copper (Cu)	Shallow soils over chalk with high organic matter; sandy and peat soils	EDTA extract: deficiency is more likely below 1.0 mg Cu/l, unless soil organic matter is above 6%, when deficiency is more likely below 2.5 mg Cu/l	Not reliable
Zinc (Zn)	Sandy soils with high pH and phosphate Index (Index 5 and higher)	EDTA extract: deficiency is more likely below 1.5 mg Zn/l	Deficiency is more likely below 15 mg Zn/kg

Treating micronutrient deficiencies
Options largely depend on when the deficiency is diagnosed. If soil analysis confirms a deficiency early in the season, liming, seed treatments, seedbed fertilisers or autumn applications are possible. If tissue analysis confirms a deficiency later in the season, treatments will be limited to foliar-applied fertilisers.

Copper – If possible, treat deficiencies using soil-applied fertilisers in the autumn. Depending on soil application rate and soil texture, copper treatments may be effective in raising soil copper levels for up to 10 years; regular soil analysis, every 3–5 years, is recommended. Deficiencies can also be treated using foliar-applied fertilisers at late tillering or early stem extension.

Manganese – Deficiencies can be treated using seed treatments or foliar-applied fertilisers.

Zinc – Deficiencies can be treated using seed treatments, or soil- or foliar-applied fertilisers. Foliar nutrients can be applied most cost-efficiently by tank-mixing with other crop inputs such as fungicides but check product labels carefully for product compatibility.

Manganese

Symptoms occur in new leaves which become pale and limp. This is followed by light grey flecking and striping, which occurs at the base of the youngest fully opened leaf. In time, leaves become paler and eventually become necrotic and collapse.

Copper

Pale, twisted leaves and stunted plants. Ears are sometimes trapped in the leaf sheath and those that emerge have white tips and blind grain sites. Blackening of the ears and straw occurs in copper-deficient wheat on organic chalk soils. This symptom is not seen in wheat grown on sandy or peat soils. Awns of barley become white and brittle and purpling of the stem and nodes is also possible.

Zinc

Pale stripes appear parallel to the mid-point of younger leaves. Affected tissue dies and turns pale brown.

Figure 4.5 Micronutrient deficiency symptoms

Wheat and triticale, sown up to the end of January – nitrogen

Table 4.15 Nitrogen for wheat and triticale (sown up to the end of January)

	SNS Index						
	0	1	2	3	4	5	6
	kg N/ha						
Light sand soils	180	150	120	90	60	0–60	0–40
Shallow soils	280[a]	240	210	180	140	80	0–40
Medium soils	250[a]	220	190	160	120	60	0–40
Deep clay soils	250[a]	220	190	160	120	60	0–40
Deep silty soils	240[a]	210	170	130	100	40	0–40
Organic soils				120	80	40–80	0–40
Peat						0–40	

a. The N recommendation exceeds the N max limit that applies within NVZs. Note the N max limit is calculated for the whole of the area of a crop type grown on farm and not for individual fields. For more details see **www.gov.uk/nitrate-vulnerable-zones**

Recent research has shown evidence of a correlation between yield and crop nitrogen demand, supporting the adjustment of nitrogen rates for expected yield when site history indicates consistently below or above average yields. If you farm in an NVZ you will be expected to have written evidence from at least two previous crops. If you don't farm in an NVZ then a sensible approach would be to take the last five years' field-specific yields, discard the highest and lowest, and take an average of the remaining three years.

Where previous experience of growing wheat indicates that yields above 8 t/ha can be realistically expected, increasing the recommended rate by 10 kg N/ha for each 0.5 t/ha additional yield, up to a maximum of 13 t/ha, could be justified. Similarly, for low yielding crops, the recommended rate could be reduced by 10 kg N/ha for each 0.5 t/ha reduction in expected yield.

However, it is important to consider factors that limit yield, eg varietal choice, soil structural condition, seedbed conditions, supply of other nutrients, weed and disease pressure and growing season/climate. If any factor is limiting, a full response to nitrogen will not be obtained. For further guidance, consult a FACTS Qualified Adviser.

Timing of application

There is no requirement for seedbed nitrogen. Depending on the total nitrogen requirement and crop development, it will often be appropriate to apply nitrogen at the following timings.

- **Less than 120 kg N/ha:**
  Apply all the recommended amount as a single dressing by early stem extension but not before early April
- **120 kg N/ha or more:**
  Apply about 40 kg N/ha between mid-February and mid-March except where:
  - There is a low risk of take-all, and
  - Shoot numbers are very high. Well-tillered crops do not need nitrogen at this stage. Crops with too many tillers will be prone to lodging and higher disease levels. The balance of the application should be applied in one or two dressings during early stem extension. Where more than 120 kg N/ha remains to be applied, half should be applied at the start of stem extension (not before April), and half at least two weeks later (not after early May)

Triticale

The N requirements of triticale are the same as those of wheat in most situations. Hence N recommendations should be calculated as for feed wheat, including the adjustment for yield potential, with the following exceptions:

- **If the variety chosen is known to have a high lodging risk, the total N rate should be reduced by 40 kg N/ha**
- **If the grain price is expected to be significantly below that which would be received for wheat, N rates should be reduced accordingly**

Wheat – use of grain nitrogen concentration

Farm nitrogen strategies for wheat can be assessed periodically using information on grain protein concentration. Grain protein at the economic optimum rate of nitrogen is about 11% (1.9% N) for feed wheat and 12% (2.1% N) for bread-making wheat. Where concentrations in yields from a number of adjacent fields are consistently above or below these values during several years, nitrogen fertiliser application rates should be adjusted down or up by 25 kg N/ha per 0.5% difference in grain protein (30 kg N/ha per 0.1% difference in grain %N).

To convert grain %protein to grain %N, divide %protein by 5.7. Both N and protein are reported on a 100% dry matter basis.

The effect of economic changes on nitrogen rates

The recommendations in the tables for wheat and barley are based on a breakeven ratio of 5.0 (cost of fertiliser nitrogen as £/kg N divided by value of grain as £/kg). If the price of nitrogen or the price of grain changes, use Table 4.21 to decide on an amount to add to or subtract from the fertiliser nitrogen application.

Wheat grown for bread-making

In some circumstances, an application of nitrogen may be economically worthwhile to boost the grain protein concentration. Typically, application of an extra 40 kg N/ha could increase grain protein by up to 1%*. Application of soil-applied additional nitrogen during stem extension may give a small yield increase as well as an increase in grain protein. Application as a foliar urea spray during the milky ripe stage will result in a larger increase in grain protein content but cannot be expected to increase yield.

Point to consider

- Tables contain the total nutrient required, remember to deduct nutrients applied as organic materials **(Section 2: Organic materials)**

*Updated January 2019

Barley, winter sown – nitrogen

Table 4.16 Nitrogen for winter-sown barley

	SNS Index						
	0	1	2	3	4	5	6
	kg N/ha						
Feed barley							
Light sand soils	170	140	110	80	60	0–40	0
Shallow soils	220[a]	190	150	120	60	20–60	0–20
Medium and deep clay soils	190[a]	170	140	110	60	20–60	0–20
Deep fertile silty soils	170	150	120	80	40	0–30	0
Organic soils				110	60	0–40	0
Peaty soils						0–40	
Malting barley (1.8% grain N)							
Light sand soils	130	90	60	0–40	0	0	0
Other mineral soils	150	120	90	50	0–40	0	0
Organic soils				50	0–40	0	0
Peaty soils						0	

a. The nitrogen recommendation exceeds the N max limit that applies within NVZs. Note the N max limit is calculated for the whole of the area of a crop type grown on farm and not for individual fields. For more details see **www.gov.uk/nitrate-vulnerable-zones**

Recent research has shown evidence of a correlation between yield and crop nitrogen demand, supporting the adjustment of nitrogen rates for expected yield when site history indicates consistently below or above average yields. If you farm in an NVZ you will be expected to have written evidence from at least two previous crops. If you don't farm in an NVZ then a sensible approach would be to take the last five years' field specific yields, discard the highest and lowest, and take an average of the remaining three years.

Where previous experience of growing winter feed barley indicates that yields above 6.5 t/ha can be realistically expected, increasing the recommended rate by 10 kg N/ha for each 0.5 t/ha additional yield, up to a maximum of 11 t/ha, could be justified. Similarly for low yielding crops, the recommended rate could be reduced by 10 kg N/ha for each 0.5 t/ha reduction in expected yield.

However, it is important to consider factors that limit yield, eg varietal choice, soil structural condition, seedbed conditions, supply of other nutrients, weed and disease pressure and growing season/climate. If any factor is limiting, a full response to nitrogen will not be obtained. For further guidance, consult a FACTS Qualified Adviser.

Timing of application

There is no requirement for seedbed nitrogen.

Depending on the total nitrogen requirement and crop development, it will often be appropriate to apply nitrogen at the following timings.

- **Less than 100 kg N/ha:**
  Apply as a single dressing by early stem extension (GS30–31)
- **Between 100 and 200 kg N/ha:**
  Split the dressing with half during late tillering in mid-February/early March and half at GS30–31
- **200 kg N/ha or more:**
  Apply three splits with 40% during late tillering in mid-February/early March, 40% at GS30–31 and 20% at GS32

These recommendations assume appropriate measures are taken to control lodging (eg choice of variety, use of plant growth regulator). Reduce the recommendation by 25 kg N/ha if the lodging risk is high.

Further information
Wheat growth guide
Barley growth guide
ahdb.org.uk/knowledge-library

Malting barley – nitrogen

Careful judgement of the nitrogen rate is important to ensure that grain N content is neither too high nor too low for the requirement of the target market. Previous experience and consultation will be important in deciding the nitrogen rate to use. Where quality premiums are expected to be low, applying a slightly higher nitrogen rate will maximise the yield potential of the crop.

Where the target grain N content is below 1.8%, the nitrogen rate from the malting section of Table 4.16 should be adjusted as necessary for predicted yield. Then, it should be reduced by approximately 15 kg N/ha to achieve 1.7% grain N, 35 kg N/ha to achieve 1.6% grain N, or 60 kg N/ha to achieve 1.5% grain N. This nitrogen should all be applied by GS30–31.

The effect of economic changes on nitrogen rates

The recommendations in Table 4.16 are based on a breakeven ratio of 5.0. If the price of nitrogen or the price of grain changes, use the Table 4.21 to decide on an amount to add to or subtract from the nitrogen application.

Point to consider

- Tables contain the total nutrient required, remember to deduct nutrients applied as organic materials **(Section 2: Organic materials)**

Oats and rye, winter sown – nitrogen

Table 4.17 Nitrogen for winter sown oats and rye

	SNS Index						
	0	1	2	3	4	5	6
	kg N/ha						
Oats							
Light sand soils	150	110	80	20–60	0–40	0	0
All other mineral soils	190	160	130	100	70	0–40	0
Organic soils				100	70	0–40	0
Peaty soils						0–40	
Rye							
Light sand soils	110	70	20–50	0–20	0	0	0
All other mineral soils	150	120	90	60	30	0-20	0
Organic soils				60	30	0-20	0
Peaty soils						0–20	

Timing of application
Depending on the total nitrogen requirement and crop development, it will often be appropriate to apply nitrogen at the following timings.

- Less than 100 kg N/ha: Apply as a single dressing by early stem extension, but not before late March
- 100 kg N/ha or more: Split the dressing with 40 kg N/ha in mid-February / early march
  - If the remaining N is less than 100 kg N/ha then apply the rest by early stem extension, but not before late March
  - If the remaining N is 100 kg N/ha or more then apply in two dressings, half at early stem extension (not before late March), and half at least two weeks later

These recommendations assume appropriate measures are taken to control lodging (eg choice of variety or use of plant growth regulator). Reduce the recommended rate by 40 kg N/ha for oats or 25 kg N/ha for rye if lodging risk is high.

The effect of economic changes on nitrogen rates
The recommendations in Table 4.17 are based on a breakeven ratio of 5.0. If the price of nitrogen or the price of grain changes, use Table 4.21 to decide on an amount to add to or subtract from the nitrogen application.

Point to consider

- Tables contain the total nutrient required, remember to deduct nutrients applied as organic materials **(Section 2: Organic materials)**

Wheat, spring sown – nitrogen

Table 4.18 Nitrogen for spring sown wheat

	SNS Index						
	0	1	2	3	4	5	6
	kg N/ha						
Light sand soils	160	130	100	70	40	0–40	0
All other mineral soils	210[a]	180	150	120	70	40	0–40
Organic soils				120	70	40	0–40
Peaty soils						0–40	

[a] The N recommendation exceeds the N max limit that applies within NVZs. Note the N max limit is calculated for the whole of the area of a crop type grown on farm and not for individual fields. For more details, see **www.gov.uk/nitrate-vulnerable-zones**

Timing of application
For crops drilled before March, apply nitrogen at early stem extension but not before early April or after early May. For rates higher than 70 kg N/ha, apply the first 40 kg N/ha of the total in the seedbed, except on light sand soils. On these soils apply 40 kg N/ha at the 3-leaf stage but not before March.

For late-drilled crops, all the nitrogen can be applied in the seedbed, except on light sand soils, where amounts more than 70 kg N/ha should be split, with 40 kg N/ha in the seedbed and the remainder by the 3-leaf stage.

Wheat grown for bread-making
In some circumstances, an application of nitrogen in addition to that given in Table 4.18 may be economically worthwhile to boost the grain protein concentration. Typically, application of an extra 40 kg N/ha could increase grain protein by up to 1%*. Application of this additional nitrogen during stem extension may give a small yield increase, as well as an increase in grain protein. Application as a foliar urea spray during, but not later than, milky ripe stage will result in a larger increase in grain protein content but cannot be expected to increase yield.

The effect of economic changes on nitrogen rates
The recommendations in the table are based on a breakeven ratio of 5.0. If the price of nitrogen or the price of grain changes, use Table 4.21 to decide on an amount to add to or subtract from the nitrogen application.

Barley, spring sown – nitrogen

Table 4.19 Nitrogen for spring sown barley

	SNS Index						
	0	1	2	3	4	5	6
	kg N/ha						
Feed							
Light sand soils	140	110	70	50	0–40	0	0
Other mineral soils	160[a]	140	110	70	30	0–30	0
Organic soils				70	30	0–30	0
Peaty soils						0–30	
Malting barley (1.8% grain N)							
Light sand soils	110	80	40	0–40	0	0	0
Other mineral soils	130	110	70	40	0–30	0	0
Organic soils				40	0–30	0	0
Peaty soils						0	

a. The N recommendation exceeds the N max limit that applies within NVZs. Note the N max limit is calculated for the whole of the area of a crop type grown on farm and not for individual fields. For more details, see **www.gov.uk/nitrate-vulnerable-zones**

*Updated January 2019

Recent research has shown evidence of a correlation between yield and crop nitrogen demand, supporting the adjustment of nitrogen rates for expected yield when site history indicates consistently below or above average yields. If you farm in an NVZ you will be expected to have written evidence from at least two previous crops. If you don't farm in an NVZ then a sensible approach would be to take the last five years' field specific yields, discard the highest and lowest, and take an average of the remaining three years.

Where previous experience of growing spring feed barley indicates that yields above 5.5 t/ha can be realistically expected, increasing the recommended rate by 10 kg N/ha for each 0.5 t/ha additional yield, up to a maximum of 9 t/ha, could be justified. Similarly, for low yielding crops, the recommended rate could be reduced by 10 kg N/ha for each 0.5 t/ha reduction in expected yield.

However, it is important to consider factors that limit yield, eg varietal choice, soil structural condition, seedbed conditions, supply of other nutrients, weed and disease pressure and growing season/climate. If any factor is limiting, a full response to nitrogen will not be obtained. For further guidance consult a FACTS Qualified Adviser.

Timing of application

For crops drilled before March, apply nitrogen at early stem extension but not before early April or after early May. For amounts greater than 70 kg N/ha, apply the first 40 kg N/ha of the total in the seedbed except on light sand soils. On these soils apply 40 kg N/ha at the 3-leaf stage but not before March.

For late-drilled crops, all the nitrogen can be applied in the seedbed except on light sand soils where amounts greater than 70 kg N/ha should be split with 40 kg N/ha in the seedbed and the remainder by the 3-leaf stage.

Malting barley – nitrogen

Careful judgement of the nitrogen rate is important to ensure that the grain N content is neither too high nor too low for the requirement of the target market. Market requirements vary widely from less than 1.65% to more than 1.85% grain N. Previous experience and consultation will be important in deciding the nitrogen rate to use. Where quality premiums are expected to be low, use of a slightly higher nitrogen rate will maximise the yield potential of the crop.

Apply all the nitrogen by early stem extension but not after the end of March. Where target grain N is below 1.8%, the nitrogen rate from the malting section of Table 4.19 should be adjusted as necessary for predicted yield, then reduced by approximately 30 kg N/ha to achieve 1.7% grain N, or 60 kg N/ha to achieve 1.6% grain N. Grain N may be diluted in high-yielding crops. This nitrogen should all be applied by mid-March.

Further information

Maltsters' Association of Great Britain (MAGB) barley requirements
www.ukmalt.com/barley-requirements

The effect of economic changes on nitrogen rates

The recommendations in Table 4.19 are based on a breakeven ratio of 5.0. If the price of nitrogen or the price of grain changes, use Table 4.21 to decide on an amount to add to or subtract from the nitrogen application.

Oats, rye and triticale, spring sown – nitrogen

Table 4.20 Nitrogen for spring-sown oats, rye and triticale

	SNS Index						
	0	1	2	3	4	5	6
	kg N/ha						
Light sand soils	90	60	30	0–30	0	0	0
All other mineral soils	140	110	70	40	0–30	0	0
Organic soils				40	0–30	0	0
Peaty soils						0	

Point to consider

- Tables contain the total nutrient required, remember to deduct nutrients applied as organic materials **(Section 2: Organic materials)**

Further information
AHDB UK Fertiliser Price Series
ahdb.org.uk/fertiliser-information

The effect of economic changes on nitrogen rates

The recommendations in Table 4.20 are based on a breakeven ratio of 5.0. If the price of nitrogen or the price of grain changes, use Table 4.21 to decide on an amount to add to or subtract from the nitrogen application.

Table 4.21 Effect of economic changes on nitrogen rate – all cereals

	Fertiliser N content (%)	Fertiliser cost (£/tonne product)					
Ammonium nitrate	34.5	138	207	276	345	414	483
Urea	46.0	184	276	368	460	552	644
Urea-ammonium nitrate liquid	28.0	112	168	224	280	336	392
Cost of fertiliser nitrogen	**£/kg N**	**0.40**	**0.60**	**0.80**	**1.00**	**1.20**	**1.40**
	Grain sale price (£/t)	**Change to recommended N for all cereals (kg N/ha)**					
	50	-30	-60	-80	-100	-110	-130
	75	0	-30	-50	-70	-80	-90
	100	10	-10	-30	-40	-60	-70
	125	20	0	-10	-30	-40	-50
	150	30	10	0	-10	-20	-30
	175	42	20	0	-10	-20	-30
	200	40	30	10	0	-10	-20
	225	40	30	20	10	0	-10
	250	50	30	20	10	0	-10
	275	50	40	30	20	10	0

Oilseeds

Oilseed rape and linseed – phosphate, potash, magnesium and sulphur

Phosphate and potash

The amounts of phosphate and potash needed to replace offtake for the seed yields shown and maintain the soil at the target Index (P Index 2 and K Index 2-) are shown in Table 4.22. The amounts of phosphate and potash are appropriate for the seed yields shown.

The phosphate and potash recommendations can be adjusted if the yields are likely to be larger or smaller than those shown in Table 4.22.

Example 4.9

At P Index 1, the phosphate recommendation for winter oilseed rape with an expected yield of 4.5 t/ha is 80 + (1 x 14) = 94 kg P_2O_5/ha.

To adjust the amounts, multiply the difference in expected seed yield by the phosphate and potash content per tonne of seed yield using the appropriate value given in Table 4.11, and then add to (for larger yields) or subtract from (for smaller yields) the amounts in Table 4.22.

Crops grown on soil at Index 0 and 1 would be expected to respond to the higher amounts of phosphate and potash shown in Table 4.22. Also, over a number of years, these extra amounts of fertiliser will help raise most soils, except light sands, to Index 2. At Index 3 and above, no phosphate and potash need be applied for a few years but check soil analyses regularly.

At Index 2, phosphate and potash can be applied when convenient during the year but at Index 0 and 1 soils they should be applied and worked into the seedbed.

Table 4.22 Phosphate and potash for oilseed rape and linseed

	P or K Index			
	0	1	2	3 and higher
	kg/ha			
Winter oilseed rape (3.5 t/ha)				
Phosphate (P_2O_5)	110	80	50	0
Potash (K_2O)	100	70	40 (2-) 20 (2+)	0
Spring oilseed rape (2 t/ha) or linseed (1.5 t/ha)				
Phosphate (P_2O_5)	90	60	30	0
Potash (K_2O)	80	50	20 (2-) 0 (2+)	0

Alternatively, calculate the required application rates using expected offtake values from Table 4.11 and soil Index adjustments from **Section 1: Principles of nutrient management and fertiliser use**.

Point to consider

- **Ensure the phosphate and potash offtake is balanced by application on Index 2 soils and check that the soil is maintained at Index 2 by soil sampling every 3–5 years**

Magnesium

At Mg Index 0 and 1, magnesium at a rate of 50 to 100 kg MgO/ha should be applied every three or four years.

Sulphur

The yield of most winter- and spring-sown oilseed rape grown on mineral soils will increase in response to an application of sulphur which will also help to minimise green seeds. Apply 50–80 kg SO_3/ha* as a sulphate-containing fertiliser to all winter- and spring-sown oilseed rape crops grown on mineral soils, in late February to early March. The green plant pigment, chlorophyll, can remain in the seed at harvest and create problems for rapeseed crushers. A large proportion of immature seed in a sample, or conditions restricting the natural breakdown of chlorophyll during ripening, can lead to high chlorophyll concentrations.

Extracted with the oil, chlorophyll interferes with subsequent processing. Crushers may be unwilling to accept seed lots with more than 4% immature (green) seed.

While a red seed coat can indicate immaturity, seed coat colour is not a reliable indicator of seed quality. The best test is to crush the seed and examine the cotyledons inside, which, in a good sample, should be yellow.

AHDB trials have shown that application of sulphur fertiliser at deficient sites reduced seed chlorophyll content. It is also worth noting that applying high rates of nitrogen fertiliser (above the recommendation) increased chlorophyll content.

Later, severely sulphur-deficient oilseed rape crops will have pale flowers; however, by this time it will be too late to correct the deficiency.

Figure 4.5 The youngest leaves of sulphur-deficient oilseed rape are often yellow

Sunflower – phosphate and potash

Phosphate is required at relatively low levels by the crop. A maintenance application of 40 to 60 kg/ha is usual. Sunflowers require a relatively high level of potassium but most of this is returned to the soil after harvest. A maintenance application of 40 kg to 60 kg/ha is usual, often as part of a compound fertiliser with phosphate.

Oilseed rape – micronutrients

AHDB research has shown that the most common micronutrient deficiencies limiting productivity of oilseed rape crops are manganese (Mn), boron (B) and Molybdenum (Mo, Table 4.23). More information is provided in Section 1: Principles of nutrient management and fertiliser use.

Visual symptoms are usually the first sign of a deficiency, however, they can be short-lived, easily confused and, by the time symptoms appear, it can be too late to correct the deficiency.

Table 4.23 Micronutrient deficiency risk factors

Micronutrient	Soil risk factor	Soil analysis	Leaf analysis
Manganese (Mn)	Under consolidated seedbeds; low soil temperature; low rainfall; over-liming; any soil with pH above 7.5; sandy soils with pH above 6.5; organic, peaty or marshland soil with pH above 6.0	Not reliable	Deficiency is more likely below 20 mg Mn/kg
Boron (B)	Sandy soils; high organic matter; pH above 7; over-liming	Hot water extract: deficiency is more likely below 0.8 mg B/l	Deficiency is more likely below 20 mg B/kg
Molybdenum (Mo)	Soil with pH below 6.5	Ammonium oxalate extract: deficiency is more likely below 0.1 mg Mo/l	Insufficient information to be able to recommend this type of analysis

*Updated January 2019

Manganese	Boron	Molybdenum
Yellowing and mottling between veins, which remain greener. Symptoms appear first on middle leaves and spread to older leaves.	Young leaves are smaller and puckered. Margins turn down and tissue becomes brittle and is easily torn. Stems crack and flowering is poor.	Reduced leaf area, pale and limp leaves.

Figure 4.6 Micronutrient deficiency symptoms in oilseed rape

Treating micronutrient deficiencies
Options largely depend on when the deficiency is diagnosed. If soil analysis confirms a deficiency early in the season, liming, seed treatments, seedbed or autumn fertiliser applications are possible. If tissue analysis confirms a deficiency later in the season, treatments will be limited to foliar-applied fertilisers.

Boron – Deficiencies can be treated using soil- or foliar-applied fertilisers.

Manganese – Deficiencies can be treated using seed treatments or foliar-applied fertilisers.

Molybdenum – Use a liming material to raise the soil pH of acidic soils to 6.5. When soil pH is more than 7 or when treatment is necessary, a seed treatment, or soil- or foliar-applied fertilisers can be used.

Foliar nutrients can be applied most cost-efficiently by tank-mixing with other crop inputs such as fungicides but check product labels carefully for compatibility.

Points to consider

Drought, frost and herbicide damage can also be mistaken for visual symptoms of nutrient deficiencies. It can be difficult to make a definitive diagnosis but, if a deficiency is suspected, it is important to consider:

- **Which nutrient deficiencies can commonly affect the crop species being grown**
- **The soil type, condition and pH**
- **The results of soil and tissue analysis**

Sunflower – micronutrients

Molybdenum, copper and manganese deficiencies in sunflower can be problems in very acid soils (<pH 5.0). Sunflowers are also sensitive to boron deficiency, which can be a particular problem on calcareous or sandy soils where boron levels are often naturally low.

Boron is taken up chiefly during the vegetative period prior to heading and signs of deficiency usually become apparent during flowering and seed maturation. A characteristic feature is poor seed-set, with many heads having large areas of hollow seeds. Other symptoms are red-brown necrotic patches and abnormal head and neck development. The timing and rates of boron application are shown in Table 4.24.

Table 4.24 Boron deficiency and its treatment in a sunflower crop

Soil factor	Soil boron level (ppm)	Treatment
Non-calcareous (pH < 7.5)	0.5	1.2 kg/ha incorporated at drilling
Calcareous (pH > 7.5)	0.5	300–500 g/ha as a foliar spray at GS 2.5–3.2
Sandy	0.5	

Oilseed rape, autumn sown – nitrogen

Table 4.25 Nitrogen for autumn- and winter-sown oilseed rape

	SNS Index						
	0	1	2	3	4	5	6
	kg N/ha						
Autumn	30	30	30	0	0	0	0
Spring							
All other mineral soils	220	190	160	120	80	40–80	0–40
Organic soils				120	80	40–80	0–40
Peaty soils						40–80	

Timing of application
Autumn nitrogen can be applied to the seedbed or as a top-dressing to encourage autumn growth but research suggests that crops sown after early September are unlikely to respond.

If the green area index (GAI) of the canopy, measured towards the end of winter, is less than 1.5, or less than 2.0 if the SMN in the top 60 cm soil is less than 25 kg N/ha, apply the nitrogen in two equal splits. Apply half at the start of spring growth (end February-early March) and green bud (mid-March to early April). Any additional nitrogen for crops yielding above 3.5 t/ha should be applied between yellow bud and early flowering.

Where the GAI of the canopy measured towards the end of winter is greater than 2.0, or greater than 1.5 with an SMN in the top 60 cm soil of at least 25 kg N/ha, then the first nitrogen should be reduced to between zero and 40 kg N/ha.

Foliar N applied as a solution of urea (20 kg N per 100 litres) at 40 kg N/ha between mid-flowering and two weeks after the end of flowering, will often increase gross output by an average of 0.25 t/ha. This may occur even where the optimum amount of nitrogen has been applied to soil. Temperature at application should be less than 19°C. The economic benefit of this treatment will depend upon the cost of the product and the price of oilseed rape. Note that this foliar-applied nitrogen contributes towards the N max allowance.

Yield variation
The recommendations are for crops yielding 3.5 t/ha. Where previous experience of growing the crop indicates that yields above 3.5 t/ha can be realistically expected, the recommended rate may be increased by up to 30 kg N/ha per 0.5 t/ha of yield, up to an expected yield of 5.0 t/ha. This adjustment should be used with caution because applying too much early nitrogen to crops with large canopies can increase lodging and possibly reduce yield.

Point to consider

- Tables contain the total nutrient required, remember to deduct nutrients applied as organic materials **(Section 2: Organic materials)**

Oilseed rape and linseed, spring sown – nitrogen

Table 4.26 Nitrogen for spring-sown oilseed rape and linseed

	SNS Index						
	0	1	2	3	4	5	6
	kg N/ha						
Spring oilseed rape							
Light sand soils	120	80	50	0–40	0	0	0
Other mineral soils	150	120	80	50	0–40	0	0
Organic soils				50	0–40	0	0
Peaty soils						0–40	
Spring linseed							
Light sand soils	80	50	0–40	0	0	0	0
All other mineral soils	100	80	50	0–40	0	0	0
Organic soils				0–40	0	0	0
Peaty soils						0	

Timing of application

Apply all the nitrogen in the seedbed. On light sand soils where the total rate is more than 80 kg N/ha, the dressing should be split with 50 kg N/ha in the seedbed and the remainder by early May.

Sunflower – nitrogen

Due to the deep-rooting nature of sunflower, it can remove nutrients from depth in the soil profile. As a result, the crop will yield satisfactorily at quite low levels of soil nitrogen and nitrogen fertiliser applications may be unnecessary.

High levels of nitrogen can lead to excessive vegetative development, encouraging disease, delaying maturity and reducing seed oil content. UK experience indicates that applications of more than 25–50 kg/ha are rarely required.

Further information
Sunflowers – a growers guide
cereals.ahdb.org.uk/publications

Point to consider

- Tables contain the total nutrient required, remember to deduct nutrients applied as organic materials **(Section 2: Organic materials)**

The effect of economic changes on nitrogen rates

The recommendations in Table 4.25 and 4.26 are based on a breakeven ratio of 2.5. If the price of nitrogen or the value of rapeseed changes, use Table 4.27 to decide on an amount to add or subtract from the nitrogen application.

Table 4.27 Effect of economic changes on nitrogen rate – oilseed rape

	Fertiliser N content (%)	Fertiliser cost (£/tonne product)					
Ammonium nitrate	34.5	138	207	276	345	414	483
Urea	46.0	184	276	368	460	552	644
Urea-ammonium nitrate liquid	28.0	112	168	224	280	336	392
Cost of fertiliser nitrogen	**£/kg N**	**0.40**	**0.60**	**0.80**	**1.00**	**1.20**	**1.40**
	Grain sale price	**Change to recommended N for oilseed rape (kg N/ha)**					
	200	20	-20	-50	-70	-80	-100
	225	30	-10	-30	-60	-70	-90
	250	40	0	-20	-50	-60	-80
	275	50	10	-10	-40	-50	-70
	300	60	20	-10	-30	-50	-60
	325	70	30	0	-20	-40	-50
	350	70	40	10	-10	-30	-50
	375	80	40	20	-10	-20	-40
	400	90	50	20	0	-20	-30
	425	90	50	30	10	-10	-30
	450	100	60	30	10	-10	-20

*Updated January 2018

Further information

AHDB UK Fertiliser Price Series

ahdb.org.uk/fertiliser-information

Peas (dried and vining) and beans

The amounts of phosphate and potash are appropriate to pea yields of 4 t/ha and bean yields of 3.5 t/ha. Where yields are likely to be greater or smaller, phosphate and potash applications should be adjusted accordingly. Table 4.11 gives typical values of the phosphate and potash content in crop material per tonne of yield.

Table 4.28 Nitrogen, phosphate, potash and magnesium for peas and beans

	SNS, P or K Index						
	0	1	2	3	4	5	6
	kg/ha						
Nitrogen (N)	0	0	0	0	0	0	0
Phosphate (P_2O_5)	100	70	40	0	0	0	0
Potash (K_2O)	100	70	40 (2-) 20 (2+)	0	0	0	0
Magnesium (MgO)	100	50	0	0	0	0	0

Further information
PGRO grower guides
www.pgro.org

Phosphate and potash

Seedbed phosphate and potash is only needed at Index 0 and 1.

Sulphur

Peas may suffer from sulphur deficiency on sensitive soil types. Where deficiency is possible, apply 25 kg SO_3/ha.

Sugar beet

Nitrogen

The recommendations do not vary with yield. Nitrogen fertilisers should be applied in spring: 30–40 kg/ha of the total N required immediately after drilling and the remainder when all the beet seedlings have emerged. If in doubt about the appropriate SNS Index, seek advice from a FACTS Qualified Adviser.

Table 4.29 Nitrogen for sugar beet

	SNS Index				
	0 and 1	2	3	4	5
	kg N/ha				
All mineral soils	120	100	80	0	0
Organic soils				40	0
Peaty soils					0

Phosphate, potash, magnesium and sodium

The amounts of phosphate and potash shown at target Index 2 are needed to replace the offtakes in a 60 t/ha crop (with tops ploughed in) and maintain the soil at the target Index.

The phosphate and potash recommendations at target or lower Indices can be adjusted if yields are likely to be larger or smaller than 60 t/ha by multiplying the difference in expected yield by the phosphate and potash content per tonne of yield given in Table 4.11.

Crops grown on soil at Index 0 and 1 would be expected to respond to the extra amounts of phosphate, potash and magnesium shown in Table 4.30. Also, over a number of years, these extra amounts of fertiliser will help to raise the Index of most soils, except light sands, to Index 2.

Example 4.10

At P Index 1, the recommendation for an expected yield of 70 t/ha where tops are incorporated is 80 + (10 x 0.8) = 88 kg P_2O_5/ha. For potash, growers can access their factory-determined estimates of the amounts of potash removed in their delivered crops from British Sugar Beet Portal as a guide to application rates on Index 2 soils.

Table 4.30 Phosphate, potash, magnesium for sugar beet

	P, K or Mg Index				
	0	1	2	3	4 and higher
	kg N/ha				
Phosphate (P_2O_5)	110	80	50	0	0
Potash (K_2O)	160	130	100	0	0
Magnesium (MgO)	150	75	0	0	0
Na_2O (use K Index)[a]	200	200	100	0	0

a. Sodium can partly replace potash in the nutrition of sugar beet when soils contain too little crop-available potash. An application of 200 kg Na_2O/ha is recommended for beet grown on soils at K Index 0 and 1. On K Index 2 soils it is only necessary to apply 100 kg Na_2O/ha when the soil contains less than 25 mg Na/L. Fen peats, silts and clays usually contain sufficient sodium and no fertiliser sodium is recommended. Sodium at the recommended rate has no adverse effect on soil structure even on soils of low structural stability.

If inorganic fertilisers containing potash and sodium are applied just before sowing and too close to the seed, plant populations can be reduced in dry conditions, especially on sandy soils. To minimise this risk, all inorganic fertilisers should be applied at least two weeks before sowing and incorporated into the soil. They may be applied in autumn or winter and ploughed in, except on light sand soils where there is a risk of some nutrient loss by leaching. On light sand soils, the fertilisers can be applied in January/February, just before ploughing or cultivating.

Boron

Boron deficiency can adversely affect sugar beet yields. An application of boron may be required where soil analysis indicates that available boron in the soil (hot water extraction) is less than 0.8 mg B/l (ppm B). Deficiency can be corrected by applying 3 kg B/ha. Seek advice from a FACTS Qualified Adviser about form, amount and timing of the application.

Sulphur

The uptake of sulphur by well grown crops is around 50–70 kg S/ha and those of high-yielding crops closer to 100 kg S/ha. Crops may suffer from sulphur deficiency especially higher-yielding crops grown on sensitive soils (sands, sandy loams and shallow soils) and where there is no routine use of organic manures in the rotation. However, sulphate-containing fertilisers only need be applied if deficiency symptoms consistently appear in other, more sensitive crops within the rotation, such as oilseed rape and barley. Where deficiency is possible, 25 kg SO_3/ha is effective.

Points to consider

- Make allowance for nutrients applied in organic manures **(Section 2: Organic materials)**
- Ensure the phosphate and potash offtake is balanced by application on Index 2 soils
- Check that soil is maintained at Index 2 by soil sampling every 3–5 years

Further information

Sugar Beet Reference Book
bbro.co.uk/publications/reference-book

British Sugar Beet Portal
www.uksugarbeet.co.uk

Biomass crops

In the UK, two crops are being grown commercially specifically for biomass for use as a source of energy – willow (*Salix* spp.) grown as short-rotation coppice (SRC) and Miscanthus (elephant grass, normally *Miscanthus x giganteous*). Other possible biomass crops such as switchgrass and poplar have only been grown in the UK under experimental conditions.

In addition to these dedicated biomass crops, some normal agricultural crops are also grown for energy purposes. These include wheat grain and sugar beet, both for bioethanol, and oilseed rape for biodiesel. Fertiliser requirements for these crops, if grown for energy use, are covered under the individual crops. Various agricultural by-products may be used for energy generation, such as incineration of cereal straw for electricity generation or anaerobic digestion of animal slurry for biogas generation.

One of the main reasons for growing energy crops is to reduce the use of fossil fuels and decrease greenhouse gas (GHG) emissions. Therefore, it is logical to ensure that GHG emissions associated with growing energy crops, directly or indirectly, are kept to a minimum.

Nitrogen fertilisers lead to large emissions of GHGs, carbon dioxide (CO_2) and nitrous oxide (N_2O), during manufacture and additional N_2O when applied to soil. N_2O is a particularly powerful GHG, each molecule having the same global warming potential as about 300 molecules of CO_2. So it is important to consider the environmental effects of nitrogen fertiliser applications when growing crops for energy.

Sources of information

Only a small number of studies on the nutrient requirements of either Miscanthus or short rotation coppice willow have been conducted, either under UK conditions or worldwide. With such a small knowledge base, it is difficult to be certain of the extent to which the individual results can be generalised, or whether they are site-specific. Consequently, the guidance given here is preliminary and based largely on replacing nutrients removed in the harvested crops, unless otherwise stated.

Miscanthus

Table 4.31 Typical offtake of nutrients in harvested biomass (excluding the first two years after planting when yields are much lower than in later years)

	Per tonne dry biomass	In a typical crop yielding 14 tonne dry biomass per ha
	kg/ha	
Nitrogen (N)	6	84
Phosphate (P_2O_5)	1	14
Potash (K_2O)	8.5[a]	120[a]

a. Potash offtake in Miscanthus is very variable as it is affected by weather and time of harvesting. These values refer to crops harvested in January; it is now common for crops to be harvested later (eg April–May) and the offtake of potash then is generally less because rainfall leaches out potash from the standing crop and returns it to the soil.

There have been no published studies to test crop responses to different applications of phosphate or potash, and only a few with nitrogen. Nitrogen and phosphate offtakes are small compared with many other crops, because much nitrogen and phosphate is transferred from stems and leaves to the rhizomes before harvest; these nutrients can be reused in future years.

As well as the nutrients removed in the harvested parts of the crop, an additional amount is required for the growth of rhizomes in the first few years after planting. On the basis of (a) a relatively small number of measured nutrient offtakes by Miscanthus, (b) comparisons with offtakes by other crops on soils at different levels of crop-available phosphate or potash, and (c) experience gained by those growing the crop, the following is proposed:

Phosphate

Maintain soil at P Index 1. Check every 3–5 years by soil testing.

Potash

Maintain soil at K Index 1–2. Check every 3–5 years by soil testing.

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Nitrogen
In some cases, a biomass yield response to 50–100 kg N/ha has been observed but rarely, if ever, to higher rates and sometimes there is no response for many years (up to 15 years at one UK experiment). For Miscanthus growing on soil previously under arable crops, and with little previous organic manure (ie in SNS Index 2 or below), the soil is likely to supply about 40 kg N/ha (depending on soil type and management history). On the basis of current information, annual fertiliser applications in the range of 60–80 kg N/ha (or organic applications estimated to supply this quantity of nitrogen) are likely to provide sufficient nitrogen for maximum production. In soils starting at a higher SNS Index, nitrogen applications are probably not required for some years.

In the first two to three years after planting, some nitrogen is required for the growth of rhizomes in addition to that removed in harvested biomass. However, the quantity of nitrogen removed in these years is less than in subsequent years so it is likely that no additional nitrogen for rhizome development is required. Thus, in contrast to some earlier suggestions, it is recommended that very little nitrogen (perhaps none) will generally be required in the first two years; nitrogen applications, as inorganic fertiliser or organic manures only should start for the third year's crop. There is some evidence that nitrogen applications applied in the first year after planting are subject to large losses and also encourage weed growth.

Applying nitrogen in late May, just before rapid growth begins, is common practice and this seems appropriate – though there has been no work to test the best time to apply nitrogen.

Sulphur
There is currently no evidence of sulphur applications being required by Miscanthus in the UK.

Willow

Typical offtakes of nutrients in wood harvested from short rotation coppice willow after three years growth following the previous coppicing are shown in Table 4.32.

Table 4.32 Nitrogen, phosphate and potash for willow

	Per tonne dry biomass	In a typical crop yielding 30 tonne dry biomass per ha
	kg N/ha	
Nitrogen (N)	3	90
Phosphate (P_2O_5)	1.8	55
Potash (K_2O)	2.4	72

For short rotation coppice willow, there is even less experimental data on nutrient requirements than for Miscanthus. Therefore, the recommendations given here are based on a combination of nutrient offtakes measured at a very small number of sites and experience of growers.

No fertilisers are required during the establishment year; so the recommendations below refer to the three-year periods after the initial cutback (in the winter after establishment) and the subsequent three-year periods after each harvest.

With short rotation coppice it is almost impossible to enter the plantation to apply fertilisers or manures in the second or third year after cutback or harvesting, unless specialist equipment is available. It is, therefore, necessary to determine nutrient requirements, and make any appropriate applications, in the first year after a cutback, normally during spring in preparation for the period of rapid growth.

In situations where biomass crops are used for bioremediation of biosolids or biofiltration of effluents, levels of nutrient application in excess of those highlighted in Table 4.32 may be justified, recognising the relatively low environmental risks associated with this approach, relative to alternative methods of disposal. In such circumstances, careful monitoring of ground and surface water is required to demonstrate absence of leaching and/or surface runoff of N and P.

Phosphate
Maintain soil at P Index 1. Check every three years (ie each harvesting cycle) by soil testing.

Potash
Maintain soil at K Index 1. Check every three years (ie each harvesting cycle) by soil testing.

Nitrogen
As with Miscanthus, a combination of nitrogen mineralised from soil organic matter plus that from atmospheric deposition and rain will supply much of the modest nitrogen requirement. The requirement is about 30 kg N/ha per year for a typical UK crop yielding 30 t dry biomass during a three-year cycle, ie 90 kg N/ha total offtake. However, larger offtakes have been observed in some situations and, as a grower gains experience of yields in specific soil types and different environments, nitrogen applications can be adjusted using the values in Table 4.32 for nitrogen removed per tonne dry biomass.

Applications of organic materials such as FYM, slurry or sewage sludge are an ideal way of maintaining a suitable supply of nitrogen and other nutrients throughout the three-year growth cycle from a single application made in the first year. The amount applied should be determined on the basis of estimated crop requirement, or within the limits described above for bioremediation or biofiltration systems.

Conversion tables

Metric to imperial

1 tonne/ha	0.4 tons/acre
100 kg/ha	80 units/acre
1 kg/tonne	2 units/ton
10 cm	4 inches
1 m^3	220 gallons
1 m^3/ha	90 gallons/acre
1 kg/m^3	9 units/1000 gallons
1 kg	2 units

Note: a 'unit' is 1% of 1 hundredweight, or 1.12lb.

Imperial to metric

1 ton/acre	2.5 tonnes/ha
100 units/acre	125 kg/ha
1 unit/ton	0.5 kg/tonne
1 inch	2.5 cm
1,000 gallons	4.5 m^3
1,000 gallons/acre	11 m^3/ha
1 unit/1,000 gallons	
1 unit	0.5 kg

Element to oxide

P to P_2O_5	Multiply by 2.291
K to K_2O	Multiply by 1.205
Mg to MgO	Multiply by 1.658
S to SO_3	Multiply by 2.5
Na to Na_2O	Multiply by 1.348
Na to salt	Multiply by 2.542

Oxide to element

P_2O_5 to P	Multiply by 0.436
K_2O to K	Multiply by 0.830
MgO to Mg	Multiply by 0.603
SO_3 to S	Multiply by 0.4
Na_2O to Na	Multiply by 0.742
Salt to Na	Multiply by 0.393

Further information
Conversion calculators
cereals.ahdb.org.uk/tools/agronomy-calculators

Fluid fertiliser

kg/tonne (w/w basis) to kg/m^3	Multiply by specific gravity (w/v basis)

Analysis of fertilisers and liming materials

The materials listed below are used individually and some are used as components of compound or multi-nutrient fertilisers. The chemical and physical forms of nutrient sources, as well as growing conditions, can influence the effectiveness of fertilisers. A FACTS Qualified Adviser can give advice on appropriate forms for different soil and crop conditions.

The reactivity, or fineness of grinding, of liming materials determines their speed of action. However, the amount of lime needed is determined mainly by its neutralising value.

Nitrogen fertilisers	**Typical % nutrient content**
Ammonium nitrate	33.5–34.5% N
Liquid nitrogen solutions	18–30% N (w/w)
Calcium ammonium nitrate (CAN)	26–28% N
Ammonium sulphate	21% N, 60% SO_3
Urea	46% N
Calcium nitrate	15.5% N, 26% CaO

Phosphate fertilisers	
Single superphosphate (SSP)	18–21% P_2O_5, typically 30% SO_3
Triple superphosphate (TSP)	45–46% P_2O_5
Di-ammonium phosphate (DAP)	18% N, 46% P_2O_5
Mono-ammonium phosphate (MAP)	12% N, 52% P_2O_5
Rock phosphate (eg Gafsa)	27–33% P_2O_5

Potash, magnesium and sodium fertilisers	
Muriate of potash (MOP)	60% K_2O
Sulphate of potash (SOP)	50% K_2O, 45% SO_3
Potassium nitrate	13% N, 45% K_2O
Kainit	11% K_2O, 5% MgO, 26% Na_2O, 10% SO_3
Sylvinite	Minimum 16% K_2O, typically 32% Na_2O
Kieserite (magnesium sulphate)	25% MgO, 50% SO_3
Calcined magnesite	Typically 80% MgO
Epsom salts (magnesium sulphate)	16% MgO, 33% SO_3
Agricultural salt	50% Na_2O

Sulphur fertilisers	
Ammonium sulphate	21% N, 60% SO_3
Epsom salts (magnesium sulphate)	16% MgO, 33% SO_3
Elemental sulphur	Typically 200–225% SO_3 (80–90% S)
Quarried gypsum (calcium sulphate)	40% SO_3
Polyhalite (eg Polysulphate)	Minimum 48% SO_3, 14% K_2O, 6% MgO, 17% CaO.

Liming materials	**Neutralising Value (NV)**
Ground chalk or limestone	50–55
Magnesian limestone	50–55, over 15% MgO
Hydrated lime	c.70
Burnt lime	c.80
Sugar beet lime	22–32 + typically 7–10 kg P_2O_5, 5–7 kg MgO, 3–5kg SO_3/tonne

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Glossary

Additionally available nitrogen (AAN) Nitrogen that will become available to the crop through mineralisation during the growing season.

Available (nutrient) Form of a nutrient that can be taken up by a crop immediately or within a short period so acting as an effective source of that nutrient for the crop.

Biosolids Treated sewage sludge.

Calcareous soil Soil that is alkaline due to the presence of free calcium carbonate or magnesium carbonate or both.

Clay Finely divided inorganic crystalline particles in soils, less than 0.002 mm in diameter.

Content (nutrient) Commonly used instead of the more accurate 'concentration' to describe nutrients in fertiliser or organic manure. For example, 6 kg N/t often is described as the nitrogen content of a manure.

Cover crop A crop sown primarily for the purpose of taking up nitrogen from the soil and which is not harvested. Also called green manure.

Crop available nitrogen The total nitrogen content of organic manure that is available for crop uptake in the growing season in which it is spread on land.

Crop nitrogen requirement The amount of crop available nitrogen that must be applied to achieve the economically optimum yield.

Deposition Transfer of nutrients from the atmosphere to soil or to plant surfaces. The nutrients, mainly nitrogen and sulphur, may be dissolved in rainwater (wet deposition) or transferred in particulate or gaseous forms (dry deposition).

Economic optimum Rate of nitrogen application that achieves the greatest (nitrogen rate) economic return from a crop, taking account of crop value and nitrogen cost.

Excess winter rainfall Rainfall between the time when the soil profile becomes fully wetted in the autumn (field capacity) and the end of drainage in the spring, less evapotranspiration during this period (ie water lost through the growing crop).

FACTS UK national certification scheme for advisers on crop nutrition and nutrient management. Membership is renewable annually. A FACTS Qualified Adviser has a certificate and an identity card.

Farmyard manure (FYM) Livestock excreta that is mixed with straw bedding material that can be stacked in a heap without slumping.

Fertiliser See Manufactured fertiliser.

Fluid fertiliser Pumpable fertiliser in which nutrients are dissolved in water (solutions) or held partly as very finely divided particles in suspension (suspensions).

Grassland Land on which the vegetation consists predominantly of grass species.

Greenhouse gas	Gas such as carbon dioxide, methane or nitrous oxide that contributes to global warming by absorbing infra-red radiation that otherwise would escape to space.
Green manure	See Cover crop.
Incorporation	A technique (discing, rotovating, ploughing or other methods of cultivation) that achieves some mixing between an organic manure and the soil. Helps to minimise loss of nitrogen to the air through volatilisation and nutrient run-off to surface waters.
Inorganic fertiliser	Manufactured fertiliser that contains only inorganic ingredients or urea.
Leaching	Process by which soluble materials such as nitrate or sulphate are removed from the soil by drainage water passing through it.
Ley	Temporary grass, usually ploughed up one to five years (sometimes longer) after sowing.
Liquid fertiliser	See Fluid fertiliser.
Livestock manure	Dung and urine excreted by livestock or a mixture of litter, dung and urine excreted by livestock, even in processed organic form. Includes FYM, slurry, poultry litter, poultry manure, separated manures, and granular or pelletised manures.
Maintenance application	Amount of phosphate or potash that must be applied to replace (phosphate or potash) the amount removed from a field at harvest (including that in any straw, tops or haulm removed).
Manufactured fertiliser	Any fertiliser that is manufactured by an industrial process. Includes conventional straight and NPK products (solid or fluid), organo-mineral fertilisers, rock phosphates, slags, ashed poultry manure and liming materials that contain nutrients.
Manure	See Livestock manure and Organic manure.
Major nutrient	Nitrogen, phosphorus and potassium that are needed in relatively large amounts by crops.
Micronutrient	Boron, copper, iron, manganese, molybdenum, zinc that are needed in very small amounts by crops (see also Major nutrients). Cobalt and selenium are taken up in small amounts by crops and are needed in human and livestock diets.
Mineral nitrogen	Nitrogen in ammonium (NH_4) and nitrate (NO_3) forms.
Mineralisable nitrogen	Organic nitrogen that is readily converted to ammonium and nitrate by microbes in the soil, for example during spring.
Mineralisation	Microbial breakdown of organic matter in the soil, releasing nutrients in crop-available, inorganic forms.
Nitrate vulnerable zones (NVZs)	Areas designated by Defra as being at risk from agricultural nitrate pollution.

Nitrous oxide (N_2O) A potent greenhouse gas that is emitted naturally from soils. The amount emitted is related to the supply of mineral nitrogen in the soil. It increases with application of manures and fertilisers, incorporation of crop residues and growth of legumes. It is greater in organic and peaty soils than in other soils.

Offtake Amount of a nutrient contained in the harvested crop (including straw, tops or haulm) and removed from the field. Usually applied to phosphate and potash.

Olsen P Concentration of available P in soil determined by a standard method (developed by Olsen) involving extraction with sodium bicarbonate solution at pH 8.5. It is the main method used in England, Wales and Northern Ireland and the basis for the soil Index for P.

Organic manure Any bulky organic nitrogen source of livestock, human or plant origin, including livestock manures.

Organic material Any bulky organic nitrogen source of livestock, human or plant origin, including livestock manures, biosolids (sewage sludge), compost, digestate and waste-derived materials.

Organic soil Soil containing between 10% and 20% organic matter (in this manual). Elsewhere, it sometimes refers to soils with between 6% and 20% organic matter.

Peaty soil (peat) Soil containing more than 20% organic matter.

Placement Application of fertiliser to a zone of the soil usually close to the seed or tuber.

Poultry manure Excreta produced by poultry, including bedding material that is mixed with excreta, but excluding duck manure with a readily available nitrogen content of 30% or less.

Prilled fertiliser Fertiliser in which particles (prills) are formed by allowing molten material to fall as droplets in a tower. Droplets solidify during the fall and tend to be more spherical and somewhat smaller than granules

Removal See Offtake.

Rhizomes Horizontal underground plant stem capable of producing the shoot and root systems of a new plant.

Sand Soil mineral particles larger than 0.05 mm.

Silt Soil mineral particles in the 0.002–0.05 mm diameter range.

Slurry Excreta of livestock (other than poultry), including any bedding, rainwater and washings mixed with it, which can be pumped or discharged by gravity. The liquid fraction of separated slurry is also defined as slurry.

SNS Index Soil Nitrogen Supply expressed in seven bands or Indices, each associated with a range in kg N/ha.

Soil Index (P, K or Mg) Concentration of available P, K or Mg, as determined by standard analytical methods, expressed in bands or Indices.

Soil Mineral Nitrogen (SMN)	Ammonium and nitrate nitrogen, measured by the standard analytical method and expressed in kg N/ha.
Soil Nitrogen Supply (SNS)	The amount of nitrogen (kg N/ha) in the soil that becomes available for uptake by the crop in the growing season, taking account of nitrogen losses.
Soil organic matter	Often referred to as humus. Composed of organic compounds ranging from undecomposed plant and animal tissues to fairly stable brown or black material with no trace of the anatomical structure of the material from which it was derived.
Soil texture	Description based on the proportions of sand, silt and clay in the soil.
Soil type	Description based on soil texture, depth, chalk content and organic matter content.
Target soil Index	Lowest soil P or K Index at which there is a high probability crop yield will not be limited by phosphorus or potassium supply. See Soil Index (P, K or Mg).
Trace element	See Micronutrient.
Volatilisation	Loss of nitrogen as ammonia from the soil to the atmosphere.

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Greenhouse Gas Action Plan:
The industry-wide Greenhouse Gas Action Plan (GHGAP) for agriculture focuses on improving resource use efficiency in order to enhance business performance while reducing GHG emissions from farming.

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Nutrient Management Guide (RB209)

Updated May 2017

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FACTS

Section 5 Potatoes

Using the Nutrient Management Guide (RB209)

This latest revision of RB209 is based on research carried out since the previous edition was published in 2010. The revision includes updated recommendations, including those for additional crops and information on the nutrient content of additional organic materials.

RB209 was first published in 1973 and was the first comprehensive set of fertiliser recommendations from the Ministry of Agriculture, Fisheries and Food (MAFF). RB209 stands for Reference Book 209.

To improve the accessibility of the recommendations and information AHDB's Nutrient Management Guide (RB209) is published as seven sections that will be updated individually.

Further information

The Nutrient Management Guide (RB209) will be updated regularly. Please email your contact details to AHDB so that we can send you new versions when they are published - comms@ahdb.org.uk

RB209: Nutrient Management

Download the app for Apple or Android phones to access the current version of all sections of the guide. With quick and easy access to videos, information and recommendations from the guide, it is practical for use in the field.

Section 1 Principles of nutrient management and fertiliser use

Section 2 Organic materials

Section 3 Grass and forage crops

Section 4 Arable crops

Cereals

Oilseeds

Sugar beet

Peas and beans

Biomass crops

Section 5 Potatoes

Section 6 Vegetables and bulbs

Section 7 Fruit, vines and hops

Always consider your local conditions and consult a FACTS Qualified Adviser if necessary.

This section provides guidance for potato crops and should be read in conjunction with Sections 1 and 2. For each crop, recommendations for nitrogen (N), phosphate (P_2O_5) and potash (K_2O) are given in kilograms per hectare (kg/ha). Magnesium (MgO) and sulphur (as SO_3) are given in kg/ha where these nutrients are needed.

Recommendations are given for the rate and timing of nutrient application. The recommendations are based on the nutrient requirements of the crop being grown, while making allowance for the nutrients supplied by the soil.

When grown in soil with a good structure, potatoes are capable of producing extensive root systems that are efficient in taking up water and nutrients, therefore, every effort should be made to ensure seedbeds are free of compaction. The value of the potato crop is dictated by the marketable yield, not the total yield and, in consequence, decisions about fertiliser rates should be considered together with factors such as site selection and seed rates.

Because of the very wide range of varietal characteristics and quality requirements for different market outlets, guidance from a FACTS Qualified Adviser should be used when making decisions for specific crop

Further information
Fertiliser Calculator
potatoes.ahdb.org.uk/online-toolbox/fertiliser-calculator

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Summary of main changes from previous edition

1. Overall presentation
   a. Fertiliser recommendations for potatoes are now presented in **Section 5: Potatoes** that incorporates the relevant appendices.
2. New and revised recommendations
   a. The guidance on assessing Soil Nitrogen Supply (SNS) has been revised to include guidance on when Soil Mineral Nitrogen (SMN) sampling can be most useful and interpretation of SMN analysis results.
   b. The guidance on soil sampling for P, K and Mg analysis has been updated.
   c. The number of varieties included in the determinacy grouping list has increased.
   d. Against a background of decreasing sulphur emissions from UK industry, a recommendation to apply 25 kg SO_3/ha where S deficiency may be likely has been included.

Further information

Soil management for potatoes
potatoes.ahdb.org.uk/agronomy/soils

Think Soils
www.ahdb.org.uk/thinksoils

AHDB Field drainage guide
cereals.ahdb.org.uk/publications

Nitrate Vulnerable Zones
www.gov.uk/guidance/nutrient-management-nitrate-vulnerable-zones

Information on irrigation and water management for potatoes
potatoes.ahdb.org.uk/agronomy/water

Checklist for decision making

Individual decisions for fertiliser use must be made separately for every field. Where more than one crop is grown in a field, these areas must be considered individually.

1. Confirm the crop to be grown and the intended market. Identify any crop quality criteria required by this market, eg dry matter content and skin finish.
2. Identify the dominant soil type in the cropped area **(Section 1: Principles of nutrient management and fertiliser use)**.
3. Assess soil structure and take action to remove soil compaction, if necessary. Poor soil structure can restrict crop growth and results in poor nutrient and water use efficiency.
4. Carry out soil analysis for pH, P, K and Mg every 3–5 years (page 7). Target values to maintain in arable rotations are:
   - **Soil pH 6.5 (5.8 on peat soils)**
   - **Soil P Index 2**
   - **Soil K lower Index 2 (2-)**
   - **Soil Mg Index 2**

5. Identify the Soil Nitrogen Supply (SNS) Index of the field, either by using the Field Assessment Method (page 11) or the Measurement Method (page 18). The Measurement Method is recommended where nitrogen supply from crop residues is expected to be high (SNS of more than 120 kg N/ha for arable rotations), or are uncertain.
6. Calculate the total and crop-available nutrients from organic materials that have been applied since harvest of the previous crop, or which will be applied to the crop being grown **(Section 2: Organic materials)**. Deduct these nutrients from the recommended rates given in the tables.
7. Also check if the field is within a Nitrate Vulnerable Zone (NVZ), consider the rules for application rates and timing for fertilisers and organic materials and adjust plans to comply with NVZ requirements.
8. Decide on the strategy for phosphate and potash use. This will be building up, maintaining or running down the soil Index **(Section 1: Principles of nutrient management)**. Allow for any surplus or deficit of phosphate or potash applied to previous crops in the rotation.
9. Calculate the amount of phosphate and potash removed in the harvested crop according to targeted crop yield (page 8). This is the amount of these nutrients that must be replaced in order to maintain the soil at the current Index.
10. Using the tables, decide on the required rate of each nutrient. Decide on the optimum timings for fertiliser application, then find the best match for these applications using available fertilisers.
11. Check that the fertiliser spreader or sprayer is in good working order and has been recently calibrated **(Section 1: Principles of nutrient management)**.
12. Keep an accurate record of the fertilisers and organic manures applied.

Phosphate, potash and magnesium recommendations

Current phosphate, potash and magnesium recommendations are based on achieving and maintaining target soil Indices for each nutrient in the soil throughout the crop rotation. Soil analysis is used as a basis for making fertiliser decisions and it should be done every 3–5 years.

Soil samples can be collected by walking in a ‘W’ pattern through a field following the steps on page 7. Identifying the major soil type and yield variation in the field is a key step in establishing the need for GPS sampling.

PAAG
Professional Agricultural Analysis Group

Most UK laboratories are members of the PAAG that offers farmers and advisers confidence in laboratory analysis.

- Proficiency tests (often called ring tests) carried out by Wageningen University, guaranteeing that analysis from any member can be trusted.
  www.wepal.nl
- List of UK laboratories
  www.nutrientmanagement.org/what-we-do/support-and-advice/find-a-laboratory
- Sampling guidelines
  www.nutrientmanagement.org/library/sampling

Taking soil samples for phosphorus, potassium and magnesium

Soil sampling must be done well to avoid misleading results and expensive mistakes.

- The soil in each field should be sampled every 3–5 years
- Collect samples at the same point in the rotation and well before growing a sensitive crop eg sugar beet
- Ideally, sample immediately after the harvest of the previous crop
- Do not sample within six months of a lime or fertiliser application (except nitrogen) and avoid sampling when the soil is very dry
- Do not take samples in headlands, or in the immediate vicinity of hedges, trees or other unusual features
- The soil sample must be representative of the area sampled. Areas of land known to differ in some important respects (eg soil type, previous cropping, applications of manure, fertiliser or lime) should be sampled separately. Small areas known to differ from the majority of a field should be excluded from the sample
- Ideally the sampled area should be no larger than four hectares
- Clean tools before starting and before sampling a new area
- Walk a 'W' pattern across the sampling area, stopping at least 25 times
- At each point collect a subsample (core) to 15 cm depth using a gouge corer or screw auger
- The subsamples should be bulked to form a representative sample and sent to the laboratory for analysis
- Use appropriate packaging (normally available from the laboratory) and label samples clearly, providing as much information about the field and crop as possible

On soils where acidity is known to occur, more frequent testing may be needed than the 4-year cycle used for phosphate, potash and magnesium. Since acidity can occur in patches, spot testing with a soil test kit across the field is often useful. Soil tests can also be useful on soils which contain fragments of free lime, since these can give a misleadingly high pH when analysed following grinding in the laboratory.

Classification of soil analysis results into Indices

The laboratory soil analysis results for P, K and Mg (in mg/kg dry soil) can be converted into soil Indices using Table 5.1.

Table 5.1 Classification of soil P, K and Mg analysis results into Indices

Index	Phosphorus (P)	Potassium (K)	Magnesium (Mg)
	Olsen P	Ammonium nitrate extract	
	mg/litre		
0	0–9	0–60	0–25
1	10–15	61–120	26–50
2	16–25	121–180 (2-) 181–240 (2+)	51–100
3	26–45	241–400	101–175
4	46–70	401–600	176–250
5	71–100	601–900	251–350
6	101–140	901–1,500	351–600
7	141–200	1,501–2,400	601–1,000
8	201–280	2,401–3,600	1,001–1,500
9	Over 280	Over 3,600	Over 1,500

Phosphate, potash and magnesium recommendations

The phosphate recommendations are higher than that required to replace offtake and are intended to achieve optimum yield. The potash recommendations are required to replace the offtake and maintain target soil Indices. The larger recommended applications for soils at Index 0 and 1 will bring the soil to Index 2 over a number of years. By not applying fertiliser at Index 3 or above, soil will run down over a number of years to the target Index.

Points to consider

- Recommendations assume good soil structure, water supply, and pest and disease control
- Recommendations are given as phosphate (P_2O_5), potash (K_2O) and magnesium oxide (MgO). Conversion tables (metric–imperial, oxide–element) are given on page 25
- Organic materials supply phosphate and potash which contribute to crop requirements. Don't forget to make allowance for the phosphate and potash applied in organic materials **(Section 2: Organic materials)**
- All recommendations are given for the mid-point of each Index. The K recommendations for the lower half (2-) and upper half (2+) of K Index 2 are the same
- Where a soil analysis value (as given by the laboratory) is close to the range of an adjacent Index, the recommendation may be reduced or increased slightly, taking account of that given for the adjacent Index. Small adjustments of less than 10 kg/ha are generally not justified
- Where more or less phosphate and potash are applied than suggested in the tables, adjustments can be made later in the rotation

The amounts of phosphate and potash shown in Table 5.2 at Index 2 are those recommended to achieve a total yield of 50 t/ha. Crops grown on soil at Indices 0 and 1 would be expected to respond to the extra amounts of phosphate, potash and magnesium shown in Table 5.2.

There is no need to adjust the recommended phosphate rates if the target yield is higher or lower than 50 t/ha.

However, the potash recommendation at target or lower Indices can be adjusted when yield is likely to be larger or smaller than 50 t/ha by multiplying the difference in expected yield by 5.8 kg/t.

Example 5.1

At K Index 1, the potash recommendation for an expected yield of 70 t/ha is 330 + (20 x 5.8) = 446 kg K_2O/ha. No adjustment for yield should be made where the soil Index is higher than target.

Table 5.2 Recommended phosphate, potash and magnesium rates for a crop yielding 50 t/ha of tubers

	P, K or Mg Index				
	0	1	2	3	4 and higher
	kg /ha				
Phosphate (P_2O_5)	250	210	170	100	0
Potash (K_2O)	360	330	300	150	0
Magnesium (MgO)	120	80	40	0	0

The amount of phosphate recommended for soils at P Index 2 or 3 is more than sufficient to replace the phosphate removed by a 50 t/ha crop (about 50 kg P_2O_5). The surplus phosphate will help to maintain the soil at a target P Index 2 for an arable crop rotation and should be allowed for when assessing the need for phosphate for following crops.

On soils at P Index 0 and 1, the surplus phosphate will help increase the soil P Index and no allowance should be made when deciding the phosphate requirement of a subsequent crop. On soils at P Index 2 or below, a large proportion of the phosphate should be water-soluble.

The amount of potash recommended at K Index 2 will only replace the amount removed by a 50 t/ha crop and potash should be applied for the next crop in the rotation to maintain the soil at K Index 2. The extra amounts of potash shown for K Index 0 and 1 soils will slowly increase the soil K Index.

Figure 5.1 Potash deficiency

Figure 5.2 Magnesium deficiency

Timing of application

All the phosphate should be applied in the spring and either worked into the seedbed or placed at planting.

Where more than 300 kg K_2O/ha is required, apply half in late autumn/winter and half in spring. On light sandy soils, all the potash fertiliser should be applied after primary cultivation and no sooner than late winter. Large amounts of potash can sometimes reduce tuber dry matter content. If applicable, reference should be made to recommendations from the processing customer. Where this occurs, the decrease may be smaller when muriate of potash (MOP, potassium chloride) is replaced by sulphate of potash (SOP, potassium sulphate).

These recommendations should be used for both bed and ridge and furrow systems. Where fertiliser is placed, a small reduction in the recommended rate of phosphate could be considered.

Points to consider

- **Ensure the potash offtake is balanced by an application of potash fertiliser on Index 2 soils**
- **Check the soil is maintained at Index 2 for both phosphate and potash by soil sampling every 3–5 years**

Example 5.2

Soil analysis shows P Index 2 and K Index 2 and main crop potatoes are to be grown. The expected yield is 65 t/ha tubers.

Based on 1 t/ha of tubers containing 1 kg P_2O_5/ha and 5.8 kg K_2O/ha, a crop yielding 65 t/ha will remove:

Phosphate	65 x 1.0 = 65 kg P_2O_5/ha
Potash	65 x 5.8 = 377 kg K_2O/ha

However, Table 5.2 recommends 170 kg P_2O_5/ha and 300 kg K_2O/ha for a crop yielding 50 t/ha.

For phosphate, the recommendation is much larger than the offtake because potatoes are likely to respond to extra phosphate at P Index 2. Therefore the phosphate application rate is not adjusted for non-standard yield in potatoes. The surplus phosphate, 105 kg P_2O_5/ha (170 - 65 = 105), should be allowed for when deciding on the phosphate application for the next crop(s) grown in the rotation.

For potash, the recommendation is less than the offtake and the deficit (377 - 300 = 77) should be made good later in the crop rotation.

- **Where organic manure is applied, it is important to calculate the quantity of nutrients added in the manure (Section 2: Organic Materials) and adjust the amount of fertiliser accordingly. Allowing for the nutrients in manure reduces the need for fertiliser, improves farm profits and reduces the risk of nutrient pollution of water**
- **Construct a nutrient balance sheet for each field and ensure the phosphate and potash offtake is balanced by an equivalent application of phosphate and potash on Index 2 soils. Check that the soil is maintained at Index 2 by soil analysis every 3–5 years**

Sulphur recommendations

Potato crops are not generally thought to be responsive to sulphur. However, atmospheric sulphur emissions have declined significantly and a yield response to sulphur is possible. If deficiency does occur, it is most likely to show first in crops grown on deep sand soils with low organic matter and in areas well away from industrial pollution.

Farmers are advised to monitor the sulphur requirements of their crops. Where sulphur deficiency has previously occurred or is expected, apply 25 kg SO_3/ha as a sulphate-containing fertiliser in the seedbed.

Figure 5.3 Sulphur deficiency

Points to consider

- **Organic materials can supply useful amounts of sulphur (Section 2: Organic materials)**
- **Sulphur recommendations are given as SO_3. Conversion tables (metric–imperial, oxide–element) are given on page 25. If applying liquid fertilisers, manufacturers can supply tables which convert kg/ha of nutrient to litres/ha of product**
- **Further information on the occurrence of sulphur deficiency and diagnostic methods can be found in Section 1: Principles of nutrient management and fertiliser use**

Lime and micronutrient recommendations

Although essential for plant growth, in most cases the very small quantities of micronutrients needed for potatoes can be supplied from soil reserves. The only significant trace element deficiency in potatoes is manganese (Mn), which can occur on peaty, organic or sandy soils at high pH and on other soil types if over-limed.

Manganese deficiency usually occurs in patches during periods of rapid growth and can be treated by one or more foliar sprays of a suitable manganese-containing material.

Potatoes can tolerate a degree of soil acidity and are best grown at soil pH levels that are lower than for most other arable crops. However liming immediately before potatoes should be avoided unless the soil pH is very low, as this can increase the risk of common scab and manganese deficiency.

Figure 5.4 Manganese deficiency

Calculating Soil Nitrogen Supply (SNS)

Fields vary widely in the amount of nitrogen available to a crop before any fertiliser or manure is applied. This variation must be taken into account to avoid inadequate or excessive applications of nitrogen.

The Soil Nitrogen Supply (SNS) system assigns an Index of 0 to 6 to indicate the likely extent of this background nitrogen supply. The Index is used in the recommendation tables to select the amount of nitrogen, as manufactured fertiliser, manure or a combination of both that typically would need to be applied to ensure optimum yield.

The SNS Index for each field can be estimated either by the Field Assessment Method using records of soil type, previous cropping and winter rainfall, or by the Measurement Method. This uses measurements of Soil Mineral Nitrogen (SMN) plus estimates of nitrogen already in the crop (at the time of soil sampling) and of available nitrogen from the mineralisation of soil organic matter and crop debris during the period of active crop growth.

Field Assessment Method

The Field Assessment Method does not take account of the nitrogen that will become available to a crop from any organic manures applied since harvest of the previous crop. The available nitrogen from organic materials applied since harvest of the previous crop, or those that will be applied to the current crop, should be calculated separately using the information in **Section 2: Organic Materials**, and deducted from the fertiliser nitrogen application rates shown in the recommendation tables.

There are five essential steps to follow to identify the appropriate SNS Index:

Step 1. Identify the soil type for the field
Step 2. Identify the previous crop
Step 3. Select the rainfall range for the field
Step 4. Identify the provisional SNS Index using the appropriate table
Step 5. Make any necessary adjustments to the SNS Index

Step 1. Identify soil type for the field
Careful identification of the soil type in each field is very important. The whole soil profile should be assessed to one metre depth for arable crops. Where the soil varies, and nitrogen is to be applied uniformly, select the soil type that occupies the largest part of the field.

The soil type can be identified using Figure 5.5, which categorises soils on their ability to supply and retain mineral nitrogen. The initial selection can then be checked using Table 5.3. Carefully assess the soil organic matter content when deciding if the soil is organic (10% to 20% organic matter for the purposes of this guide) or peaty (more than 20% organic matter). If necessary, seek professional advice on soil type assessments, remembering this will only need to be done once.

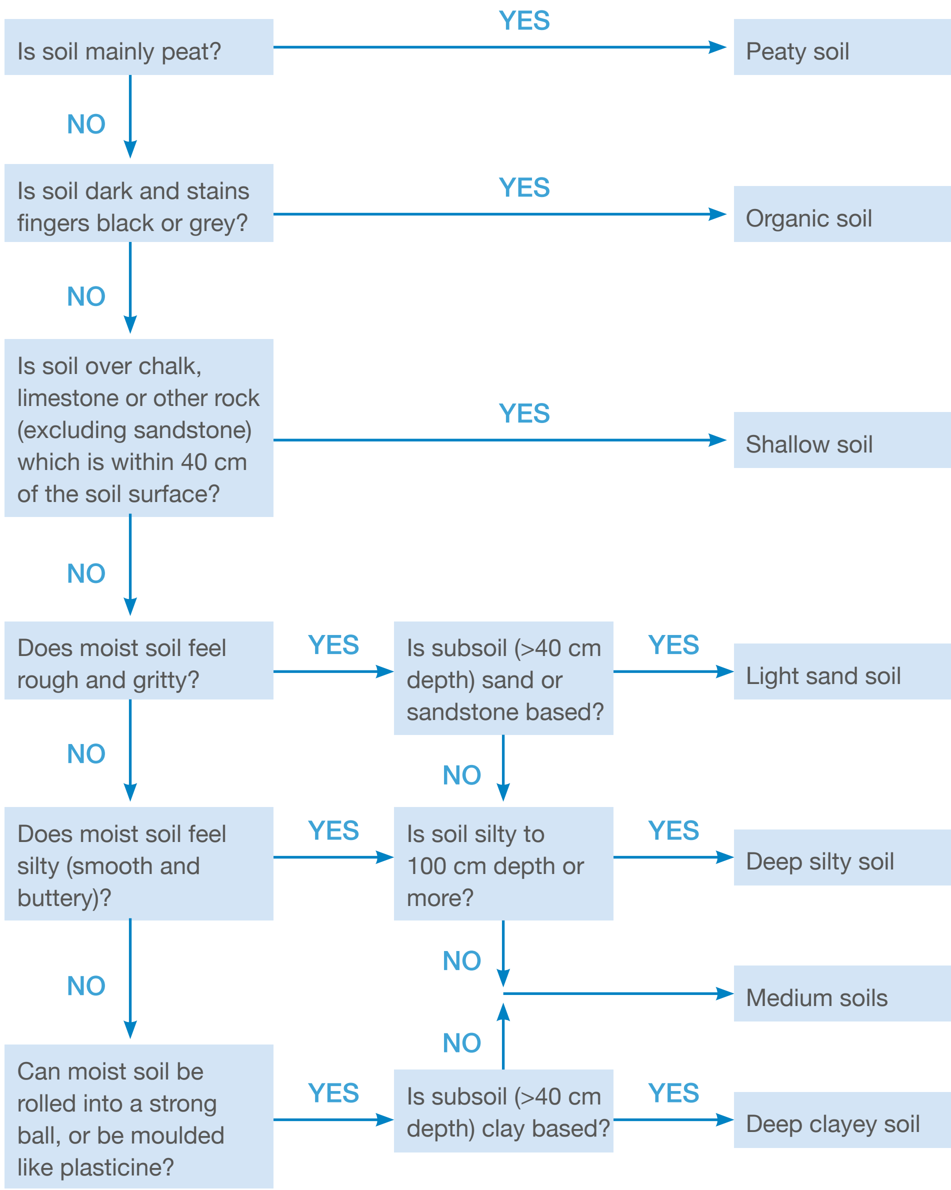

Figure 5.5 Soil category assessment

Table 5.3 Soil category assessment

Soil category	Description of soil types within category	Properties
Light sand soils	Soils which are sand, loamy sand or sandy loam to 40 cm depth and are sand or loamy sand between 40– 80 cm, or over sandstone rock.	Soils in this category have poor water holding capacity and retain little nitrogen.
Shallow soils	Soils over impermeable subsoils and those where the parent rock (chalk, limestone or other rock) is within 40 cm of the soil surface. Sandy soils developed over sandstone rock should be regarded as light sand soils.	Soils in this category are less able to retain or supply nitrogen at depth.
Medium soils	Mostly medium-textured mineral soils that do not fall into any other soil category. This includes sandy loams over clay, deep loams, and silty or clayey topsoils that have sandy or loamy subsoils.	Soils in this category have moderate ability to retain nitrogen and allow average rooting depth.
Deep clayey soils	Soils with predominantly sandy clay loam, silty clay loam, clay loam, sandy clay, silty clay or clay topsoil overlying clay subsoil to more than 40 cm depth. Deep clayey soils normally need artificial field drainage.	Soils in this category are able to retain more nitrogen than lighter soils.
Deep silty soils	Soils of sandy silt loam, silt loam or silty clay loam textures to 100 cm depth or more. Silt soils formed on marine alluvium, warp soils (river alluvium) and brickearth soils are in this category. Silty clays of low fertility should be regarded as other mineral soils.	Soils in this category are able to retain more nitrogen than lighter soils and allow rooting to greater depth.
Organic soils	Soils that are predominantly mineral but with between 10–20% organic matter to depth. These can be distinguished by darker colouring that stains the fingers black or grey.	Soils in this category are able to retain more nitrogen than lighter soils and have higher nitrogen mineralisation potential.
Peat soils	Soils that contain more than 20% organic matter derived from sedge or similar peat material.	Soils in this category have very high nitrogen mineralisation potential.

Step 2. Identify previous crop
Usually, this is straightforward but sometimes clarification may be needed:

High residual nitrogen vegetables (‘high N vegetables’) are leafy, nitrogen-rich Brassica crops such as calabrese, Brussels sprouts and some crops of cauliflower where significant amounts of crop debris are returned to the soil, especially in rotations where an earlier Brassica crop has been grown within the previous twelve months. To be available for crop uptake, this organic nitrogen must have had time to mineralise but the nitrate produced must not have been at risk to loss by leaching.

Medium residual nitrogen vegetables (‘medium N vegetables’) are crops such as lettuce, leeks and long-season Brassicas, such as Dutch white cabbage, where a moderate amount of crop debris is returned to the soil.

Low residual nitrogen vegetables (‘low N vegetables’) are crops such as carrots, onions, radish, swedes or turnips where the amount of crop residue is relatively small.

Step 3. Select low, moderate or high rainfall

The appropriate rainfall category should be identified, based on either annual rainfall or excess winter rainfall. Ideally, an estimate of excess winter rainfall is required because this is closely related to drainage by which nitrate will be lost through leaching. Figure 5.6 below shows long-term (1981–2010) average excess winter rainfall and in an average year can be used to select the rainfall category.

There are three SNS Index tables representing 'low rainfall' (annual rainfall less than 600 mm, or less than 150 mm excess winter rainfall), 'moderate rainfall' (between 600–700 mm annual rainfall, or 150–250 mm excess winter rainfall), and 'high rainfall' areas (more than 700 mm annual rainfall, more than 250 mm excess winter rainfall).

Figure 5.6 Excess winter rainfall (mm)

Step 4. Identify the provisional SNS Index using the appropriate table

Tables 5.4 (low rainfall), 5.5 (moderate rainfall) and 5.6 (high rainfall) should be used where the field has not been in grass within the past three years. Select one of these tables according to rainfall for the field. Take account of the footnotes to the tables.

Higher than typical Indices can occur where there has been a history of grassland or frequent applications of organic manures. Soil analysis for Soil Mineral Nitrogen (SMN) is recommended in these situations.

If grass has been grown in the previous three years, also look at Table 5.7. Select the higher of the Index levels based on the last crop grown (from Table 5.4, 5.5 or 5.6) and that based on the grass history (Table 5.7).

Points to consider

- Do not confuse SNS (Soil Nitrogen Supply) and SMN (Soil Mineral Nitrogen)
- SMN is the measured amount of mineral nitrogen (nitrate-N plus ammonium-N) in the soil profile
- SNS = SMN (0–90 cm or maximum rooting depth in shallow soils over rock) + crop N (at time of sampling for SMN) + estimate of available N from mineralisation of organic matter

Table 5.4 Soil Nitrogen Supply (SNS) Indices for low rainfall (500–600 mm annual rainfall, up to 150 mm excess winter rainfall) – based on the last crop grown

Previous crop	Soil type					
	Light sand soils or shallow soils over sandstone	Medium soils or shallow soils not over sandstone	Deep clayey soils	Deep silty soils	Organic soils	Peat soils
Beans	1	2	3	3	All crops in SNS Index 3, 4, 5 or 6. Consult a FACTS Qualified Adviser.	All crops in SNS Index 4, 5 or 6. Consult a FACTS Qualified Adviser.
Cereals	0	1	2	2		
Forage crops (cut)	0	1	2	2		
Oilseed rape	1	2	3	3		
Peas	1	2	3	3		
Potatoes	1	2	3	3		
Sugar beet	1	1	2	2		
Uncropped land	1	2	3	3		
Vegetables (low N)[b]	0	1	2	2		
Vegetables (medium N)[b]	1	3	3[a]	3[a]		
Vegetables (high N)[b]	2	4[a]	4[a]	4[a]		

a. Index may need to be increased by up to 1 where significantly larger amounts of leafy residues are incorporated (see Step 5). Where there is uncertainty, soil sampling for SMN may be appropriate.

b. Refer to Step 2.

Table 5.5 Soil Nitrogen Supply (SNS) Indices for moderate rainfall (600–700 mm annual rainfall, or 150–250 mm excess winter rainfall) – based on the last crop grown

Previous crop	Soil type					
	Light sand soils or shallow soils over sandstone	Medium soils or shallow soils not over sandstone	Deep clayey soils	Deep silty soils	Organic soils	Peat soils
Beans	1	2	2	3	All crops in SNS Index 3, 4, 5 or 6. Consult a FACTS Qualified Adviser.	All crops in SNS Index 4, 5 or 6. Consult a FACTS Qualified Adviser.
Cereals	0	1	1	1		
Forage crops (cut)	0	1	1	1		
Oilseed rape	0	2	2	2		
Peas	1	2	2	3		
Potatoes	0	2	2	2		
Sugar beet	0	1	1	1		
Uncropped land	1	2	2	2		
Vegetables (low N)[a]	0	1	1	1		
Vegetables (medium N)[a]	0	2	3	3		
Vegetables (high N)[a]	1	3	4	4		

a. Refer to Step 2.

Table 5.6 Soil Nitrogen Supply (SNS) Indices for high rainfall (over 700 mm annual rainfall, or over 250 mm excess winter rainfall) – based on the last crop grown

Previous crop	Soil type					
	Light sand soils or shallow soils over sandstone	Medium soils or shallow soils not over sandstone	Deep clayey soils	Deep silty soils	Organic soils	Peat soils
Beans	0	1	2	2	All crops in SNS Index 3, 4, 5 or 6. Consult a FACTS Qualified Adviser.	All crops in SNS Index 4, 5 or 6. Consult a FACTS Qualified Adviser.
Cereals	0	1	1	1		
Forage crops (cut)	0	1	1	1		
Oilseed rape	0	1	1	2		
Peas	0	1	2	2		
Potatoes	0	1	1	2		
Sugar beet	0	1	1	1		
Uncropped land	0	1	1	2		
Vegetables (low N)[b]	0	1	1	1		
Vegetables (medium N)[b]	0	1	1	2		
Vegetables (high N)[b]	1[a]	2	2	3		

a. Index may need to be lowered by 1 where residues incorporated in the autumn and not followed immediately by an autumn-sown crop.

b. Refer to Step 2.

Table 5.7 Soil Nitrogen Supply (SNS) Indices following ploughing out of grass leys

	SNS Index		
Light sands or shallow soils over sandstone – all rainfall areas	Year 1	Year 2	Year 3
All leys with 2 or more cuts annually receiving little or no manure 1–2 year leys, low N 1–2 year leys, 1 or more cuts 3–5 year leys, low N, 1 or more cuts	0	0	0
1–2 year leys, high N, grazed 3–5 year leys, low N, grazed 3–5 year leys, high N, 1 cut then grazed	1	2	1
3–5 year leys, high N, grazed	3	2	1
Other medium soils and shallow soils – not over sandstone – all rainfall areas			
All leys with 2 or more cuts annually receiving little or no manure 1–2 year leys, low N 1–2 year leys, 1 or more cuts 3–5 year leys, low N, 1 or more cuts	1	1	1
1–2 year leys, high N, grazed 3–5 year leys, low N, grazed 3–5 year leys, high N, 1 cut then grazed	2	2	1
3–5 year leys, high N, grazed	3	3	2
Deep clayey soils and deep silty soils in low rainfall areas (500–600 mm annual rainfall)			
All leys with 2 or more cuts annually receiving little or no manure 1–2 year leys, low N 1–2 year leys, 1 or more cuts 3–5 year leys, low N, 1 or more cuts	2	2	2
1–2 year leys, high N, grazed 3–5 year leys, low N, grazed 3–5 year leys, high N, 1 cut then grazed	3	3	2
3–5 year leys, high N, grazed	5	4	3
Deep clayey soils and deep silty soils in moderate (600–700 mm annual rainfall) or high (over 700 mm annual rainfall) rainfall areas			
All leys with 2 or more cuts annually receiving little or no manure 1–2 year leys, low N 1–2 year leys, 1 or more cuts 3–5 year leys, low N, 1 or more cuts	1	1	1
1–2 year leys, high N, grazed 3–5 year leys, low N, grazed 3–5 year leys, high N, 1 cut then grazed	3	2	1
3–5 year leys, high N, grazed	4	3	2

The Indices shown in Table 5.7 assume that little or no organic manures has been applied. Where silage fields have received the organic manures produced by livestock that have eaten the silage and the manure has been applied in spring, they should be regarded as containing nitrogen residues equivalent to a previous grazing history.

'Low N' grassland means average annual inputs of less than 250 kg N/ha in fertiliser plus crop available nitrogen in manure used in the last two years, or swards with little clover.

'High N' grassland means average annual applications of more than 250 kg N/ha in fertiliser plus crop available nitrogen in manure used in the last two years, or clover-rich swards or lucerne.

Step 5. Make any necessary adjustment to the SNS Index for certain conditions

When using the Field Assessment Method, it is not necessary to estimate the amount of nitrogen taken up by the crop over winter. This is already taken into account in the tables.

Manure history: Where regular applications of organic manures have been made to previous crops in the rotation, increase the Index value by one or two levels depending on manure type, application rate and frequency of application.

Point to consider

- The nitrogen contribution from manures applied after harvest of the previous crop should not be considered when deciding the SNS Index; this contribution should be deducted from the recommended nitrogen application rate using the information in **Section 2: Organic Materials**

Field vegetables as previous crop: On medium, deep silty or deep clayey soils, nitrogen residues in predominantly vegetable rotations can persist for several years especially in the drier parts of the country. This is likely to be especially evident following 'high or medium N vegetables'. The SNS tables make some allowance for this long persistency of nitrogen residues but the Index level may need to be adjusted upwards particularly where:

- Winter rainfall is low
- The history of vegetable cropping is longer than one year
- Larger than average amounts of crop residue or unused fertiliser are left behind (see footnote to Table 5.4)

In rotations where vegetable crops are grown infrequently and where there is uncertainty, soil sampling for SMN may be appropriate.

Fertiliser residues from previous crop: The Index assessments assume that the previous crop grew normally and that it received the recommended rate of nitrogen applied as fertiliser and/or organic manures. The Index should be increased if there is reason to believe nitrogen residues are likely to be greater than normal and these residues will not be lost by leaching. This could occur where a cover crop was sown in autumn and grew well over winter. The Index may need to be adjusted downwards if there is reason to believe nitrogen residues are likely to be smaller than usual.

After any adjustment, the SNS Index can be used in the recommendation tables.

Measurement Method

This method is particularly appropriate where the SNS is likely to be large and uncertain. This includes:

- Fields with a history of organic manure application and vegetable rotations where the timing of residue incorporation can strongly affect Soil Mineral Nitrogen (SMN) for the following crop
- Fields where long leys or permanent pasture have been recently ploughed out (but not in the first year after ploughing out)
- Fields where there have been problems such as regular lodging of cereals, very high grain protein or nitrogen contents, or previous crop failure (for example, due to drought or disease)
- Fields where there is significant variation in soil texture and/or large amounts of crop residues are incorporated. Nitrogen residues also can be large following outdoor pigs

The SNS Index can be identified using the results of direct measurement of SMN to 90 cm depth in spring, 60 cm depth in autumn/early winter, or to maximum rooting depth in shallow soils over rock. An estimate of net mineralisable nitrogen must be added to the SMN result when calculating the SNS.

SNS is likely to be low on light sand and shallow soils that have not received regular additions of organic manure or crop residues, particularly in moderate to high rainfall areas. In this scenario, prediction of SNS using the Field Assessment Method is advised.

The Measurement Method is not recommended for peat soils, or in the first season after ploughing out long leys or permanent pasture, where net mineralisation can be very large and uncertain and the measured SMN may be a relatively small component of SNS. For these soils, the Field Assessment Method or local experience will be better guides to SNS.

Points to consider

- Do not confuse Soil Nitrogen Supply (SNS) and Soil Mineral Nitrogen (SMN)
- SMN is the measured amount of mineral nitrogen (nitrate-N plus ammonium-N) in the soil profile
- SNS = a measurement of SMN + an estimate of subsequent N mineralisation

The Measurement Method does not take account of the available nitrogen supplied from organic manures applied after the date of soil sampling for SMN. The available nitrogen from manures applied after sampling should be calculated separately using the information in **Section 2: Organic Materials**, and deducted from the nitrogen rate shown in the appropriate recommendation table.

The nitrogen contribution from manures applied before sampling for SMN will be largely taken account of in the measured value and should not be calculated separately.

When using the Measurement Method there are three steps to follow:

Step 1. Measure Soil Mineral Nitrogen (SMN)
Step 2. Make an allowance for net mineralisable nitrogen
Step 3. Identify Soil Nitrogen Supply (SNS) Index

In detail, these three steps are:

Step 1. Measure Soil Mineral Nitrogen (SMN)
Soil sampling must be done well to avoid misleading results and expensive mistakes.

Guidance on how to collect a SMN sample

- In most situations, sampling in late winter or early spring before nitrogen fertiliser is applied gives slightly better predictions of SNS than sampling in the autumn because overwinter leaching is accounted for, especially in high rainfall areas or on shallow or light sand soils. On soils less prone to leaching, sampling in autumn or early spring is equally effective.
- Avoid sampling within two to three months of applying nitrogen fertiliser or organic manures, or within a month after sowing
- Areas of land known to differ in some important respects (eg soil type, previous cropping, application of manures or nitrogen fertiliser) should be sampled separately
- Do not sample unrepresentative areas, such as ex-manure heaps or headlands
- Avoid collecting and sending samples immediately before the weekend or a public holiday
- Samples must be taken to be representative of the area sampled. A minimum of 10–15 soil cores should be taken following a ‘W’ pattern across each field/area to be sampled
- In larger fields (10–20 ha), increase the number of cores to 15–20 unless the soil type is not uniform, in which case more than one sample should be taken. This can be done by dividing the field into smaller blocks from each of which 10–15 soil cores are taken
- Each position should be sampled at three depths in the spring: 0–30 cm, 30–60 cm and 60–90 cm. Sampling to 60 cm is adequate in the autumn
- Samples from each depth should be bulked to form a representative sample of that depth. If the bulk sample is too big, take a representative subsample to send to the laboratory; but do not stir the sample excessively
- Use appropriate packaging (normally available from the laboratory) and label samples clearly, providing as much information about the field and crop as possible
- Samples should be analysed within three days of sampling; samples must be kept cool (2–4°C) but not frozen during storage or transport

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.

Analysis in the laboratory
Samples should be analysed for nitrate-N and ammonium-N. Analytical results in mg N/kg should be converted to kg/ha, taking into account the dry bulk density of the soil, then summed to give a value for the whole soil profile. For the majority of mineral soils a ‘standard’ bulk density of 1.33 g/ml can be used and the calculation can be simplified to:

SMN (kg N/ha) = mg N/kg x 2 (for each 15 cm layer of soil)

SMN (kg N/ha) = mg N/kg x 4 (for each 30 cm layer of soil)

SMN (kg N/ha) = mg N/kg x 8 (for each 60 cm layer of soil)

Step 2. Make an adjustment for net mineralisable nitrogen
Nitrogen mineralised from soil organic matter and crop debris after soil sampling is a potentially important source of nitrogen for crop uptake. However, in mineral soils of low to average organic matter content (<4% in England and Wales or <10% in Scotland and Northern Ireland), the amount of net mineralisable nitrogen will be relatively small and for practical purposes, no further adjustment is needed when using the recommendations in this guide. The only exception being after cold winters, when an estimate of around 20 kg N/ha may be appropriate.

An adjustment may be needed where soil organic matter content is above average or where there has been a history of regular manure applications. In these situations, a commercial measurement of Additionally Available N (AAN) gives the most useful prediction of mineralisation.

As a guide, where measurement is not done, for every 1% organic matter above 4%, a topsoil may release an additional 10 kg N/ha. Therefore a soil that has a topsoil organic matter content of 10% may release around 60 kg/ha more potentially available nitrogen than an equivalent soil with 4% organic matter content.

However, some soils with an organic matter content of above 4% may release little nitrogen and local knowledge must be used when estimating mineralisable nitrogen. Therefore, it is not possible to specify a routine amount by which to adjust SNS based on soil organic matter level.

Add any adjustment for net mineralisable nitrogen to the total of SMN and nitrogen in the crop to give SNS.

Step 3. Identify the SNS Index

Table 5.8 Soil Nitrogen Supply (SNS) Index

SNS	SNS Index	SNS	SNS Index
Less than 60	0	121–160	4
61–80	1	161–240	5
81–100	2	More than 240	6
101–120	3		

Adopting changes to nitrogen use
Large SMN measurements can overestimate SNS and small SMN measurements can underestimate SNS. Uptake of soil N by crops is rarely less than 50 kg N/ha, so SNS estimates less than this should be treated as 50 kg N/ha and no less.

Unless high SNS results (>160 kg N/ha) are confidently expected, they should also be treated with caution. If SNS estimates indicate that large changes (either increases or decreases) in nitrogen fertiliser use are required, crops should be monitored closely through spring for signs of nitrogen deficiency or excess and the planned nitrogen strategy should be adjusted if necessary. It may be best for changes in nitrogen use to be introduced gradually over a few seasons so that the effect on crop performance can be monitored.

Nitrogen recommendations

Identifying the variety determinacy group

Nitrogen recommendations split potato varieties into one of four groups according to their degree of determinacy (a measure of the crop's capacity to maintain leaf production after the first appearance of flowers). AHDB research at NIAB-CUF has consistently shown that for a given length of growing season, indeterminate varieties (variety groups 3 and 4) require less nitrogen than determinate varieties (variety groups 1 and 2).

The variety groups shown in Table 5.9 include the ratings for those varieties included in previous editions of this guide and for other varieties based on NIAB trials and breeder/agent experience of foliage habit (determinacy is not the same as the NIAB foliage-maturity score).

In addition, factors such as total nutrient balance, water availability and seed management, will also influence foliage longevity. The list is provided as an indication of determinacy groups but you are advised to seek the latest information from your agronomist or seed supplier for any particular variety.

Table 5.9 Variety determinacy groups

Information provided by NIAB-CUF and AHDB

	Group			
	1	2	3	4
	Determinate varieties	Partially determinate varieties	Indeterminate varieties	
	Short haulm longevity	**Medium haulm longevity**	**Long haulm longevity**	**Very long haulm longevity**
Variety	Accord	Atlantic	Agria	Asterix
	Annabelle	Amanda	Ambo	Cara
	Anya	Arcade	Amora	Lady Balfour
	Colmo	Carlingford	Cabaret	Markies
	Estima	Charlotte	Caesar	Royal
	Innovator	Courage	Cosmos	Vales Everest
	Maris Bard	Dundrod	Cultra	Vales Sovereign
	Minerva	Endeavour	Daisy	
	Premiere	Harmony	Desiree	
	Rocket	Juliette	Eos	
	Vales Emerald	Kestrel	Fambo	
	Winston	Lady Claire	Fianna	
		Lady Rosetta	Hermes	
		Marfona	Kerr's Pink	
		Maris Peer	King Edward	
		Maritiema	Lady Christl	
		Melody	Lady Valora	
		Miranda	Maris Piper	
		Mozart	Morene	
		Nadine	Navan	
		Nicola	Pentland Dell	
		Orchestra	Pentland Squire	
		Orla	Picasso	
		Osprey	Record	
		Pentland Javelin	Rooster	
		Rembrandt	Russet Burbank	
		Romano	Sante	
		Saxon	Sassy	
		Shannon	Saturna	
		Shepody	Slaney	
		Vivaldi	Stemster	
		Wilja	Valor	
			Victoria	

Identifying growing season length

The length of the growing season is the number of days between 50% emergence and haulm death from either natural senescence or defoliation.

Table 5.10 Recommended N application rate for potatoes (kg/ha) per season length and variety determinacy group

Length of growing season	Variety determinacy group	SNS Index		
		0 and 1	2,3 and 4	5 and 6
		kg N/ha		
<60 days	1	100–140	70–110	40–60
	2	80–120	50–80	0–40
	3	60–100	40–70	0–40
	4[a]	N/A	N/A	N/A
60–90 days	1	160–210	130–160	90–120
	2	100–160	60–120	40–80
	3	60–140	40–100	0–60
	4	40–80	20–40	0–40
90–120 days	1	220–270	190–220	150–180
	2	150–220	110–160	80–120
	3	110–180	80–100	40–60
	4	80–140	40–60	0–40
>120 days	1	N/A	N/A	N/A
	2	190–250	150–180	120–150
	3	150–210	120–140	80–100
	4	100–180	60–80	20–40

One of the following four options should be selected in Table 5.10:

- Less than 60 days
- Between 60 and 90 days
- Between 90 and 120 days
- More than 120 days

Nitrogen increases yield by prolonging haulm life. It has no consistent effect on tuber numbers and, consequently, where it gives an increase in yield, the mean tuber size will be greater.

Similarly, if the intended season length is at the lower (or upper) end of the ranges given in Table 5.10, consider nitrogen applications at the lower (or upper) ends of the ranges given.

Fine tuning nitrogen recommendations

Planting date

The recommendations assume that loss of ground cover should begin close to the time of defoliation and harvest. If crops are planted later than intended but the defoliation date remains unaltered, this will reduce the length of the growing season, which will justify a reduction in the nitrogen application rate.

Cold soils

Crops planted into cold soils are slow to emerge and often have restricted canopy development. For determinate crops planted into cold soils and where emergence is delayed but the intended season length remains the same, consider increasing the amount of nitrogen applied by 15–20 kg N/ha.

Also, for all varieties at the upper end of season length, consider using the nitrogen recommendation from the upper end of the range.

N/A= Not Applicable

a. Consideration can be given to group 4 varieties grown for less than 60 days with the addition of 0 to 40 kg/ha for all soil Indices.

Timing of nitrogen application
If top dressing is planned for management reasons or to reduce the risk of leaching for crops grown on light sand and shallow soils, apply about two-thirds of the nitrogen recommendation in the seedbed and the remainder shortly after emergence. Aim to apply all the nitrogen by the time of tuber initiation (about three weeks after 50% plant emergence).

For other crops, apply all of the recommended nitrogen in the seedbed.

The effect of irrigation
Differences in the nitrogen requirement of irrigated or rain-fed crops are generally small, however, nitrogen rates could be reduced by 15–20 kg N/ha in rain-fed, determinate crops in order to achieve the same yield.

Further information
Irrigation and water use best practice guide for potatoes
potatoes.ahdb.org.uk/agronomy/water

Placement of nitrogen in bed systems
The same recommendations should be used for bed as well as ridge and furrow systems. Where fertiliser application methods reduce the amount of nitrogen falling into furrow-bottoms (eg placement or banded applications) reductions in the total amount of nitrogen applied could be considered.

Problems with previous potato crops
If similar crops grown in previous seasons have had problems with excessive canopy production and were defoliated at complete ground cover, consider reducing the nitrogen application rate.

Similarly, if there have been frequent problems with delayed skin-set, consider reducing the nitrogen rate towards the lower end of the recommended range.

Allowances should be made for the likely supply of nitrogen from incorporated cover crop residues. However, growers will need guidance on how to assess the amount of N taken up by the cover crop and what proportion is likely to be made available. Growers should refer to **Section 1: Principles of nutrient management and fertiliser use**, for further information.

Points to consider

Excess (or 'insurance') applications of nitrogen can:

- Decrease yield especially in shorter season indeterminate varieties
- Increase haulm size, prevent effective penetration of fungicidal sprays, delay natural senescence and create difficulties with desiccation
- Delay achievement of skin set
- Sometimes affect achievement of target dry matter concentrations.

Selecting the most appropriate fertiliser

For a single nutrient, the recommended amount can be applied using a straight fertiliser. Where more than one nutrient is required, a compound or blended fertiliser can be used. In this case, the compound or blend selected will depend on the ratio of the nutrients in the fertiliser; the amount applied should give as near the recommended amount of each nutrient as possible.

Often it will not be possible to match exactly the recommendations with available fertilisers. In most cases, the first priority is to get the amount of nitrogen correct because crops respond most to nitrogen. Slight variation in the rates of phosphate or potash will have less effect on yield, especially on Index 2 soils, and any discrepancy can be corrected in fertiliser applications to future crops. The approximate nutrient content of commonly used fertilisers is described on page 26.

Example 5.3

Field location:	Cambridge
Variety:	Maris Piper
Intended planting date:	15 April
Intended defoliation date:	15 September
Soil type:	Medium
Previous crop:	Winter barley
Use of organic manure:	No
Other information:	All N to be applied before tuber initiation; no previous problems with either premature canopy senescence or excess canopy production.

1. Calculate SNS. It is a low rainfall area, the soil type is medium and the previous crop is a cereal. Table 5.4 indicates that the SNS Index = 1.
2. Identify variety group using Table 5.9, Maris Piper is variety group 3.
3. Calculate length of growing season. The crop is to be planted mid-April (emerging mid-May) and defoliated in mid-September. Total 125 days (>120 days).
4. Use Table 5.10 to calculate N requirement. 180 kg N/ha (150–210 kg N/ha).
5. Assess factors to fine-tune recommendation (pages 22–23). The crop should have an effective root system and applied N should be efficiently used, but the growing season is long, 180 kg N/ha.
6. Include allowance for applied organic manures. No manures applied, 0 kg N/ha.
7. Manufactured-N fertiliser 180 kg N/ha.

Example 5.4

Field location:	Somerset
Variety:	Estima
Intended planting date:	30 April
Intended defoliation date:	15 August
Soil type:	Medium
Previous crop:	Oilseed rape
Use of organic manure:	Yes
Other information:	All N to be applied before tuber initiation 40t/ha cattle FYM applied in winter after four months storage, and ploughed in one week later.

1. Calculate SNS. It is a high rainfall area and the soil type is medium. Table 5.6 indicates that the SNS Index = 1.
2. Identify variety group using Table 5.9. Estima is variety group 1.
3. Calculate length of growing season. Planted end April (emerging end May) and defoliated in mid August = 80 days. Season length = 60 to 90 days.
4. Use Table 5.10, to calculate N Requirement 185 kg N/ha (160–210 kg N/ha).
5. Assess factors to fine-tune recommendations (pages 22–23). It was an unusually cold spring, crop slow to emerge with the potential for a restricted canopy therefore consider additional N, 200 kg N/ha.
6. Allowance for applied organic manures 40 t/ha of cattle FYM, 24 kg/ha of crop-available N.
7. Manufactured-N fertiliser 176 kg N/ha.

Conversion tables

Metric to imperial

1 tonne/ha	0.4 tons/acre
100 kg/ha	80 units/acre
1 kg/tonne	2 units/ton
10 cm	4 inches
1 m^3	220 gallons
1 m^3/ha	90 gallons/acre
1 kg/m^3	9 units/1000 gallons
1 kg	2 units

Note: a ‘unit’ is 1% of 1 hundredweight, or 1.12lbs.

Imperial to metric

1 ton/acre	2.5 tonnes/ha
100 units/acre	125 kg/ha
1 unit/ton	0.5 kg/tonne
1 inch	2.5 cm
1,000 gallons	4.5 m^3
1,000 gallons/acre	11 m^3/ha
1 unit/1,000 gallons	
1 unit	0.5 kg

Element to oxide

P to P_2O_5	Multiply by 2.291
K to K_2O	Multiply by 1.205
Mg to MgO	Multiply by 1.658
S to SO_3	Multiply by 2.5
Na to Na_2O	Multiply by 1.348
Na to salt	Multiply by 2.542

Oxide to element

P_2O_5 to P	Multiply by 0.436
K_2O to K	Multiply by 0.830
MgO to Mg	Multiply by 0.603
SO_3 to S	Multiply by 0.4
Na_2O to Na	Multiply by 0.742
Salt to Na	Multiply by 0.393

Further information

Conversion calculators

cereals.ahdb.org.uk/tools/agronomy-calculators

Fluid fertiliser

kg/tonne (w/w basis) to kg/m^3	Multiply by specific gravity (w/v basis)

Analysis of fertilisers and liming materials

The materials listed below are used individually and some are used as components of compound or multi-nutrient fertilisers. The chemical and physical forms of nutrient sources, as well as growing conditions, can influence the effectiveness of fertilisers. A FACTS Qualified Adviser can give advice on appropriate forms for different soil and crop conditions.

The reactivity, or fineness of grinding, of liming materials determines their speed of action. However, the amount of lime needed is determined mainly by its neutralising value.

Nitrogen fertilisers	**Typical % nutrient content**
Ammonium nitrate	33.5–34.5% N
Liquid nitrogen solutions	18–30% N (w/w)
Calcium ammonium nitrate (CAN)	26–28% N
Ammonium sulphate	21% N, 60% SO_3
Urea	46% N
Calcium nitrate	15.5% N, 26% CaO

Phosphate fertilisers	
Single superphosphate (SSP)	18–21% P_2O_5, typically 30% SO_3
Triple superphosphate (TSP)	45–46% P_2O_5
Di-ammonium phosphate (DAP)	18% N, 46% P_2O_5
Mono-ammonium phosphate (MAP)	12% N, 52% P_2O_5
Rock phosphate (eg Gafsa)	27–33% P_2O_5

Potash, magnesium and sodium fertilisers	
Muriate of potash (MOP)	60% K_2O
Sulphate of potash (SOP)	50% K_2O, 45% SO_3
Potassium nitrate	13% N, 45% K_2O
Kainit	11% K_2O, 5% MgO, 26% Na_2O, 10% SO_3
Sylvinite	Minimum 16% K_2O, typically 32% Na_2O
Kieserite (magnesium sulphate)	25% MgO, 50% SO_3
Calcined magnesite	Typically 80% MgO
Epsom salts (magnesium sulphate)	16% MgO, 33% SO_3
Agricultural salt	50% Na_2O

Sulphur fertilisers	
Ammonium sulphate	21% N, 60% SO_3
Epsom salts (magnesium sulphate)	16% MgO, 33% SO_3
Elemental sulphur	Typically 200–225% SO_3 (80–90% S)
Quarried gypsum (calcium sulphate)	40% SO_3
Polyhalite (e.g. Polysulphate)	Minimum 48% SO_3, 14% K_2O, 6% MgO, 17% CaO.

Liming materials	**Neutralising Value (NV)**
Ground chalk or limestone	50–55
Magnesian limestone	50–55, over 15% MgO
Hydrated lime	c.70
Burnt lime	c.80
Sugar beet lime	22–32 + typically 7–10 kg P_2O_5, 5–7 kg MgO, 3–5 kg SO_3/tonne

Glossary

Available (nutrient) Form of a nutrient that can be taken up by a crop immediately or within a short period so acting as an effective source of that nutrient for the crop.

Clay Finely divided inorganic crystalline particles in soils, less than 0.002 mm in diameter.

Content (nutrient) Commonly used instead of the more accurate 'concentration' to describe nutrients in fertiliser or organic manure. For example, 6kg N/t often is described as the nitrogen content of a manure.

Cover crop A crop sown primarily for the purpose of taking up nitrogen from the soil and which is not harvested. Also called green manure.

Crop available nitrogen The total nitrogen content of organic manure that is available for crop uptake in the growing season in which it is spread on land.

Crop nitrogen requirement The amount of crop available nitrogen that must be applied to achieve the economically optimum yield.

Deposition Transfer of nutrients from the atmosphere to soil or to plant surfaces. The nutrients, mainly nitrogen and sulphur, may be dissolved in rainwater (wet deposition) or transferred in particulate or gaseous forms (dry deposition).

Excess winter rainfall Rainfall between the time when the soil profile becomes fully wetted in the autumn (field capacity) and the end of drainage in the spring, less evapo-transpiration during this period (ie, water lost through the growing crop).

FACTS UK national certification scheme for advisers on crop nutrition and nutrient management. Membership renewable annually. A FACTS Qualified Adviser has a certificate and an identity card.

Fertiliser See Manufactured fertiliser.

Fluid fertiliser Pumpable fertiliser in which nutrients are dissolved in water (solutions) or held partly as very finely divided particles in suspension (suspensions).

Grassland Land on which the vegetation consists predominantly of grass species.

Green manure See Cover crop.

Incorporation A technique (discing, rotovating, ploughing or other methods of cultivation) that achieves some mixing between an organic manure and the soil. Helps to minimise loss of nitrogen to the air through volatilisation, and nutrient runoff to surface waters.

Leaching Process by which soluble materials such as nitrate or sulphate are removed from the soil by drainage water passing through it.

Ley Temporary grass, usually ploughed up one to five years (sometimes longer) after sowing.

Liquid fertiliser	See Fluid fertiliser.
Manufactured fertiliser	Any fertiliser that is manufactured by an industrial process. Includes conventional straight and NPK products (solid or fluid), organo-mineral fertilisers, rock phosphates, slags, ashed poultry manure and liming materials that contain nutrients.
Micronutrient	Boron, copper, iron, manganese, molybdenum and zinc that are needed in very small amounts by crops. Cobalt and selenium are taken up in small amounts by crops and are needed in human and livestock diets.
Mineral nitrogen	Nitrogen in ammonium (NH_4) and nitrate forms (NO_3).
Mineralisable nitrogen	Organic nitrogen that is readily converted to ammonium and nitrate by microbes in the soil, for example, during spring.
Mineralisation	Microbial breakdown of organic matter in the soil, releasing nutrients in crop-available, inorganic forms.
Neutralising value (NV)	Percentage calcium oxide (CaO) equivalent in a material. 100 kg of a material with a neutralising value of 52% will have the same neutralising value as 52 kg of pure CaO. NV is determined by a laboratory test.
Nitrate vulnerable zones (NVZs)	Areas designated by Defra as being at risk from agricultural nitrate pollution.
Offtake	Amount of a nutrient contained in the harvested crop (including straw, tops or haulm) and removed from the field. Usually applied to phosphate and potash.
Olsen P	Concentration of available P in soil determined by a standard method (developed by Olsen) involving extraction with sodium bicarbonate solution at pH 8.5. It is the main method used in England, Wales and Northern Ireland and the basis for the Soil Index for P.
Organic material	Any bulky organic nitrogen source of livestock, human or plant origin, including livestock manures, biosolids (sewage sludge), compost, digestate and waste-derived materials.
Organic soil	Soil containing between 10% and 20% organic matter (in this manual). Elsewhere, sometimes refers to soils with between 6% and 20% organic matter.
Peaty soil (peat)	Soil containing more than 20% organic matter.
Placement	Application of fertiliser to a zone of the soil usually close to the seed or tuber.
Sand	Soil mineral particles larger than 0.05 mm.
Silt	Soil mineral particles in the 0.002–0.05 mm diameter range.
SNS Index	Soil Nitrogen Supply expressed in seven bands or Indices, each associated with a range in kg N/ha.
Soil Index (P, K or Mg)	Concentration of available P, K or Mg, as determined by standard analytical methods, expressed in bands or Indices.
Soil Mineral Nitrogen (SMN)	Ammonium and nitrate nitrogen measured by the standard analytical method and expressed in kg N/ha.

Soil Nitrogen Supply (SNS)	The amount of nitrogen, (kg N/ha) in the soil that becomes available for uptake by the crop in the growing season, taking account of nitrogen losses.
Soil organic matter	Often referred to as humus. Composed of organic compounds ranging from undecomposed plant and animal tissues to fairly stable brown or black material with no trace of the anatomical structure of the material from which it was derived.
Soil texture	Description based on the proportions of sand, silt and clay in the soil.
Soil type	Description based on soil texture, depth, chalk content and organic matter content.
Target soil Index	Lowest soil P or K Index at which there is a high probability crop yield will not be limited by phosphorus or potassium supply. See Soil Index (P, K or Mg).

Notes

Notes

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AHDB
AGRICULTURE & HORTICULTURE DEVELOPMENT BOARD

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Greenhouse Gas Action Plan:
The industry-wide Greenhouse Gas Action Plan (GHGAP) for agriculture focuses on improving resource use efficiency in order to enhance business performance whilst reducing GHG emissions from farming.

greenhouse gas action plan

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Nutrient Management Guide (RB209)

Updated January 2019

Section 6 Vegetables and bulbs

Using the Nutrient Management Guide (RB209)

This latest revision of RB209 is based on research carried out since the previous edition was published in 2010. The revision includes updated recommendations, including those for additional crops and information on the nutrient content of additional organic materials.

RB209 was first published in 1973 and was the first comprehensive set of fertiliser recommendations from the Ministry of Agriculture, Fisheries and Food (MAFF). RB209 stands for Reference Book 209.

To improve the accessibility of the recommendations and information AHDB's Nutrient Management Guide (RB209) is published as seven separate sections that will be updated individually.

Further information
The Nutrient Management Guide (RB209) will be updated regularly.

Please email your contact details to AHDB so that we can send you updates when they are published - **comms@ahdb.org.uk**

RB209: Nutrient Management
Download the app for Apple or Android phones to access the current version of all sections of the guide. With quick and easy access to videos, information and recommendations from the guide, it is practical for use in the field.

Always consider your local conditions and consult a FACTS Qualified Adviser if necessary.

Section 1 Principles of nutrient management and fertiliser use
Section 2 Organic materials
Section 3 Grass and forage crops
Section 4 Arable crops
Cereals
Oilseeds
Sugar beet
Peas and beans
Biomass crops
Section 5 Potatoes
Section 6 Vegetables and bulbs
Section 7 Fruit, vines and hops

This section provides guidance for vegetables and bulbs, and should be read in conjunction with Sections 1 and 2. For each crop, recommendations for nitrogen (N), phosphate (P_2O_5) and potash (K_2O) are given in kilograms per hectare (kg/ha). Magnesium (MgO), sulphur (as SO_3) and sodium (Na_2O) recommendations, also in kg/ha, are given where these nutrients are needed.

Recommendations are given for the rate and timing of nutrient application. These are based on the nutrient requirements of the crop being grown, while making allowance for the nutrients supplied by the soil.

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AHDB publications portal
ahdb.org.uk/knowledge-library

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Download the app for Apple or Android phones to access all AHDB Crop Walker's Guides.

Summary of main changes from previous edition

1. Overall presentation
   a. Recommendations for vegetables and bulbs are now presented in **Section 6: Vegetables and bulbs** that incorporates key guidance on assessing soil nitrogen supply and relevant appendices.

3. New and revised recommendations
   a. Guidance on assessing SNS has been revised to include when Soil Mineral Nitrogen (SMN) sampling can be most useful and interpretation of SMN analysis for crops with different rooting depths.
   b. As the risk of sulphur deficiency is becoming more widespread, sulphur recommendations are included for all field vegetable and bulb crops, where deficiency has been recognised or is expected.
   c. Nitrogen recommendations for sweetcorn have been increased.
   d. Recommendations for baby leaf lettuce, wild rocket, coriander and mint have been added.
   e. Recommendations for top-dressing of nitrogen to leeks have been revised.
   f. Information on the interpretation of leaf nutrient analysis has been added for Brussels sprouts, cabbage, cauliflower, calabrese, onions, leeks, carrots and parsnips.

Checklist for decision making

Decisions for fertiliser use must be made separately for each field. Where more than one crop is grown in a field, crops must be considered individually.

1. Confirm the crop to be grown and the intended market. Identify any specific crop quality requirements for this market.

2. Identify the dominant soil type in the cropped area **(Section 1: Principles of nutrient management and fertiliser use)**.

3. Assess soil structure and take action to remove soil compaction and improve drainage, if necessary. Poor soil structure can restrict crop growth and results in poor nutrient use efficiency.

4. Carry out soil analysis for pH, P, K and Mg every 3–5 years **(Section 1: Principles of nutrient management and fertiliser use)**.
   Target values for vegetable rotations are:
   - Soil pH 6.5 or 7.0 for Brassicas if clubroot is a problem (pH 5.8 on peat soils)
   - Soil P Index 3
   - Soil K Index 2+
   - Soil Mg Index 2.

Further information

AHDB Field drainage guide
ahdb.org.uk/knowledge-library/field-drainage-guide

Soil management
ahdb.org.uk/greatsoils

Simply Sustainable Soils
www.leafuk.org/leaf/farmers/simplysustainablesoils

Think soils
ahdb.org.uk/knowledge-library/thinksoils

5. Identify the Soil Nitrogen Supply (SNS) Index of the field either by using the Field Assessment Method (page 7) or the Measurement Method (page 14).
6. Calculate the nutrients that will be supplied from organic materials that have been applied since harvest of the previous crop **(Section 2: Organic materials)**. Deduct these nutrients from the recommended rates given in the tables. Crop assurance schemes and protocols may restrict application of organic materials.
7. Decide on the strategy for phosphate and potash use. This will be either building up, maintaining or running down the soil Index levels **(Section 1: Principles of nutrient management and fertiliser use)**. Allow for any surplus or deficit of phosphate or potash applied to previous crops in the rotation.
8. Calculate the amount of phosphate and potash removed in the harvested crop (Table 6.8). This is the amount of these nutrients that must be replaced in order to maintain the soil at the target Index.
9. Decide if starter or banded fertiliser would be appropriate.
10. Using the tables, decide on the required rate of each nutrient. Decide on the optimum timings for fertiliser application; then find the best match for these applications using available fertilisers.
11. Check that the fertiliser spreader or sprayer is in good working order and has been recently calibrated **(Section 1: Principles of nutrient management and fertiliser use)**
12. Keep an accurate record of all fertilisers and organic materials applied.

Further information
AHDB UK Fertiliser Price Series
ahdb.org.uk/fertiliser-information

Crop nitrogen requirement

The nitrogen recommendations for vegetables are based on the following:

1. Size of the crop – the size, frame or weight of the crop needed to produce optimal economic yields.
2. Nitrogen uptake – the optimum nitrogen uptake associated with a crop of that size.
3. Supply of nitrogen – based on the nitrogen supply from the soil within rooting depth, including any nitrogen mineralised from organic matter during the growing season.

Recommendations in the tables in this section are given for typical crops produced in the main part of the growing season. Crops planted earlier may need extra nitrogen because the supply of nitrogen from mineralisation is less than later in the growing season.

Some vegetables, such as beetroot, can have wide ranging yield potential depending on the market. The baby beet crop will have a smaller nitrogen demand but is shallow rooted so will require similar amounts of nitrogen to higher yielding processing crops.

The recommendations assume effective pest and disease control and that crops are grown on soils in good structural condition. Where crops are grown with minimal control measures or the crop is intended for storage, smaller amounts of nitrogen fertiliser should be considered.

In all cases too much nitrogen fertiliser can give rise to poor quality crops, especially when growing conditions are difficult. Where large amounts of nitrogen residues from previous crops are expected, measurement of Soil Mineral Nitrogen (SMN) can be helpful.

Calculating Soil Nitrogen Supply

Fields vary widely in the amount of nitrogen available to a crop before any fertiliser or manure is applied. This variation must be taken into account to avoid inadequate or excessive applications of nitrogen. The Soil Nitrogen Supply (SNS) system assigns an Index of 0 to 6 to indicate the likely extent of this background nitrogen supply. The Index is used in the recommendation tables to indicate the amount of nitrogen, as manufactured fertiliser, manure or a combination of both, that would typically need to be applied to ensure optimum yield.

The SNS Index for each field can be determined either by the Field Assessment Method using records of soil type, previous cropping and excess winter rainfall or by the Measurement Method using measurements of Soil Mineral Nitrogen (SMN).

Further information

Soil Nitrogen Supply for field vegetables
horticulture.ahdb.org.uk/publication/0912-soil-nitrogen-supply-field-vegetables

The Field Assessment Method is suited for predicting SNS in the spring after autumn-harvested crops where SMN is expected to be low (<120 kg N/ha) but is less useful in complex horticultural rotations, particularly where there are repeated crops in the same season. Consider sampling SMN in fields with high or uncertain amounts of residues, such as intensively cropped Brassica rotations, or in fields where there is a past history of grass or regular inputs of organic manures.

Where there are repeated crops in the same season (ie multiple salad crops), the Measurement Method is recommended to determine the SNS Index of the second and third crops. The Measurement Method is also recommended where planting or sowing is late, as Soil Mineral Nitrogen may be higher than expected due to mineralisation.

Field Assessment Method

The Field Assessment Method does not take account of the nitrogen that will become available to a crop from any organic manures applied since harvest of the previous crop.

The available nitrogen from manures applied since harvest of the previous crop, or those that will be applied to the current crop should be calculated separately using the information in **Section 2: Organic materials** and deducted from the fertiliser nitrogen application rates shown in the recommendation tables.

There are five essential steps to follow to identify the appropriate SNS Index:

Step 1. Identify the soil type for the field

Step 2. Identify the previous crop

Step 3. Select the rainfall range for the field

Step 4. Identify the provisional SNS Index using the appropriate table

Step 5. Make any necessary adjustments to the SNS Index.

In detail, these steps are:

Step 1. Identify soil type for the field
Careful identification of the soil type in each field is very important. The whole soil profile should be assessed to at least rooting depth. Where the soil varies, and nitrogen is to be applied uniformly, select the soil type that occupies the largest part of the field.

The soil type can be identified using Figure 6.1, which categorises soils on their ability to supply and retain mineral nitrogen. The initial selection can then be checked using Table 6.1. Carefully assess the soil organic matter content when deciding if the soil is organic (10% to 20% organic matter for the purposes of this guide) or peaty (more than 20% organic matter). If necessary, seek professional advice on soil type assessments, remembering this will need to be done only once.

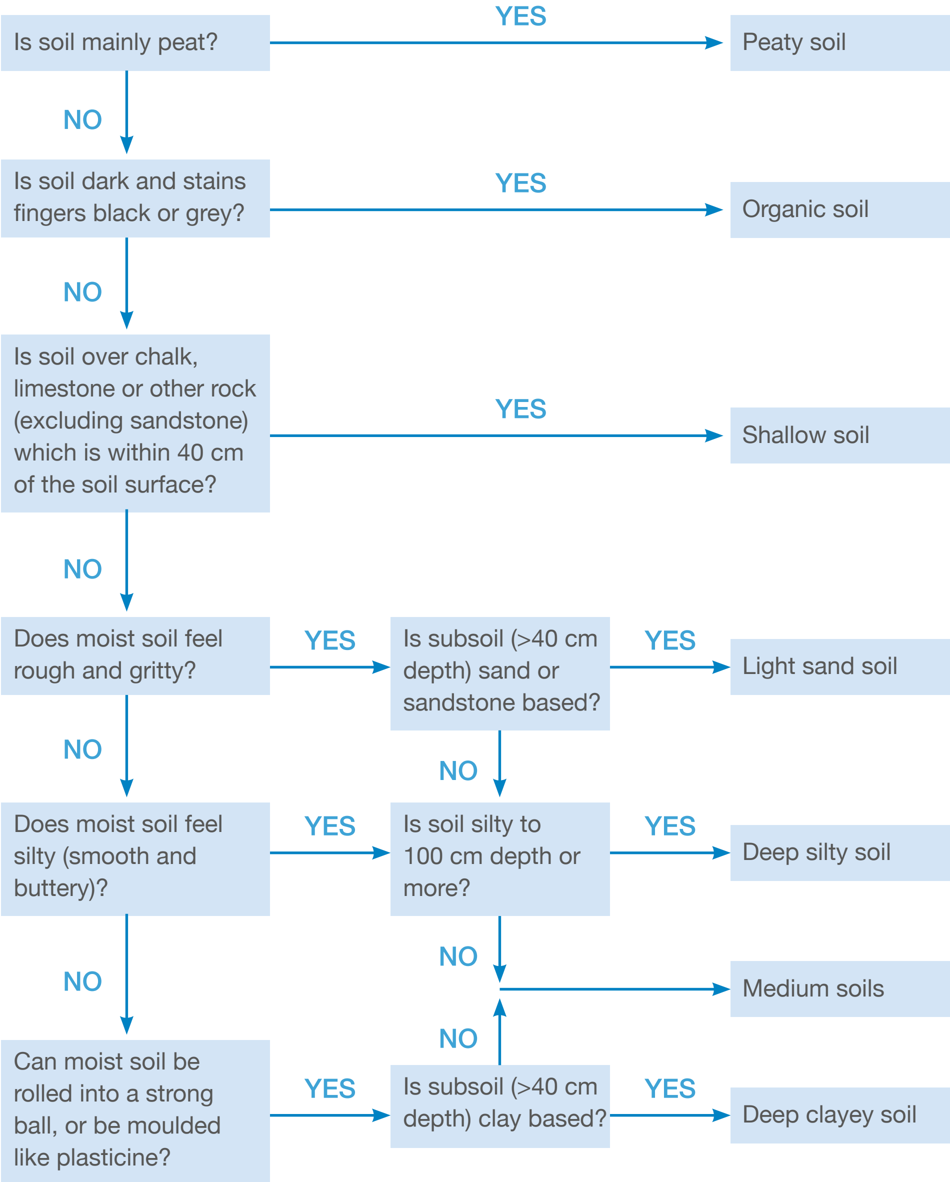

Figure 6.1 Soil category assessment

Table 6.1 Soil category assessment

Soil category	Description of soil types within category	Properties
Light sand soils	Soils which are sand, loamy sand or sandy loam to 40 cm depth and are sand or loamy sand between 40–80 cm, or over sandstone rock.	Soils in this category have poor water holding capacity and retain little nitrogen.
Shallow soils	Soils over impermeable subsoils and those where the parent rock (chalk, limestone or other rock) is within 40 cm of the soil surface. Sandy soils developed over sandstone rock should be regarded as light sand soils.	Soils in this category are less able to retain or supply nitrogen at depth.
Medium soils	Mostly medium-textured mineral soils that do not fall into any other soil category. This includes sandy loams over clay, deep loams, and silty or clayey topsoils that have sandy or loamy subsoils.	Soils in this category have moderate ability to retain nitrogen and allow average rooting depth.
Deep clayey soils	Soils with predominantly sandy clay loam, silty clay loam, clay loam, sandy clay, silty clay or clay topsoil overlying clay subsoil to more than 40 cm depth. Deep clayey soils normally need artificial field drainage.	Soils in this category are able to retain more nitrogen than lighter soils.
Deep silt soils	Soils of sandy silt loam, silt loam or silt clay loam textures to 100 cm depth or more. Silt soils formed on marine alluvium, warp soils (river alluvium) and brickearth soils are in this category. Silt clays of low fertility should be regarded as other mineral soils.	Soils in this category are able to retain more nitrogen than lighter soils and allow rooting to greater depth.
Organic soils	Soils that are predominantly mineral but with between 10–20% organic matter to depth. These can be distinguished by darker colouring that stains the fingers black or grey.	Soils in this category are able to retain more nitrogen than lighter soils and have higher nitrogen mineralisation potential.
Peat soils	Soils that contain more than 20% organic matter derived from sedge or similar peat material.	Soils in this category have very high nitrogen mineralisation potential.

Step 2. Identify previous crop
In vegetable rotations, the type and management of crop residues has a large influence on the SNS Index. There are three categories of vegetable crop residues – low, medium and high.

High residual nitrogen vegetables (‘high N vegetables’) are leafy, nitrogen-rich Brassica crops such as calabrese, Brussels sprouts and some crops of cauliflower, where significant amounts of crop debris are returned to the soil, especially in rotations where an earlier Brassica crop has been grown within the previous twelve months. To be available for crop uptake, this organic nitrogen must have had time to mineralise but the nitrate produced must not have been at risk to loss by leaching.

Medium residual nitrogen vegetables ('medium N vegetables') are crops such as lettuce, leeks and long-season Brassicas such as Dutch white cabbage where a moderate amount of crop debris is returned to the soil.

Low residual nitrogen vegetables ('low N vegetables') are crops such as carrots, onions, radish, swedes or turnips where the amount of crop residue is relatively small.

Step 3. Select low, moderate or high rainfall
The appropriate rainfall category should be identified, based on either annual rainfall or excess winter rainfall. Ideally an estimate of excess winter rainfall is required because this is closely related to drainage by which nitrate will be lost through leaching. Figure 6.2 shows long-term (1981–2010) average excess winter rainfall which, in an average year, can be used to select the rainfall category.

Figure 6.2 Excess winter rainfall (mm)

There are three SNS Index tables representing 'low rainfall' (annual rainfall less than 600 mm, or less than 150 mm excess winter rainfall), 'moderate rainfall' (between 600–700 mm annual rainfall, or 150–250 mm excess winter rainfall), and 'high rainfall' areas (over 700 mm annual rainfall, over 250 mm excess winter rainfall).

Step 4. Identify the provisional SNS Index
Tables 6.2 (low rainfall), 6.3 (moderate rainfall) and 6.4 (high rainfall) should be used where the field has not been in grass within the past three years. Take account of the footnotes to the tables.

For organic soils, the SNS is likely to vary widely, typically between Index 3 and 6. Assessments of SNS on these soils should take into account previous experience of crop response to nitrogen. For peats and peaty soils, the SNS is expected to be at Index 5 or 6, irrespective of previous cropping, manuring or excess winter rainfall. However, local experience should be used to judge the nitrogen supply from these soils, particularly when growing shallow-rooted vegetables.

Higher than typical Indices can also occur where there has been a history of grassland or frequent applications of organic materials. Soil analysis for Soil Mineral Nitrogen (SMN) is recommended in these situations.

If grass has been grown in the previous three years, also look at Table 6.5. Select the higher of the Index levels based on the last crop grown (Table 6.2, 6.3, 6.4) and that based on the grass history (Table 6.5).

Table 6.2 Soil Nitrogen Supply (SNS) Indices for low rainfall (500–600 mm annual rainfall, up to 150 mm excess winter rainfall) – based on the last crop grown

Previous crop	Soil type					
	Light sand soils or shallow soils over sandstone	Medium soils or shallow soils not over sandstone	Deep clayey soils	Deep silty soils	Organic soils	Peat soils
Beans	1	2	3	3	All crops in SNS Index 3, 4, 5 or 6. Consult a FACTS Qualified Adviser.	All crops in SNS Index 4, 5 or 6. Consult a FACTS Qualified Adviser.
Cereals	0	1	2	2		
Forage crops (cut)	0	1	2	2		
Oilseed rape	1	2	3	3		
Peas	1	2	3	3		
Potatoes	1	2	3	3		
Sugar beet	1	1	2	2		
Uncropped land	1	2	3	3		
Vegetables (low N)[b]	0	1	2	2		
Vegetables (medium N)[b]	1	3	3[a]	3[a]		
Vegetables (high N)[b]	2	4[a]	4[a]	4[a]		

a. Index may need to be increased by up to 1 where significantly larger amounts of leafy residues are incorporated (see Step 5). Where there is uncertainty, soil sampling for SMN may be appropriate.

b. Refer to Step 2.

Table 6.3 Soil Nitrogen Supply (SNS) Indices for moderate rainfall (600–700 mm annual rainfall, or 150–250 mm excess winter rainfall) – based on the last crop grown

Previous crop	Soil type					
	Light sand soils or shallow soils over sandstone	Medium soils or shallow soils not over sandstone	Deep clayey soils	Deep silty soils	Organic soils	Peat soils
Beans	1	2	2	3	All crops in SNS Index 3, 4, 5 or 6. Consult a FACTS Qualified Adviser.	All crops in SNS Index 4, 5 or 6. Consult a FACTS Qualified Adviser.
Cereals	0	1	1	1		
Forage crops (cut)	0	1	1	1		
Oilseed rape	0	2	2	2		
Peas	1	2	2	3		
Potatoes	0	2	2	2		
Sugar beet	0	1	1	1		
Uncropped land	1	2	2	2		
Vegetables (low N)[a]	0	1	1	1		
Vegetables (medium N)[a]	0	2	3	3		
Vegetables (high N)[a]	1	3	4	4		

a. Refer to Step 2.

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Table 6.4 Soil Nitrogen Supply (SNS) Indices for high rainfall (over 700 mm annual rainfall, or over 250 mm excess winter rainfall) – based on the last crop grown

Previous crop	Soil type					
	Light sand soils or shallow soils over sandstone	Medium soils or shallow soils not over sandstone	Deep clayey soils	Deep silty soils	Organic soils	Peat soils
Beans	0	1	2	2	All crops in SNS Index 3, 4, 5 or 6. Consult a FACTS Qualified Adviser.	All crops in SNS Index 4, 5 or 6. Consult a FACTS Qualified Adviser.
Cereals	0	1	1	1		
Forage crops (cut)	0	1	1	1		
Oilseed rape	0	1	1	2		
Peas	0	1	2	2		
Potatoes	0	1	1	2		
Sugar beet	0	1	1	1		
Uncropped land	0	1	1	2		
Vegetables (low N)[b]	0	1	1	1		
Vegetables (medium N)[b]	0	1	1	2		
Vegetables (high N)[b]	1[a]	2	2	3		

a. Index may need to be lowered by 1 where residues incorporated in the autumn and not followed immediately by an autumn-sown crop.

b. Refer to Step 2.

Table 6.5 Soil Nitrogen Supply (SNS) Indices following ploughing out of grass leys

	SNS Index		
Light sands or shallow soils over sandstone – all rainfall areas	**Year 1**	**Year 2**	**Year 3**
All leys with 2 or more cuts annually receiving little or no manure 1–2 year leys, low N 1–2 year leys, 1 or more cuts 3–5 year leys, low N, 1 or more cuts	0	0	0
1–2 year leys, high N, grazed 3–5 year leys, low N, grazed 3–5 year leys, high N, 1 cut then grazed	1	2	1
3–5 year leys, high N, grazed	3	2	1
Other medium soils and shallow soils – not over sandstone – all rainfall areas			
All leys with 2 or more cuts annually receiving little or no manure 1–2 year leys, low N 1–2 year leys, 1 or more cuts 3–5 year leys, low N, 1 or more cuts	1	1	1
1–2 year leys, high N, grazed 3–5 year leys, low N, grazed 3–5 year leys, high N, 1 cut then grazed	2	2	1
3–5 year leys, high N, grazed	3	3	2
Deep clayey soils and deep silty soils in low rainfall areas (500–600 mm annual rainfall)			
All leys with 2 or more cuts annually receiving little or no manure 1–2 year leys, low N 1–2 year leys, 1 or more cuts 3–5 year leys, low N, 1 or more cuts	2	2	2
1–2 year leys, high N, grazed 3–5 year leys, low N, grazed 3–5 year leys, high N, 1 cut then grazed	3	3	2
3–5 year leys, high N, grazed	5	4	3
Deep clayey soils and deep silty soils in moderate (600–700 mm annual rainfall) or high (over 700 mm annual rainfall) rainfall areas			
All leys with 2 or more cuts annually receiving little or no manure 1–2 year leys, low N 1–2 year leys, 1 or more cuts 3–5 year leys, low N, 1 or more cuts	1	1	1
1–2 year leys, high N, grazed 3–5 year leys, low N, grazed 3–5 year leys, high N, 1 cut then grazed	3	2	1
3–5 year leys, high N, grazed	4	3	2

The Indices shown in Table 6.5 assume that little or no organic manure has been applied. Where silage fields have received the organic manures produced by livestock that have eaten the silage and the manure has been applied in spring, such fields should be regarded as containing nitrogen residues equivalent to a previous grazing history.

'Low N' grassland means average annual inputs of less than 250 kg N/ha in fertiliser plus crop-available nitrogen in manure used in the last two years, or swards with little clover.

'High N' grassland means average annual applications of more than 250 kg N/ha in fertiliser plus crop-available nitrogen in manure used in the last two years, or clover-rich swards or lucerne.

Step 5. Make any necessary adjustment to the SNS Index for certain conditions

On medium, deep silty or deep clayey soils, nitrogen residues in predominantly vegetable rotations can persist for several years, especially in the drier parts of the country. This is likely to be especially evident following 'high or medium N vegetables'. The SNS tables make some allowance for this long persistency of nitrogen residues but the Index level may need to be adjusted upwards, particularly where winter rainfall is low, where the history of vegetable cropping is longer than one year, and in circumstances where larger than average amounts of crop residue or unused fertiliser are left behind (see footnote to Table 6.2). In rotations where vegetable crops are grown infrequently in essentially arable rotations, the Index level may need to be adjusted downwards.

Nitrogen-rich leafy residues from many Brassica crops are ploughed into the land at various times of the year. The nitrogen in these materials can become available for use by the next crop very rapidly in summer but more slowly in the winter when the soil temperature is lower.

In this situation where double-cropping is practised in the summer season, the SNS Index can be increased by 1 if following 'medium N vegetables' and by up to 2 following 'high N vegetables'. It is important that the growing conditions of the first crop are fully taken into account, especially where nitrogen may be leached from light sand soils in wet seasons or where excess irrigation has been applied. Care needs to be taken where residues are ploughed in after late December; the nitrogen may not become available for uptake by the next crop until after that crop requires the bulk of its nitrogen supply.

Manure history: Where regular applications of organic manures have been made to previous crops in the rotation, increase the Index value by one or two levels depending on manure type, application rate and frequency of application.

Fertiliser residues from previous crop: Nitrogen fertilisation and management of the previous vegetable crop can also have a large impact on SNS. The Index assessments assume that the previous crop grew normally and that it received the recommended rate of nitrogen applied as fertiliser and/or organic manures. Where nitrogen fertiliser recovery of the previous crop is expected to be higher or lower than normal, the SNS Index may need to be adjusted to account for greater or smaller than normal nitrogen residues remaining in the soil.

Where there is uncertainty about the amount of nitrogen in the soil, sampling for Soil Mineral Nitrogen (SMN) may be appropriate.

Measurement Method

Direct measurement of SMN provides a more reliable basis for nitrogen decisions in a number of situations. This method is particularly appropriate where the SNS is likely to be large (>120 kg/ha) or uncertain. This includes fields in intensively cropped Brassica rotations or fields receiving regular inputs of organic manures or where there is history of grass (but SMN sampling is not recommended during the first year after ploughing out grass).

Where there are repeated crops in the same season (ie multiple salad crops) the Measurement Method is recommended to determine the SNS Index of the second and third crops. The Measurement Method is also recommended where planting or sowing is late as Soil Mineral Nitrogen may be higher than expected due to mineralisation.

For field vegetable crops it is important to ensure that nitrogen is available to rooting depth, especially with young or shallow rooted crops, and SMN sampling is also useful to show the availability of SMN within the rooting depth of the crop.

SNS is likely to be low on light sand and shallow soils that have not received regular additions of organic manure or crop residues, particularly in moderate to high rainfall areas; under these circumstances, prediction of SNS using the Field Assessment Method is advised. The Field Assessment Method is also recommended on peaty soils or in the first season after ploughing out long leys or permanent pasture. In these situations, nitrogen released by mineralisation of soil organic matter is a large component of the SNS and the Field Assessment Method or local experience will be a better guide to SNS.

The SNS Index can be identified using the results of direct measurement of SMN (nitrate-N plus ammonium-N) to rooting depth. For field vegetables, SNS is equivalent to measured SMN; as SMN samples are taken before planting there is no need to make allowances for crop nitrogen content, and there is also no need to add an estimate of nitrogen mineralisation during the growing season as nitrogen from mineralisation is already taken into account in the recommendation tables.

The Measurement Method does not take account of the available nitrogen supplied from organic manures applied after the date of soil sampling for SMN. The available nitrogen from manures applied after sampling should be calculated separately using the information in **Section 2: Organic materials**, and deducted from the nitrogen rate shown in the appropriate recommendation table. The nitrogen contribution from manures applied before sampling for SMN will be largely taken account of in the measured value and should not be calculated separately.

When using the Measurement Method there are two steps to follow:

Step 1. Measure Soil Mineral Nitrogen (SMN)

Step 2. Identify Soil Nitrogen Supply (SNS) Index.

In detail these four steps are:

Step 1. Measure Soil Mineral Nitrogen (SMN)
Soil sampling must be done well to avoid misleading results and expensive mistakes.

Guidance on how to collect a SMN sample

- SMN samples should be collected as close to planting as possible, and not within two months of applying nitrogen fertiliser or organic materials
- Areas of land known to differ in some important respects (eg soil type, previous cropping, application of manures or nitrogen fertiliser) should be sampled separately
- Do not sample unrepresentative areas, such as ex-manure heaps or headlands
- Avoid collecting and sending samples immediately before the weekend or a public holiday
- Samples must be taken to be representative of the area sampled. A minimum of 10–15 soil cores should be taken following a 'W' pattern across each field/area to be sampled
- In larger fields (10–20 ha), increase the number of cores to 15–20 unless the soil type is not uniform, in which case more than one sample should be taken. This can be done by dividing the field into smaller blocks from each of which 10–15 soil cores are taken
- Take samples in 30 cm sections to 90 cm (0–30 cm, 30–60 cm and 60–90 cm) or to rooting depth. Table 6.6 includes typical rooting depths for field vegetable crops; sampling the soil to 90 cm depth is difficult to do manually
- Samples from each depth should be bulked to form a representative sample of that depth. If the bulk sample is too big, take a representative subsample to send to the laboratory; do not stir the sample excessively
- Use appropriate packaging (normally available from the laboratory) and label samples clearly, providing as much information about the field and crop as possible
- Samples should be analysed within three days of sampling. Samples must be kept cool (2–4˚C) but not frozen during storage or transport

It is important to avoid cross-contamination of samples from different depths. Using a mechanised one 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.

Analysis in the laboratory
Samples should be analysed for nitrate-N and ammonium-N. Analytical results in mg N/kg should be converted to kg/ha, taking into account the dry bulk density of the soil, then summed to give a value for the whole soil profile. For the majority of mineral soils a 'standard' bulk density of 1.33 g/ml can be used and the calculation can be simplified to:

SMN (kg N/ha) = mg N/kg x 2 (for each 15 cm layer of soil)

SMN (kg N/ha) = mg N/kg x 4 (for each 30 cm layer of soil)

SMN (kg N/ha) = mg N/kg x 8 (for each 60 cm layer of soil)

Step 2. Identify the SNS Index

Table 6.6 SNS Indices based on sampling (N kg/ha) to 30, 60 and 90 cm depth

SNS Index	0	1	2	3	4	5	6
	kg N/ha						
SMN kg/ha to 30 cm	<20	20–27	28–33	34–40	41–53	54–80	>80
SMN kg/ha to 60 cm	<40	41–53	54–67	68–80	81–107	108–160	>160
SMN kg/ha to 90 cm	<60	61–80	81–100	101–120	121–160	161–240	>240

Where SMN is measured to a different depth (ie 45 cm), the SNS Index should be determined by assuming a uniform concentration of mineral nitrogen in the soil.

Example 6.1

If SMN measured to 45 cm is 54 kg N/ha, then assuming a uniform concentration of nitrogen in the soil, SMN to 60 cm would be 54 kg N/ha x (60 cm/45 cm) = 72 kg N/ha to 60 cm, equivalent to SNS Index 3.

Example 6.2

Brussels sprouts are to be grown on a deep silt soil following winter wheat. Annual rainfall is 650 mm.

Select Table 6.3 (SNS Indices for moderate rainfall areas). On a deep silt soil following cereals, the SNS Index is 1. Refer to the Brussels sprouts recommendation in Table 6.12 which gives a recommendation of 300 kg N/ha.

Example 6.3

Sweetcorn is grown on a light sand soil following courgettes. Annual rainfall is 750 mm. 40 m^3/ha of crop-based digestate was applied in April prior to planting and incorporated into the soil within six hours.

Select Table 6.4 (SNS Indices for high rainfall areas). Courgettes are likely to leave a moderate amount of crop debris and can therefore be categorised as a medium N residue vegetable. On light sand soil after medium N vegetables, the SNS is Index 0. Refer to the sweetcorn recommendation in Table 6.18 which gives a recommendation of 220 kg N/ha.

Since the crop-based digestate was applied after harvest of the last crop, its nitrogen contribution must be calculated separately. This digestate application provides 50 kg N/ha of crop-available nitrogen that is equivalent to inorganic nitrogen fertiliser **(Section 2: Organic materials)**

Crop nitrogen recommendation of 220 kg N/ha minus 50 kg N/ha crop-available nitrogen supply from digestate = 170 kg N/ha as fertiliser should be applied.

Example 6.4

Two crops of baby leaf lettuce are grown on a deep silt soil after cereals. Annual rainfall is 550 mm.

The Field Assessment Method is used to determine SNS for the first crop sown in March. Select Table 6.2 (SNS Indices for low rainfall areas). On deep silt soils after cereals, the SNS Index is 2. Refer to the baby leaf lettuce recommendation in Table 6.20 which gives a recommendation of 40 kg/ha N.

The Measurement Method is used to determine SNS for the second crop. The soil is sampled to rooting depth (0–30 cm) in July prior to planting the second crop. The analysis report shows that the SMN (0–30 cm) is 62 kg N/ha, which is SNS Index 5. The nitrogen recommendation for baby leaf lettuce at Index 5 is zero. No fertiliser nitrogen should be applied to the second crop.

Phosphate, potash and magnesium recommendations

Many vegetables respond to fresh applications of phosphate and potash fertiliser, especially at low soil Indices and it is important that these needs are fully met. The target soil Indices for vegetable rotations are P Index 3 and K Index 2+.

The phosphate and potash recommendations given in the tables are sufficient to replace crop offtake at the target soil Index and therefore to maintain the target soil Index. The amount of phosphate and potash needed to supply maintenance needs will depend on crop yields and nutrient offtake. For a more precise calculation of maintenance requirements, use Table 6.8 which contains information on phosphate and potash in crop material. Where the soil is below the target phosphate or potash Index, the recommendations given in the tables are higher to allow the soil to 'build up' to the target Index over time.

There are instances where small amounts of nitrogen and phosphate fertiliser placed beneath seedlings or transplants can improve establishment, early growth and subsequent use of nutrients. The use of these techniques is encouraged but the amount in any starter dose applied should be deducted from the total application required.

Some vegetable crops are susceptible to magnesium deficiency and may show yield responses to magnesium fertiliser on soils at Mg Index 0 and 1. Magnesium recommendations for all field vegetable crops are for 150 kg MgO/ha at Index 0 and 100 kg MgO/ha at Index 1.

Points to consider

- **Recommendations assume good soil structure, water supply, and pest and disease control**
- **Recommendations are given as phosphate (P_2O_5), potash (K_2O) and magnesium oxide (MgO) . Conversion tables (metric-imperial, oxide-element) are given on page 43**
- **Don't forget to make allowance for the phosphate and potash applied in organic materials (Section 2: Organic materials)**
- **All recommendations are given for the mid-point of each Index. For some crops, there are different recommendations depending on whether the soil is in the lower half (2-) or upper half (2+) of K Index 2**
- **Where a soil analysis value (as given by the laboratory) is close to the range of an adjacent Index, the recommendation may be reduced or increased slightly taking account of the recommendation given for the adjacent Index. Small adjustments of less than 10 kg/ha are generally not justified**
- **Where more or less phosphate and potash are applied than suggested in the tables, adjustments can be made later in the rotation**

Taking soil samples for pH, phosphorus, potassium, magnesium and sodium

Soil sampling must be done well to avoid misleading results and expensive mistakes.

- The soil in each field should be sampled every 3–5 years
- Take top soil samples to 15 cm depth using a soil auger
- Collect samples at the same point in the rotation and well before growing a sensitive crop eg sugar beet
- Ideally, sample immediately after the harvest of the previous crop
- Do not sample within six months of a lime or fertiliser application (except nitrogen) and avoid sampling when the soil is very dry
- Do not take samples in headlands, or in the immediate vicinity of hedges, trees or other unusual features
- The soil sample must be representative of the area sampled. Areas of land known to differ in some important respects (eg soil type, previous cropping, applications of manure, fertiliser or lime) should be sampled separately. Small areas known to differ from the majority of a field should be excluded from the sample
- Ideally the sampled area should be no larger than four hectares
- Clean tools before starting and before sampling a new area
- Walk a ‘W’ pattern across the sampling area, stopping at least 25 times
- At each point collect a subsample (core) to 15 cm depth using a gouge corer or screw auger
- The subsamples should be bulked to form a representative sample and sent to the laboratory for analysis
- Use appropriate packaging (normally available from the laboratory) and label samples clearly, providing as much information about the field and crop as possible

On soils where acidity is known to occur, more frequent testing may be needed than the four year cycle used for phosphate, potash and magnesium. Since acidity can occur in patches, spot testing with a soil indicator test across the field is often useful. Soil indicator tests can also be useful on soils which contain fragments of free lime, since these can give a misleadingly high pH when analysed following grinding in the laboratory.

PAAG
Professional Agricultural Analysis Group

Most UK laboratories are members of the PAAG that offers farmers and advisers confidence in laboratory analysis:

- Proficiency tests (often called ring tests) carried out by Wageningen University, guaranteeing that analysis from any member can be trusted.
  www.wepal.nl
- List of UK laboratories
  www.nutrientmanagement.org/what-we-do/support-and-advice/find-a-laboratory
- Sampling guidelines
  www.nutrientmanagement.org/library/sampling

Classification of soil analysis results into Indices

The laboratory soil analysis results for P, K and Mg (in mg/kg dry soil) can be converted into soil Indices using Table 6.7.

Table 6.7 Classification of soil P, K and Mg analysis results into Indices

Index	Phosphorus (P)		Potassium (K)	Magnesium (Mg)
	Olsen P	Resin P	Ammonium nitrate extract	
	mg/litre			
0	0–9	0–19	0–60	0–25
1	10–15	20–30	61–120	26–50
2	16–25	31–49	121–180 (2-) 181–240 (2+)	51–100
3	26–45	50–85	241–400	101–175
4	46–70	86–132	401–600	176–250
5	71–100	>132	601–900	251–350
6	101–140		901–1,500	351–600
7	141–200		1,501–2,400	601–1,000
8	201–280		2,401–3,600	1,001–1,500
9	Over 280		Over 3,600	Over 1,500

Phosphate and potash in crop material

Table 6.8 Typical values of phosphate and potash in crop materials

		Phosphate (P_2O_5)[a]	Potash (K_2O)[a]
		kg/t of fresh material	
Swedes	Roots only	0.7	2.4
Broad beans		1.6	3.6
French beans		1.0	2.4
Beetroot		1.0	4.5
Cabbage		0.9	3.6
Carrots		0.7	3.0
Cauliflowers		1.4	4.8
Onions	Bulbs only	0.7	1.8
Sprouts	Buttons	2.6	6.3
	Stems	2.1	7.2
Bulbs		2.4	6.3
Coriander		0.8	5.5
Mint		1.0	3.9

a. The information on the potash and phosphate content of field vegetable crops is limited and the values above should be treated as guides only.

Sulphur recommendations

There is evidence that Brassica crops respond to sulphur. Where sulphur deficiency has been recognised or is expected in vegetable Brassicas, apply 50–75 kg/ha SO_3.

There are no UK trials on the sulphur response of other vegetable crops. However, atmospheric sulphur emissions have declined significantly and a yield response to sulphur in other crops is possible. Where sulphur deficiency has been recognised or is expected in other vegetable crops, apply 25 kg/ha SO_3. Sulphur should be applied as a sulphate-containing fertiliser at or soon after planting. Crops are most at risk of sulphur deficiency where they are grown on light sandy soils, soils with a low organic matter content, and in high rainfall areas.

Points to consider

- Recommendations are given as sulphur trioxide (SO_3). Conversion tables (metric-imperial, oxide-element) are given on page 43
- Don't forget to make allowance for the crop available sulphur applied in organic materials **(Section 2: Organic materials)**
- Further guidance on sulphur can be found in Section 1: Principles of nutrient management and fertiliser use

Micronutrient recommendations

Crop requirements for micronutrients are usually met by supply from the soil. However, they are essential to the plant and, if a deficiency is suspected, it is important to diagnose and treat accordingly.

Many soils contain sufficient supplies of micronutrients to achieve potential crop yields. However, the availability of these nutrients for plant uptake can be restricted by other factors, such as:

- pH
- Concentration of other nutrients in the soil
- Poor soil structure, which can impede root growth and nutrient uptake.

Visual symptoms of a deficiency of a specific micronutrient are often short-lived and can be confused with those caused by other growth problems, ie drought, frost or herbicide damage. Furthermore, by the time symptoms appear it can be too late to correct a deficiency.

Consequently, decisions about when to apply micronutrients should be informed by crop and soil risk factors before visual symptoms develop. Soil risk factors are described in Table 6.9 and crop-specific guidance is provided from page 24 onwards.

Visual diagnosis of a micronutrient deficiency should be confirmed by leaf and/or soil analysis.

Table 6.9 Micronutrient deficiencies

Micronutrient	Soil risk factors	Soil analysis	Leaf analysis	Treating deficiencies
Boron (B)	Sandy soils, soils high in organic matter or with a pH above 7 are at risk of boron deficiency. Over-liming can also increase the risk	Hot water extract: deficiency is more likely below 0.8 mg B/l	Deficiency is more likely below 20 mg B/kg	If possible, treat deficiencies with a soil-applied fertiliser prior to planting. Deficiencies can also be treated using a foliar spray at an early growth stage
Copper (Cu)	Soils most at risk of copper deficiency are organic and peat soils in the Fens and leached sandy soils, particularly on reclaimed heathland Deficiency can occur in shallow soils over chalk with high organic matter, sandy and peat soils	EDTA extract: deficiency is more likely below 1.0 mg Cu/l, unless soil organic matter is above 6%, when deficiency is more likely below 2.5 mg Cu/l	Deficiency is more likely below 5 mg Cu/kg Tissue analysis is less reliable than soil analysis for diagnosing deficiencies	If possible treat deficiencies with a soil applied fertiliser prior to planting. Deficiencies can also be treated using a foliar spray of copper oxychloride or cuprous oxide
Manganese (Mn)	Symptoms are often transient. Deficiency can be triggered by over-liming A high soil pH can increase the likelihood of deficiency and all soils above pH 7.5 are at risk. Sandy soils with a pH above 6.5 and organic, peaty or marshland soils above pH 6 are at a greater risk Under-consolidated seedbeds, low soil temperatures and low rainfall, can be at higher risk of deficiency	Not reliable	Deficiency is more likely below 20 mg Mn/kg	Deficiencies can be treated using a foliar spray of manganese sulphate
Molybdenum (Mo)	Soils with pH below 6.5 are at greater risk of molybdenum deficiency	Ammonium oxalate extract: deficiency is more likely below 0.1 mg Mo/l	Insufficient information to be able to recommend this type of analysis	Use a liming material to raise the soil pH of acidic soils to 6.5. When soil pH is more than 7 and when treatment is necessary, apply a soil or foliar treatment of sodium molybdate
Zinc (Zn)	Deficiency is very rare in the UK, however sandy soils with high pH and high phosphate status are more likely to have lower levels of zinc	EDTA extract: deficiency is more likely below 1.5 mg Zn/l	Deficiency is more likely below 15–20 mg Zn/kg	Deficiencies can be treated using soil- or foliar-applied fertilisers

Leaf analysis

Suspected nutrient deficiencies based on the appearance of symptoms can be confirmed by leaf nutrient analysis. In such cases, the leaf nutrient concentrations will usually be well below the normal range and there should, therefore, be little doubt about the diagnosis.

Leaf nutrient analysis can also be used to test for subclinical deficiencies or toxicities that may be already limiting growth but which are not yet resulting in visible symptoms.

Interpretation of laboratory results is possible by comparison with normal levels expected for the crop. Values presented in this guide are based on the best information available:

- Brussels sprouts and cabbage, page 26
- Cauliflower and calabrese, page 28
- Bulb onions, salad onions and leeks, page 35
- Carrots and parsnips, page 37

Guidance on how to collect leaf samples

It is essential to collect leaf samples that accurately reflect the nutritional status of the crop submitted for analysis. Therefore, to adequately represent any field or smaller area of crop, the following sampling procedure should be followed:

- Sample at the correct crop stage as described in Table 6.10 (unless the sample is for the confirmation of a deficiency)
- Samples should not be taken from crops that have recently been sprayed with nutrients or fungicides
- Avoid collecting and sending samples immediately before the weekend or a public holiday
- If areas of fields differ significantly, sample each separately
- Walk a ‘W’ pattern across the sampling area, stopping at least 25 times
- At each point collect the youngest fully expanded leaf from the plant. Aim to send the laboratory a minimum of 250 g of fresh material in total
- Ensure there is no soil contamination
- Do not sample diseased or dead plants, those damaged by insects and mechanical equipment or stressed by extremes of cold, heat or moisture
- Dry any wet leaves and immediately send to a laboratory between sheets of paper towel
- Use appropriate packaging (normally available from the laboratory) and label samples clearly, providing as much information about the field and crop as possible
- Do not post fresh material in an airtight container
- Send by overnight courier or deliver directly to the laboratory

Table 6.10 Correct growth stage to sample

Crop	Growth Stage
Cabbage	Mid-growth – as the plant is beginning to heart
Brussels sprouts	Mid-growth – as the plant initiates the first buttons
Cauliflower	First indication of buttoning
Broccoli	Mid-growth – when first spears are starting to form
Turnip and swede	First indication of root swelling
Onions and leeks	Four true leaves, taking complete leaves
Carrots and parsnips	Six true leaves or when the roots are 10+ mm in diameter

Selecting the most appropriate fertiliser

For a single nutrient, the recommended amount can be applied using a straight fertiliser. Where more than one nutrient is required, a compound or blended fertiliser can be used. In this case, the compound or blend selected will depend on the ratio of the nutrients in the fertiliser and the amount applied should give as near the recommended amount of each nutrient as possible.

Often it will not be possible to exactly match the recommendations with available fertilisers. In most cases, the first priority is to get the amount of nitrogen correct because crops respond most to nitrogen.

Slight variation in the rates of phosphate or potash will have less effect on yield, especially on Index 2 soils, and any discrepancy can be corrected in fertiliser applications to future crops.

Example 6.5

Bulb onions grown in an SNS Index 3, P Index 2 and K Index 2+ field requires 90 kg N/ha, 50 kg P_2O_5/ha and 35 kg K_2O/ha. A 20:10:10 NPK compound fertiliser is available.

Applied at 450 kg/ha, this fertiliser will supply 90 kg N/ha, 45 kg P_2O_5/ha and 45 kg K_2O/ha. The deficit of 5 kg P_2O_5/ha and surplus of 15 kg K_2O/ha are both small and can be ignored.

Metric to imperial conversion tables are given on page 43. If applying liquid fertilisers, manufacturers can supply tables which convert kg/ha of nutrient to litres/ha of product.

Techniques for applying fertiliser

Starter fertiliser

The injection of high phosphate liquid fertiliser 2–3 cm below the seed, or around the roots of transplants, can improve the growth and quality of crops, such as bulb and salad onions, lettuce and leeks. Starter fertiliser is particularly useful for crops grown in mixed rotations on soils at P Index 3 or below.

However, responses have been found at P Index 4. No more than 20 kg N/ha and 60 kg P_2O_5/ha should be applied as starter fertiliser, which may be deducted from the recommended total application. In most experiments, comparable yields with starter fertiliser have been obtained with much lower amounts of nitrogen than when fertiliser has been broadcast.

The use of injected liquid starter fertiliser in combination with a supplementary dressing of a conventional fertiliser can increase the overall efficiency of nutrient use, and typically reduces the total fertiliser requirement of field vegetables by up to half. Liquid starter fertilisers containing chloride may reduce plant establishment and should be avoided.

Band spreading/placement of fertiliser

For some wide-row crops, there can be benefits from applying early nitrogen in a band or injecting it around the plant, followed by a broadcast top-dressing. This may reduce the overall amount of nitrogen required. In experiments using the banding approach, yield and quality of cauliflowers was maintained and post-harvest soil nitrogen residues were less, reducing the risk of nitrate leaching.

Placement of phosphate fertiliser has been shown to increase yields compared to surface broadcast application on low P Index soils. Where fertiliser is placed, a small reduction in the recommended rate of phosphate could be considered.

Fertigation

Fertigation, applying nutrients in irrigation water, has been shown to produce Batavia lettuce with better quality compared with broadcasting fertiliser because nutrients and water can be more effectively targeted to crop need. Field experiments have demonstrated that by using fertigation, savings of up to 33% in nitrogen applications can be made. While the technique has the potential to reduce nitrogen use, some preliminary testing should be carried out to fine-tune the amounts and timing of nutrients, especially on crops other than lettuce.

Vegetables

Asparagus

Table 6.11 Nitrogen, phosphate, potash and magnesium for asparagus

	SNS, P, K or Mg Index					
	0	1	2	3	4	5 or higher
	kg/ha					
Establishment year						
Nitrogen (N) – all soil types	150	150	150	90	20	0
Phosphate (P_2O_5)	175	150	125	100	75	0
Potash (K_2O)	250	225	200	150	125	0
Subsequent years						
Nitrogen (N) – year 2, all soil types	See note below					
Nitrogen (N) – other years, all soil types	See note below					
Phosphate (P_2O_5)	75	75	50	50	25	0
Potash (K_2O)	100	50	50	50	0	0
Magnesium (MgO)	150	100	0	0	0	0

Establishment year – nitrogen
Apply one third of the total nitrogen dressing before sowing or planting, one third when the crop is fully established (around mid-June for crowns, mid-July for transplants) and one third at the end of August.

Subsequent years – nitrogen
In year two, apply 120 kg N/ha by end-February/early March.

In subsequent years, the amount and timing of nitrogen depends on the previous winter. If the crop is on light soil and over winter rainfall was high, apply 40–80 kg N/ha by the end of February with an additional 40–80 kg N/ha applied after harvest.

Following moderate or low amounts of winter rainfall, apply 40–80 kg N/ha just after harvest to provide nitrogen for fern growth.

Where SMN is measured, top up with fertiliser nitrogen to achieve a target of 120 kg N/ha of mineral nitrogen in the top 30 cm of soil during the cropping period.

Sodium
Asparagus can respond to applied sodium. Apply up to 500 kg Na_2O/ha per year at the end of June but not in the establishment year.

Sulphur
Where sulphur deficiency has been recognised or is expected, apply 25 kg SO_3/ha as a sulphate-containing fertiliser at or soon after planting in the establishment year, and in early spring for established crops.

Points to consider

- Make allowance for nutrients applied in organic materials **(Section 2: Organic materials)**
- Ensure the phosphate and potash offtake is balanced by application at P Index 3 and K Index 2+; check that the soil is maintained at these target Indices by soil sampling every 3–5 years

Further information

Asparagus nutrient management
horticulture.ahdb.org.uk/publication/1413-asparagus-nutrient-management

Asparagus Crop Walkers' Guide
ahdb.org.uk/knowledge-library/asparagus-crop-walkers-guide

Brussels sprouts and cabbage

Table 6.12 Nitrogen, phosphate, potash and magnesium for Brussels sprouts and cabbage

	SNS, P, K or Mg Index						
	0	1	2	3	4	5	6
	kg/ha						
Nitrogen (N)[b] – all soil types							
Brussels sprouts	330	300	270	230	180	80	0[a]
Storage cabbage	340	310	280	240	190	90	0[a]
Head cabbage pre-31 December	325	290	260	220	170	70	0[a]
Head cabbage post-31 December	240	210	180	140	90	0[a]	0[a]
Collards pre-31 December	210	190	180	160	140	90	0[a]
Collards post-31 December	310	290	270	240	210	140	90
Phosphate (P_2O_5)[c], all crops	200	150	100	50	0	0	0
Potash (K_2O)[c], all crops	300	250	200 (2-) 150 (2+)	60	0	0	0
Magnesium (MgO), all crops	150	100	0	0	0	0	0

a. A small amount of nitrogen may be needed if soil nitrogen levels are low in the top 30 cm of soil.

b. On light soils where leaching may occur or when crops are established by direct seeding, no more than 100 kg N/ha should be applied prior to seeding or transplanting. On retentive soils in drier parts of the country where leaching risk is low and spring planted Brassicas are established from modules, more nitrogen can be applied prior to planting. The remainder of the nitrogen requirement should be applied after establishment.

c. Phosphate and potash requirements are for average crops and it is important to calculate specific phosphate and potash removals based on yields, especially for the larger yielding cabbage crops. As a general rule for cabbage crops, increase potash application by 40 kg/ha K_2O for every 10 t/ha fresh weight yield over 40 t/ha.

Storage cabbage – nitrogen
For storage cabbage grown on fertile soils the recommendations for nitrogen may need to be decreased in order to reduce the risks of storage losses.

Post-31 December crops – nitrogen
Apply no more than 100 kg N/ha at sowing or transplanting, less if there is risk of frost damage. The remaining nitrogen should be applied to reflect crop growth. Further top dressings of nitrogen will depend on the harvest date and expected yield, some nitrogen will be required to support growth during the winter, particularly for crops harvested in late winter.

For crops harvested in late spring, more of the top-dressing should be left until the beginning of regrowth in spring.

Brussel sprouts and cabbage – sulphur
Where sulphur deficiency has been recognised or is expected, apply 50–75 kg SO_3/ha as a sulphate-containing fertiliser at or soon after planting.

Brassica crops – boron
Brassica crops are sensitive to boron deficiency and exhibit numerous very characteristic symptoms, but not all occur on all species. For all crops the first symptoms may be rolling and curling of the leaves that become brittle and are mottled round the margins. Cracked and corky stems, petioles and midribs can occur on all Brassica species.

Brussels sprouts – boron
Interveinal chlorosis is worst on old leaves. Hollows are also found in the stems. Brussels sprout plants will produce few sprouts if boron deficiency sets in before they are formed. If deficiency occurs later, the sprouts will be small and loose.

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Cabbage – boron

Small blister-like swellings appear on the stem and lower surface of the leaf stalks. The stem is frequently hollow and discoloured internally with brown watery areas in the pith. Premature fall of older leaves may occur and heads are often yellow and small when boron deficiency is severe.

Toxicity

Boron toxicity is occasionally found as a result of over application. Symptoms are marginal chlorotic bands on old leaves. Leaf analysis can be used to confirm toxicity of boron.

Leaf analysis

Suspected nutrient deficiencies based on the appearance of symptoms can be confirmed by leaf nutrient analysis. In such cases, the leaf nutrient concentrations will usually be well below the 'critical level' and there should, therefore, be little doubt about the diagnosis.

Leaf nutrient analysis can also be used to test for subclinical deficiencies or toxicities that may be already limiting growth but which are not yet resulting in visible symptoms. In this case, sample Brussels sprouts mid-growth as the plant initiates the first buttons and cabbage mid-growth as the plant is beginning to heart.

Interpretation of laboratory results is possible by comparison with normal levels expected for the crop. Values in Table 6.13 are based on the best information available.

Table 6.13 Interpretation of leaf nutrient analysis for Brussels sprouts and cabbage

		Normal range	
Element	Unit	Brussels spouts	Cabbage
Nitrogen (N)	%	3.0–5.0	3.0–5.0
Phosphorus (P)	%	0.26–0.6	0.3–0.5
Potassium (K)	%	2.5–4.0	3.0–4.5
Magnesium (Mg)	%	0.2–0.7	0.2–0.7
Sulphur (S)	%	0.3–0.8	0.3–0.8
Calcium (Ca)	%	0.5–2.0	1.5–3.0
Manganese (Mn)	mg/kg	25–200	25–200
Boron (B)	mg/kg	25–60	25–60
Copper (Cu)	mg/kg	5–20	5–20
Zinc (Zn)	mg/kg	20–200	20–200
Iron (Fe)[a]	mg/kg	50–200	50–200

a. Of limited use as even the smallest amount of soil contamination invalidates the analysis and the deficiency may not be related to the actual content.

Points to consider

- Make allowance for nutrients applied in organic materials **(Section 2: Organic materials)**
- Ensure the phosphate and potash offtake is balanced by application at P Index 3 and K Index 2+ and check that the soil is maintained at these target Indices by soil sampling every 3–5 years

Further information

Nutrient deficiencies of Brassicas poster
horticulture.ahdb.org.uk/publication/nutrient-deficiencies-brassicas

Interpretation of leaf nutrient analysis results
horticulture.ahdb.org.uk/publication/2105-interpretation-brassica-leaf-nutrient-analysis-results

Cauliflowers and calabrese

Table 6.14 Nitrogen, phosphate, potash and magnesium for cauliflowers and calabrese

	SNS, P, K or Mg Index						
	0	1	2	3	4	5	6
	kg/ha						
Nitrogen (N) – all soil types							
Cauliflower, summer/ autumn[a]	290	260	235	210	170	80	0[b]
Cauliflower, winter hardy/roscoff[a]							
– seedbed	100	100	100	100	60	0[a]	0[b]
– top-dressing	190	160	135	110	100	80	0[b]
Calabrese[a]	235	200	165	135	80	0[b]	0[b]
Phosphate (P_2O_5), all crops	200	150	100	50	0	0	0
Potash (K_2O), all crops	275	225	175 (2-) 125 (2+)	35	0	0	0
Magnesium (MgO), all crops	150	100	0	0	0	0	0

a. The recommendations assume overall application. Band spreading of nitrogen may be beneficial (Techniques for Applying Fertiliser, page 23).

b. A small amount of nitrogen may be needed if soil nitrogen levels are low in the top 30 cm of soil.

Cauliflower and calabrese – nitrogen
Where there is a risk of poor establishment or leaching, apply no more than 100 kg N/ha at sowing or transplanting. The remainder should be applied when the crop is established but before the surface soil dries out.

There is a benefit from banding or placing the nitrogen to be applied at sowing or transplanting. If nitrogen is only applied to half the width of the row, reduce the seedbed application by 33%.

The SNS Index for second crops grown in the same season is likely to be between Index 4 and 6 depending on the growing conditions of the first crop. The Measurement Method can be used to determine the SNS Index (page 14).

Cauliflower, winter hardy/roscoff – nitrogen
Apply no more than 100 kg N/ha at sowing or transplanting, less if there is risk of frost damage. The amount of nitrogen applied subsequently will depend on crop growth, for example up to 60 kg N/ha per month in the south west and 20 kg N/ha in the north.

Where seedbed SNS exceeds Index 4 and crops are likely to be harvested in April or later, the topdressing should be left until the start of growth in the spring. The SNS may need to be recalculated to take account of any over winter losses of nitrogen, uptake of nitrogen by the crop as well as mineral nitrogen to 90 cm.

Cauliflower and calabrese – sulphur
Where sulphur deficiency has been recognised or is expected, apply 50–75 kg SO_3/ha as a sulphate-containing fertiliser at or soon after planting.

Brassica crops – boron
Brassica crops are sensitive to boron deficiency and exhibit numerous, very characteristic symptoms, but not all occur on all species. For all crops, the first symptoms may be rolling and curling of the leaves that become brittle and are mottled round the margins. Cracked and corky stems, petioles and midribs can occur on all Brassica species.

Cauliflower – boron
Cotyledons may grow very large with subsequent very thick, brittle, finger-like new leaves. The stem is frequently hollow and discoloured internally near the curd. If boron deficiency appears before curd formation, the stem stops growing, causing a flat-topped plant with many side shoots and the curd fails to develop. In contrast, if the curd is already present, the curd turns brown giving a discoloured product unsuitable for marketing.

Calabrese – boron

First symptoms of boron deficiency are similar to those for cabbage but chlorosis is marginal, with brilliant red and yellow colours. Premature fall of older leaves may occur.

Toxicity

Boron toxicity is occasionally found as a result of over application. Symptoms are marginal chlorotic bands on old leaves. Leaf analysis can be used to confirm toxicity of boron.

Leaf nutrient analysis

Suspected nutrient deficiencies based on the appearance of symptoms can be confirmed by leaf nutrient analysis. In such cases, the leaf nutrient concentrations will usually be well below the 'critical level' and there should, therefore, be little doubt about the diagnosis.

Leaf nutrient analysis can also be used to test for subclinical deficiencies or toxicities that may be already limiting growth but which are not yet resulting in visible symptoms.

Interpretation of laboratory results is possible by comparison with normal levels expected for the crop. Values in Table 6.15 are based on the best information available.

Table 6.15 Interpretation of leaf nutrient analysis for cauliflower and calabrese

		Normal range	
Element	Unit	Cauliflower	Calabrese
Nitrogen (N)	%	3.0–5.0	3.5–5.5
Phosphorus (P)	%	0.3–0.7	0.3–0.7
Potassium (K)	%	3.0–4.0	2.0–4.0
Magnesium (Mg)	%	0.2–0.7	0.2–0.7
Sulphur (S)	%	0.3–0.8	0.3–0.8
Calcium (Ca)	%	1.0–2.0	1.2–2.5
Manganese (Mn)	mg/kg	25–200	25–200
Boron (B)	mg/kg	25–60	25–60
Copper (Cu)	mg/kg	5–20	5–20
Zinc (Zn)	mg/kg	20–200	20–200
Iron (Fe)[a]	mg/kg	50–200	50–200

a. Of limited use as even the smallest amount of soil contamination invalidates the analysis and the deficiency may not be related to the actual content.

Points to consider

- Make allowance for nutrients applied in organic materials **(Section 2: Organic materials)**
- Ensure the phosphate and potash offtake is balanced by application at P Index 3 and K Index 2+; check that the soil is maintained at these target Indices by soil sampling every 3 – 5 years

Further information

Interpretation of leaf nutrient analysis results (cabbage, Brussels sprouts, cauliflower, broccoli, turnip and swede)
horticulture.ahdb.org.uk/publication/2105-interpretation-brassica-leaf-nutrient-analysis-results

Self-blanching celery

Table 6.16 Nitrogen, phosphate, potash and magnesium for self-blanching celery

	SNS, P, K or Mg Index						
	0	1	2	3	4	5	6
	kg/ha						
Nitrogen (N) – all soil types							
– seedbed	75	75	75	75	0[a]	0[a]	0[a]
– top-dressing[b]	see note below table						
Phosphate (P_2O_5)	250	200	150	100	50	0	0
Potash (K_2O)	450	400	350 (2-) 300 (2+)	210	50	0	0
Magnesium (MgO)	150	100	0	0	0	0	0

a. A small amount of nitrogen may be needed if soil nitrogen levels are low in the top 30 cm of soil.

b. A top dressing of 75–150 kg N/ha will be required 4–6 weeks after planting.

Sodium

Celery is responsive to sodium and it is recommended for celery grown on all soils except peaty and some Fen silt soils, which generally contain adequate amounts of sodium. Sodium can be applied as agricultural salt at 400 kg/ha (200 kg Na_2O/ha). The application will not have any adverse effect on soil structure, even on soils of low structural stability.

Sulphur

Where sulphur deficiency has been recognised or is expected, apply 25 kg SO_3/ha as a sulphate-containing fertiliser at or soon after planting.

Points to consider

- Make allowance for nutrients applied in organic materials **(Section 2: Organic materials)**
- Ensure the phosphate and potash offtake is balanced by application at P Index 3 and K Index 2+; check that the soil is maintained at these target Indices by soil sampling every 3–5 years

Further information

Outdoor Salads: Lettuce & Celery Crop Walkers' Guide
horticulture.ahdb.org.uk/publication/outdoor-salads-lettuce-celery-crop-walkers-guide-0

Peas (market pick) and beans

Table 6.17 Nitrogen, phosphate, potash and magnesium for peas (market pick) and beans

	SNS, P, K or Mg Index						
	0	1	2	3	4	5	6
	kg/ha						
Peas for fresh market							
Nitrogen (N) – all soil types	0	0	0	0	0	0	0
Phosphate (P_2O_5)	185	135	85	35	0	0	0
Potash (K_2O)	190	140	90 (2-) 40 (2+)	0	0	0	0
Magnesium (MgO)	100	50	0	0	0	0	0
Beans							
Nitrogen (N) – all soil types							
Broad beans	0	0	0	0	0	0	0
Dwarf and runner beans – seedbed	180	150	120	80	30	0[a]	0[a]
Runner beans – top-dressing[a]	see note below						
Phosphate (P_2O_5), all crops	200	150	100	50	0	0	0
Potash (K_2O), all crops	200	150	100 (2-) 50 (2+)	0	0	0	0
Magnesium (MgO), all crops	100	50	0	0	0	0	0

a. A small amount of nitrogen may be needed if soil nitrogen levels are low in the top 30 cm of soil.

Dwarf/runner beans – nitrogen

Apply no more than 100 kg N/ha at sowing or planting. The remainder should be applied when the crop is fully established.

Runner beans can require a further top-dressing of up to 75 kg N/ha at early picking stage.

Peas and beans – sulphur

Where sulphur deficiency has been recognised or is expected, apply 25 kg SO_3/ha as a sulphate-containing fertiliser at or soon after planting.

Points to consider

- Make allowance for nutrients applied in organic materials **(Section 2: Organic materials)**
- Ensure the phosphate and potash offtake is balanced by application at P Index 3 and K Index 2+; check that the soil is maintained at these target Indices by soil sampling every 3–5 years

Further information

Pea and Bean Crop Walkers' Guide
horticulture.ahdb.org.uk/publication/pea-bean-crop-walkers-guide-0

Agronomy and variety information
www.pgro.org

Radish, sweetcorn and courgettes

Table 6.18 Nitrogen, phosphate, potash and magnesium for radish, sweetcorn and courgettes

	SNS, P, K or Mg Index						
	0	1	2	3	4	5	6
	kg/ha						
Nitrogen(N) – all soil types							
Radish	100	90	80	65	50	20	0[a]
Sweetcorn	220	175	125	75	0[a]	0[a]	0[a]
Courgettes							
– seedbed	100	100	100	40	0[a]	0[a]	0[a]
– top-dressing[a]	Up to 75 kg N/ha may be required						
Phosphate (P_2O_5), all crops	175	125	75	25	0	0	0
Potash (K_2O), all crops	250	200	150 (2-) 100 (2+)	0	0	0	0
Magnesium (MgO), all crops	150	100	0	0	0	0	0

a. A small amount of nitrogen may be needed if soil nitrogen levels are low in the top 30 cm of soil, see Techniques for applying fertiliser on page 23.

Radish and sweetcorn – nitrogen

Apply no more than 100 kg N/ha in the seedbed. Apply the remainder as a top-dressing when the crop is fully established.

Radish and sweetcorn – sulphur

Where sulphur deficiency has been recognised or is expected, apply 25 kg SO_3/ha as a sulphate-containing fertiliser at or soon after planting.

Points to consider

- Make allowance for nutrients applied in organic materials **(Section 2: Organic materials)**
- Ensure the phosphate and potash offtake is balanced by application at P Index 3 and K Index 2+; check that the soil is maintained at these target Indices by soil sampling every 3–5 years

Further information

Nitrogen and phosphorus recommendations for optimising yield and quality of sweetcorn
horticulture.ahdb.org.uk/publication/1416-nitrogen-and-phosphorus-recommendations-optimising-yield-and-quality-sweetcorn

Outdoor Cucurbits: Nutrient Deficiencies & Physiological Disorders poster
horticulture.ahdb.org.uk/publication/outdoor-cucurbits-nutrient-deficiencies-and-physiological-disorders

Lettuce and leafy salads

Table 6.19 Nitrogen, phosphate, potash and magnesium for lettuce and leafy salads

	SNS, P, K or Mg Index						
	0	1	2	3	4	5	6
	kg/ha						
Nitrogen (N) – all soil types[a]							
Lettuce – whole head	200	180	160	150	125	75	30
Lettuce – baby leaf	60	50	40	30	10	0	0
Wild rocket	125	115	100	90	75	40	0
Phosphate (P_2O_5)[b]	250	200	150	100	c	c	0
Potash (K_2O)	250	200	150 (2-) 100 (2+)	0	0	0	0
Magnesium (MgO)	150	100	0	0	0	0	0

a. Recommendations may need to be reduced if there is a risk of exceeding tissue nitrate concentrations eg for late-season crops grown under dull conditions.

b. The recommendations assume overall application. A starter fertiliser containing nitrogen and phosphate may be beneficial.

c. At P Index 4 and 5, up to 60 kg P_2O_5/ha as starter fertiliser may be beneficial (Techniques for applying fertiliser, page 23).

Lettuce, whole head – nitrogen

These recommendations are provided for the larger Crisp and Escarole lettuces, while other lower yielding types such as Lollo Rossa, Little Gem, Cos, Endives and Butterhead may need less nitrogen. Each situation will need to be judged carefully, as rooting depth of the lower yielding varieties is likely to be 30 cm, compared with 60 cm for the larger crop, so less of the soil nitrogen will be available.

Apply no more than 100 kg N/ha at sowing or planting on light sandy soils. The remainder should be applied when the crop is fully established. When crop covers are used, all the nitrogen will need to be applied as a base dressing, but care should be taken to avoid poor establishment in dry soils.

Lettuce, baby leaf – nitrogen

Early season crops grown in cold or adverse conditions may require up to an additional 60 kg N/ha to maximise yields. If applying additional nitrogen, tissue nitrate concentration analysis is recommended.

Wild rocket – nitrogen

Early season crops grown in cold or adverse conditions may require up to an additional 25 kg N/ha to maximise yields. If applying additional nitrogen, tissue nitrate concentration analysis is recommended.

All leafy salads – nitrogen and phosphate

Starter fertilisers containing nitrogen and phosphate can provide equivalent crop yields, with lower amounts of nitrogen than from broadcast fertiliser.

Fertigation can produce better quality crops as nutrients and water can be more effectively targeted to crop need. Experiments have demonstrated savings of up to 33% in nitrogen applications compared with broadcast fertilisers.

Where more than one crop is grown in the same year, there should be sufficient residues of phosphate, potash and magnesium for a second crop. The SNS Index for second crops grown in the same season will be between Index 3 and 5, depending on the growing conditions of the first crop. Measurement of Soil Mineral Nitrogen is recommended to determine the SNS Index of the second and third crops grown within the same season (page 15).

Minimising nitrate levels

EU legislation stipulates nitrate limits for leafy salads so growers need to ensure nitrogen applications do not cause crops to exceed these limits. This is particularly important for late-season crops of leafy salad where even small amounts of fertiliser may lead to high tissue nitrate concentration.

All leafy salads – sulphur

Where sulphur deficiency has been recognised or is expected, apply 25 kg SO_3/ha as a sulphate-containing fertiliser at or soon after planting.

Points to consider

- Make allowance for nutrients applied in organic materials **(Section 2: Organic materials)**
- Ensure the phosphate and potash offtake is balanced by application at P Index 3 and K Index 2+ and check that the soil is maintained at these target Indices by soil sampling every 3–5 years

Further information

Nitrogen recommendations for optimising yield and quality of baby leaf lettuce
horticulture.ahdb.org.uk/publication/1614-nitrogen-recommendations-optimizing-yield-and-quality-baby-leaf-lettuce

Nitrogen recommendations for optimising yield and minimising nitrate levels in baby leaf salad crops
horticulture.ahdb.org.uk/publication/0813-nitrogen-recommendations-optimising-yield-and-minimising-nitrate-levels-baby-leaf

Outdoor Salads: Lettuce and Celery Crop Walkers' Guide
horticulture.ahdb.org.uk/publication/outdoor-salads-lettuce-celery-crop-walkers-guide-0

Red Tractor Assurance Fresh Produce Crop Protocols
assurance.redtractor.org.uk/standards/fresh-produce-crop-protocols

Onions and leeks

Table 6.20 Nitrogen, phosphate, potash and magnesium for onions and leeks

	SNS, P, K or Mg Index						
	0	1	2	3	4	5	6
	kg/ha						
Nitrogen (N) – all soil types							
Bulb onions[a]	160	130	110	90	60	0[b]	0[b]
Salad onions[a]	130	120	110	100	80	50	20
Leeks[a]	200	190	170	160	130	80	40
Phosphate (P_2O_5)	200	150	100	50	[c]	[c]	0
Potash (K_2O)	275	225	175 (2-) 125 (2+)	35	0	0	0
Magnesium (MgO)	150	100	0	0	0	0	0

a. The recommendations assume overall application. A starter fertiliser containing nitrogen and phosphate may be beneficial.

b. A small amount of nitrogen may be needed if soil nitrogen levels are low in the top 30cm of soil.

c. At P Index 4 and 5, up to 60 kg P_2O_5/ha as starter fertiliser may be beneficial.

Bulb onions – nitrogen
At SNS Index 0 on light sands where spring Soil Mineral Nitrogen levels to rooting depth are 30 kg N/ha or less, a further 15 kg N/ha can be supplied.

Apply no more than 100 kg N/ha to the seedbed. The remainder should be applied when the crop is fully established for the spring crop and the following spring for the autumn-sown crop.

Salad onions – nitrogen
At SNS Index 0 on light sands where spring Soil Mineral Nitrogen levels to rooting depth are 15 kg N/ha or less, a further 15 kg N/ha can be supplied.

Apply no more than 100 kg N/ha to the seedbed of the spring-sown crop. The remainder should be applied when the crop is fully established.

For the autumn-sown crop, care must be taken not to apply too much nitrogen as the crop is prone to disease. Apply no more than 40 kg N/ha. If the crop is planted on organic or peaty soils or where large amounts of crop residue have been incorporated, no seedbed nitrogen is required. The remainder should be applied the following spring.

Leeks – nitrogen
Fertiliser nitrogen should be split to match the growth of the crop. Usually no more than 50 kg N/ha should be applied in the seedbed for drilled crops and no more than 100 kg N/ha for transplants. The remainder should be applied as one or more top-dressings when the crop is fully established. An additional top-dressing of 50–100 kg N/ha in the autumn may be beneficial where the risk of frost damage is low, on all soils except peat, to support growth and colour.

Under NVZ rules, no fertiliser nitrogen should be applied to leeks during the closed period unless supported by written advice from a FACTS Qualified Adviser. If applying nitrogen in the closed period, then a FACTS Qualified Adviser must provide a written recommendation.

Onions and leeks – sulphur
Where sulphur deficiency has been recognised or is expected, apply 25 kg SO_3/ha as a sulphate-containing fertiliser at or soon after planting.

Leaf nutrient analysis
Suspected nutrient deficiencies based on the appearance of symptoms can be confirmed by leaf nutrient analysis. In such cases, the leaf nutrient concentrations will usually be well below the 'critical level' and there should, therefore, be little doubt about the diagnosis.

Leaf nutrient analysis can also be used to test for subclinical deficiencies or toxicities that may be already limiting growth but which are not yet resulting in visible symptoms. In this case, sample at the four true leaf stage, taking complete leaves. Guidance on collecting leaf samples is described on page 22.

Interpretation of laboratory results is possible by comparison with normal levels expected for the crop. Values in Table 6.21 are based on the best information available.

Points to consider

- Make allowance for nutrients applied in organic materials **(Section 2: Organic materials)**
- Ensure the phosphate and potash offtake is balanced by application at P Index 3 and K Index 2+; check that the soil is maintained at these target Indices by soil sampling every 3–5 years

Table 6.21 Interpretation of leaf nutrient analysis for onions and leeks

		Normal range		
Element	Unit	Bulb onions	Salad onions	Leeks
Nitrogen (N)	%	2.5–4.0	2.0–3.2	2.0–3.8
Phosphorus (P)	%	0.25–0.4	0.25–0.41	0.27–0.41
Potassium (K)	%	2.5–5.0	1.9–4.3	1.4–2.3
Magnesium (Mg)	%	0.3–0.5	0.3–0.5	0.3–0.5
Sulphur (S)	%	0.5–1.0	0.5–1.0	0.5–1.0
Calcium (Ca)	%	1.0–2.5	1.0–2.5	1.0–2.5
Manganese (Mn)	mg/kg	30–300	30–300	30–300
Boron (B)	mg/kg	25–50	25–50	25–50
Copper (Cu)	mg/kg	6–20	6–20	6–20
Zinc (Zn)	mg/kg	25–100	25–100	25–100
Iron (Fe)[a]	mg/kg	60–300	60–300	60–300

a. Of limited use as even the smallest amount of soil contamination invalidates the analysis and the deficiency may not be related to actual content.

Further information

Allium Crop Walkers' Guide
ahdb.org.uk/knowledge-library/alliums-crop-walkers-guide

Nitrogen requirements for leeks
horticulture.ahdb.org.uk/publication/3212-nitrogen-requirements-leeks

Interpretation of leaf nutrient analysis (bulb onions, salad onions and leeks)
horticulture.ahdb.org.uk/publication/2205-interpretation-leaf-nutrient-analysis

Root vegetables

Table 6.22 Nitrogen, phosphate, potash and magnesium for root vegetables

	SNS, P or K Index						
	0	1	2	3	4	5	6
	kg/ha						
Beetroot							
Nitrogen (N) – all soil types	290	260	240	220	190	120	60
Phosphate (P_2O_5)	200	150	100	50	0	0	0
Potash (K_2O)	300	250	200 (2-) 150 (2+)	60	0	0	0
Swedes							
Nitrogen (N) – all soil types	135	100	70	30	0[a]	0[a]	0[a]
Phosphate (P_2O_5)	200	150	100	50	0	0	0
Potash (K_2O)	300	250	200 (2-) 150 (2+)	60	0	0	0

a. A small amount of nitrogen may be needed if soil nitrogen levels are low in the top 30 cm of soil.

	SNS, P, K or Mg Index						
	0	1	2	3	4	5	6
	kg/ha						
Turnips, Parsnips							
Nitrogen (N) – all soil types	170	130	100	70	20	0[a]	0[a]
Phosphate (P_2O_5)	200	150	100	50	0	0	0
Potash (K_2O)	300	250	200 (2-) 150 (2+)	60	0	0	0
Carrots							
Nitrogen (N) – all soil types	100	70	40	0[a]	0[a]	0[a]	0[a]
Phosphate (P_2O_5)	200	150	100	50	0	0	0
Potash (K_2O)	275	225	175 (2-) 125 (2+)	35	0	0	0
All crops							
Magnesium (MgO)	150	100	0	0	0	0	0

All root crops – nitrogen

Apply no more than 100 kg N/ha in the seedbed. The remainder should be applied as a top-dressing when the crop is fully established.

All root crops – phosphate and potash

High yielding root crops can take up large amounts of phosphate and potash. The amounts removed can be calculated from the known yield and the amount of phosphate and potash per tonne fresh produce shown in Table 6.8. It is important to do this to maintain the target Index for both phosphate and potash. Where straw is used to protect carrots and is subsequently incorporated into the soil, it contributes approximately 1 kg P_2O_5 and 8 kg K_2O, per tonne of straw. This should be considered when calculating the phosphate and potash requirements of following crops.

All root crops – sulphur

Where sulphur deficiency has been recognised or is expected, apply 25 kg SO_3/ha as a sulphate-containing fertiliser at or soon after planting.

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Carrots – sodium
On sandy soils, apply 200 kg Na_2O/ha as salt and deeply cultivate the application into the soil before drilling.

Carrots – boron
Boron deficiency can affect carrots on light textured soils with a pH >6.5, particularly in dry seaons. Symptoms include death of the aperical growing point and growth of lateral buds. Carrots can show a darkening of the root surface (‘shadow’).

Leaf nutrient analysis
Suspected nutrient deficiencies based on the appearance of symptoms can be confirmed by leaf nutrient analysis. In such cases, the leaf nutrient concentrations will usually be well below the ‘critical level’ and there should, therefore, be little doubt about the diagnosis.

Leaf nutrient analysis can also be used to test for ‘subclinical’ deficiencies or toxicities that may be already limiting growth but which are not yet resulting in visible symptoms. In this case, sample carrots and parsnips at the six true leaf stage or when the roots are 10+ mm in diameter. Guidance on collecting leaf samples is described on page 22.

Interpretation of laboratory results is possible by comparison with normal levels expected for the crop. The interpretations in Table 6.23 are based on the best information available.

Table 6.23 Interpretation of leaf nutrient analysis for carrots and parsnips

		Carrots			Parsnips
Element	Unit	Deficient	Normal range	Toxic	Normal range
Nitrogen (N)	%	<2.0	2.0–4.5	-	3.0–4.8
Phosphorus (P)	%	<0.2	0.2–0.5	-	0.3–0.7
Potassium (K)	%	<2.0	2.5–6.0	-	3.5–6.0
Magnesium (Mg)	%	<0.15	0.2–0.5	-	0.4–0.8
Sulphur (S)	%	-	0.2–0.4	-	0.4–0.5
Calcium (Ca)	%	<1.0	1.0–3.5	-	1.2–2.0
Manganese (Mn)	mg/kg	<20	20–200	-	30–200
Boron (B)	mg/kg	<20	20–60	>150	25–60
Copper (Cu)	mg/kg	<5	5–25	>20	6–30
Zinc (Zn)	mg/kg	<20	20–50	>100	20–40
Iron (Fe)	mg/kg	-	50–100	-	50–500
Sodium (Na)	%	-	0.0–0.2	-	0.0–0.2

Points to consider

- Make allowance for nutrients applied in organic materials **(Section 2: Organic materials)**
- Ensure the phosphate and potash offtake is balanced by application at P Index 3 and K Index 2+; check that the soil is maintained at these target Indices by soil sampling every 3–5 years

Further information

Carrot & Parsnip Crop Walkers’ Guide (contains photos of nutrient deficiencies)
ahdb.org.uk/knowledge-library/carrot-parsnip-crop-walkers-guide

Interpretation of leaf nutrient analysis results (carrots and parsnips)
horticulture.ahdb.org.uk/publication/0804-interpretation-leaf-nutrient-analysis-results

Bulbs and bulb flowers

Table 6.24 Nitrogen, phosphate, potash and magnesium for bulbs and bulb flowers

	SNS, P, K or Mg Index						
	0	1	2	3	4	5	6
	kg/ha						
Nitrogen (N)	125	100	50	0	0	0	0
Phosphate (P_2O_5)	200	150	100	50	0	0	0
Potash (K_2O)	300	250	200 (2-) 150 (2+)	60	0	0	0
Magnesium (MgO)	150	100	0	0	0	0	0

Bulbs – nitrogen
Apply nitrogen as a top-dressing just before emergence.

Narcissus – nitrogen
If growth was poor in the previous year, a top-dressing of 50 kg N/ha may be required in the second or subsequent year.

Bulbs – sulphur
Where sulphur deficiency has been recognised or is expected, apply 25 kg SO_3/ha as a sulphate-containing fertiliser at or soon after planting.

Points to consider

- Make allowance for nutrients applied in organic materials **(Section 2: Organic materials)**
- Ensure the phosphate and potash offtake is balanced by application at P Index 3 and K Index 2+; check that the soil is maintained at these target Indices by soil sampling every 3–5 years

Further information

Narcissus Manual
horticulture.ahdb.org.uk/publication/narcissus-manual

Information for growers of bulbs and outdoor flowers
horticulture.ahdb.org.uk/sector/bulbs-and-outdoor-flowers

Herbs

Table 6.25 Nitrogen, phosphate, potash and magnesium for herbs

	SNS, P, K or Mg Index						
	0	1	2	3	4	5	6
	kg/ha						
Coriander							
Nitrogen (N)	140	125	115	105	90	55	30
Phosphate (P_2O_5)	175	125	75	25	0	0	0
Potash (K_2O)	315	265	215 (2-) 165 (2+)	75	0	0	0
Magnesium (MgO)	150	100	0	0	0	0	0
Mint – establishment year							
Nitrogen (N)	180	170	160	150	130	100	70
Phosphate (P_2O_5)	175	125	75	25	0	0	0
Potash (K_2O)	200	150	100 (2-) 50 (2+)	0	0	0	0
Magnesium (MgO)	150	100	0	0	0	0	0
Mint – subsequent years							
Nitrogen (N)	180	170	160	150	130	100	70
Phosphate (P_2O_5)	175	125	75	25	0	0	0
Potash (K_2O)	280	230	180 (2-) 130 (2+)	40	0	0	0
Magnesium (MgO)	150	100	0	0	0	0	0

Coriander – nitrogen
Apply no more than 100 kg N/ha in the seedbed. The remainder should be applied as a top-dressing when the crop is fully established.

The fertiliser recommendations given here should be considered as guideline figures and may need to be adjusted based on local experience, taking into account factors such as planting date, expected yield and end market.

Mint – nitrogen
In the establishment year, apply no more than 100 kg N/ha before planting. The remainder should be applied as a top-dressing when the crop is fully established.

For established crops, the nitrogen recommendations are per cut, and should typically be split into two top-dressings. Avoid over-fertilising mint, as the shelf life is reduced when Soil Mineral Nitrogen to 30 cm depth is over 200 kg N/ha.

The fertiliser recommendations given here should be considered as guideline figures and may need to be adjusted based on local experience, taking into account factors such as age of crop, expected yield and end market.

Coriander and mint – potash
Coriander and mint take up large amounts of potash, which must be replaced in order to maintain the target soil Index. The actual amount of potash removed by the crop can be calculated from the known yield and the amount of potash per tonne fresh weight shown in Table 6.8.

Coriander and mint – sulphur
Where sulphur deficiency has been recognised or is expected, apply 25 kg SO_3/ha as a sulphate-containing fertiliser at or soon after planting.

Points to consider

- Make allowance for nutrients applied in organic materials **(Section 2: Organic materials)**
- Ensure the phosphate and potash offtake is balanced by application at P Index 3 and K Index 2+; check that the soil is maintained at these target Indices by soil sampling every 3–5 years

Modifying the crop nitrogen requirement

Vegetable crops are planted at many different times of the year and have a range of expected yields. FACTS Qualified Advisers can customise individual field recommendations using Table 6.22 and the following information:

1. Size of the crop – the size, frame, or weight of the crop needed to produce optimal economic yields.
2. Nitrogen uptake – the optimum nitrogen uptake associated with a crop of that size.
3. Supply of nitrogen – based on the nitrogen supply from the soil within rooting depth, including any nitrogen mineralised from organic matter during the growing season.

1. Size of the crop (t/ha Dry weight yield)

$$\text{Dry wt yield} = \frac{(\text{Fresh wt yield x dm\%/100})}{\text{DW-HI}}$$

Fresh wt Yield (t/ha): The yield of marketable produce removed or expected to be removed from the field in commercial practice. Data based on field experiments or expert opinion for well grown crops.

dm %: The % dry matter of marketable produce for optimally fertilised crops.

DW-HI: The dry weight-harvest Index is the proportion of the whole crop that is taken for market, expressed on a dry weight basis. For example, in onions 81% (0.81) of the green crop is bulb but only 26% (0.26) of the sprout crop is produced as sprouts.

2. Nitrogen uptake in an optimally grown crop (kg/ha)

Total N Uptake (kg/ha) = Dry wt Yield t/ha x N% x 10

N%: The estimated nitrogen concentration of an optimally fertilised whole plant at harvest. Generally %N declines as yields increase. For small changes in yield, eg if yield increases by 10%, it could be assumed that nitrogen uptake increases by the same amount. For bigger changes, the increase in nitrogen uptake will be less than the increase in yield and the formula below should be used.

$$\%N_{Crit} = a(1+be^{-0.26W})$$

$\%N_{Crit}$: The critical N concentration; a and b are parameters controlling the shape of the curve.

W: Total dry matter yield t/ha.

3. Supply of nitrogen and calculation of Crop Nitrogen Requirement (CNR)

CNR = (NUptake – MineralisedN + SoilMinN) x (FertRec/100)

Mineralised N: The amount of nitrogen released from soil organic matter by mineralisation during the cropping period. This is normally between planting and harvesting dates but for some crops, such as lettuce and onions where early nitrogen supply is important, a shorter period has been chosen (see Table 6.1).

The calculations are based on mineralisation within the WELL_N model (ie 0.7kg/ha at 15.9°C, scaled for Wellesbourne temperature). When temperature is less than 4°C, mineralisation is assumed to be negligible.

SoilMinN: Soil Mineral Nitrogen to rooting depth.

Fert Rec: Fertiliser recovery assumed to be 60%.

Table 6.26 Information for modification of vegetable crop nitrogen requirement

Crop	Fresh market yield t/ha	% Dry matter marketable	Dry wt harvest Index	Total dry matter t/ha	Relation N% and dry matter yield		% N	Total N uptake kg/ha	Mineralised kg/ha	Period dates	Root depth cm
					'a'	'b'					
Brussels sprouts	20.3	17.0	0.26	13.3	2.50	3.50	2.8	368	121	20/05–17/12	90
White cabbage storage	110.0	8.6	0.65	14.6	2.55	0.80	2.6	378	122	01/05–12/11	90
Head cabbage – Pre-31 December	60.0	8.6	0.48	10.8	2.55	0.80	2.7	270	44	18/05–19/07	90
Head cabbage – post 31 December	53.0	8.6	0.46	10.0	2.55	0.80	2.7	203	74	31/07–15/01	90
Collards – Pre-31 December	20.0	8.6	0.34	5.1	3.45	0.60	4.0	260	51	16/07–24/09	45
Collards – Pre-31 December	30.0	8.6	0.38	6.8	3.45	0.60	3.8	300	41	15/09–15/01	60
Cauliflower over winter	-	-	-	8.1	3.45	0.60	3.7	300	85	30/07–10/03	75
Calabrese	16.3	10.4	0.17	10.0	1.80	3.50	2.3	226	36	27/04–25/06	90
Cauliflower summer	30.6	8.2	0.37	6.8	3.45	0.60	3.8	259	44	21/05–21/07	75
Lettuce (crisp)	45.5	5.3	0.50	4.8	2.60	1.10	3.4	165	22	15/05–15/06	45
Radish	50.0	-	-	-	-	-	-	100	24	21/05–11/06	30
Bulb onions spring	60.5	12.7	0.81	9.4	1.20	3.50	1.6	147	20	13/03–12/05	60
Bulb onions overwintered	60.5	12.7	0.81	9.4	1.20	3.50	1.6	147	20	as above	60
Salad onions	30.0	12.7	0.81	4.7	1.2	3.50	2.4	114	20	as above	30
Salad onions overwintered	30.0	12.7	0.81	4.7	1.2	3.50	2.4	114	20	as above	30
Leeks	47.0	14.2	0.57	11.8	2.00	4.00	2.4	279	132	21/04–12/12	45
Beetroot	60.0	-	-	-	-	-	-	270*	65	18/05–16/08	60
Parsnips and turnips	48.0	-	-	-	-	-	-	241*	92	30/03–27/08	90
Swede	84.4	11.7	0.62	16.0	1.35	1.87	1.4	222	92	30/03–27/08	90
Carrots	150.0	11.4	0.81	21.2	0.82	7.00	0.8	178	66	02/05–08/08	90
Coriander	48.0	8.0	0.95	4.0	2.38	0.96	4.7	129	29.5	21/05–02/07	30
Mint	25.0	12.3	0.59	5.3	1.57	3.34	3.2	153	27.6	28/05–6/07	30

* N uptake taken from German KNS System 2007.

Insufficient data to include asparagus, celery, peas and beans, sweetcorn, courgettes or bulbs

Conversion tables

Metric to imperial

1 tonne/ha	0.4 tons/acre
100 kg/ha	80 units/acre
1 kg/tonne	2 units/ton
10 cm	4 inches
1 m^3	220 gallons
1 m^3/ha	90 gallons/acre
1 kg/m^3	9 units/1000 gallons
1 kg	2 units

Note: a 'unit' is 1% of 1 hundredweight, or 1.12lbs.

Imperial to metric

1 ton/acre	2.5 tonnes/ha
100 units/acre	125 kg/ha
1 unit/ton	0.5 kg/tonne
1 inch	2.5 cm
1,000 gallons	4.5 m^3
1,000 gallons/acre	11 m^3/ha
1 unit/1,000 gallons	
1 unit	0.5 kg

Element to oxide

P to P_2O_5	Multiply by 2.291
K to K_2O	Multiply by 1.205
Mg to MgO	Multiply by 1.658
S to SO_3	Multiply by 2.5
Na to Na_2O	Multiply by 1.348
Na to salt	Multiply by 2.542

Oxide to element

P_2O_5 to P	Multiply by 0.436
K_2O to K	Multiply by 0.830
MgO to Mg	Multiply by 0.603
SO_3 to S	Multiply by 0.4
Na_2O to Na	Multiply by 0.742
Salt to Na	Multiply by 0.393

Fluid fertiliser

kg/tonne (w/w basis) to kg/m^3	Multiply by specific gravity (w/v basis)

Further information

Conversion calculators
cereals.ahdb.org.uk/tools/agronomy-calculators

Glossary

Available (nutrient) Form of a nutrient that can be taken up by a crop immediately or within a short period so acting as an effective source of that nutrient for the crop.

Clay Finely divided inorganic crystalline particles in soils, less than 0.002 mm in diameter.

Closed period Period of the year when nitrogen fertilisers or certain manures should not be applied unless specifically permitted. Closed periods apply within NVZs.

Content (nutrient) Commonly used instead of the more accurate 'concentration' to describe nutrients in fertiliser or organic material. For example, 6 kg N/t often is described as the nitrogen content of a manure.

Crop available nitrogen The total nitrogen content of organic material that is available for crop uptake in the growing season in which it is spread on land.

Crop nitrogen requirement The amount of crop available nitrogen that must be applied to achieve the economically optimum yield.

Digestate Organic material produced by anaerobic digestion of biodegradable organic materials. May be separated into liquid and fibre fractions after digestion.

Excess winter rainfall Rainfall between the time when the soil profile becomes fully wetted in the autumn (field capacity) and the end of drainage in the spring. There is less evapotranspiration during this period (ie water lost through the growing crop).

FACTS UK national certification scheme for advisers on crop nutrition and nutrient management. Membership is renewable annually. A FACTS Qualified Adviser has a certificate and an identity card.

Fertiliser See Manufactured fertiliser.

Grassland Land on which the vegetation consists predominantly of grass species.

Leaching Process by which soluble materials such as nitrate or sulphate are removed from the soil by drainage water passing through it.

Ley Temporary grass, usually ploughed up one to five years (sometimes longer) after sowing.

Lime requirement Amount of standard limestone needed in tonnes/ha to increase soil pH from the measured value to a higher specified value (often 6.5 for arable crops). Can be determined by a laboratory test or inferred from soil pH.

Liquid fertiliser Pumpable fertiliser in which nutrients are dissolved in water (solutions) or held partly as very finely divided particles in suspension (suspensions).

Manufactured fertiliser Any fertiliser that is manufactured by an industrial process. Includes conventional straight and NPK products (solid or fluid), organo-mineral fertilisers, rock phosphates, slags, ashed poultry manure, liming materials that contain nutrients.

Manure See Livestock manure.

Micronutrient Boron, copper, iron, manganese, molybdenum and zinc are needed in very small amounts by crops. Cobalt and selenium are taken up in small amounts by crops and are needed in human and livestock diets.

Mineral nitrogen Nitrogen in ammonium (NH_4) and nitrate (NO_3) forms.

Mineralisation Microbial breakdown of organic matter in the soil, releasing nutrients in crop-available, inorganic forms.

Nitrate vulnerable zones (NVZs) Areas designated by Defra as being at risk from agricultural nitrate pollution.

Offtake Amount of a nutrient contained in the harvested crop (including straw, tops or haulm) and removed from the field. Usually applied to phosphate and potash.

Olsen P Concentration of available P in soil determined by a standard method (developed by Olsen) involving extraction with sodium bicarbonate solution at pH 8.5. The main method used in England, Wales and Northern Ireland and the basis for the soil Index for P.

Organic manure Any bulky organic nitrogen source of livestock, human or plant origin, including livestock manures.

Organic soil Soil containing between 10% and 20% organic matter (in this Manual). Elsewhere, it sometimes refers to soils with between 6% and 20% organic matter.

Peaty soil (peat) Soil containing more than 20% organic matter.

Placement Application of fertiliser to a zone of the soil usually close to the seed or tuber.

Removal See Offtake.

Sand Soil mineral particles larger than 0.05 mm.

Silt Soil mineral particles in the 0.002–0.05 mm diameter range.

SNS Index Soil Nitrogen Supply expressed in seven bands or Indices, each associated with a range in kg N/ha.

Soil Index (P, K or Mg) Concentration of available P, K or Mg, as determined by standard analytical methods, expressed in bands or Indices.

Soil Mineral Nitrogen (SMN) Ammonium and nitrate nitrogen, measured by the standard analytical method and expressed in kg N/ha.

Soil Nitrogen Supply (SNS) The amount of nitrogen (kg N/ha) in the soil that becomes available for uptake by the crop in the growing season, taking account of nitrogen losses.

Soil organic matter	Often referred to as humus. Composed of organic compounds ranging from undecomposed plant and animal tissues to fairly stable brown or black material with no trace of the anatomical structure of the material from which it was derived.
Soil texture	Description based on the proportions of sand, silt and clay in the soil.
Soil type	Description based on soil texture, depth, chalk content and organic matter content.
Target soil Index	Lowest soil P or K Index at which there is a high probability crop yield will not be limited by phosphorus or potassium supply. See Soil Index (P, K or Mg).

Notes

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Greenhouse Gas Action Plan:
The industry-wide Greenhouse Gas Action Plan (GHGAP) for agriculture focuses on improving resource use efficiency in order to enhance business performance whilst reducing GHG emissions from farming.

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Nutrient Management Guide (RB209)

Updated May 2017

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FACTS

Section 7 Fruit, vines and hops

Using the Nutrient Management Guide (RB209)

This latest revision of RB209 is based on research carried out since the previous edition was published in 2010. The revision includes updated recommendations, including those for additional crops and information on the nutrient content of additional organic materials.

RB209 was first published in 1973 and was the first comprehensive set of fertiliser recommendations from the Ministry of Agriculture, Fisheries and Food (MAFF). RB209 stands for Reference Book 209.

To improve the accessibility of the recommendations and information AHDB's Nutrient Management Guide (RB209) is published as seven sections that will be updated individually.

Further information
The Nutrient Management Guide (RB209) will be updated regularly.

Please email your contact details to AHDB so that we can send you updates when they are published - comms@ahdb.org.uk

RB209: Nutrient Management
Download the app for Apple or Android phones to access the current version of all sections of the guide. With quick and easy access to videos, information and recommendations from the guide, it is practical for use in the field.

Section 1 Principles of nutrient management and fertiliser use
Section 2 Organic materials
Section 3 Grass and forage crops
Section 4 Arable crops
Cereals
Oilseeds
Sugar beet
Peas and beans
Biomass crops
Section 5 Potatoes
Section 6 Vegetables and bulbs
Section 7 Fruit, vines and hops

This section provides guidance for fruit, vines and hops. For each crop, recommendations for nitrogen (N), phosphate (P_2O_5), potash (K_2O), magnesium (MgO), and sulphur (as SO_3) are given in kilograms per hectare (kg/ha).

Recommendations are given for the rate and timing of fertiliser application. The recommendations are based on the nutrient requirements of the crop being grown, making allowance for the nutrients supplied by the soil.

Always consider your local conditions and consult a FACTS Qualified Adviser if necessary.

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Summary of main changes from previous edition

1. Overall presentation

   a. Fertiliser recommendations for fruit, vines and hops are now presented in **Section 7: Fruit, vines and hops** that incorporates the relevant appendices.

2. New and revised fertiliser recommendations

   a. The guidance on the timing of nitrogen applications to blackcurrants and raspberries has been revised.

   b. As the risk of sulphur deficiency is becoming more widespread, new sulphur recommendations are given.

   c. Guidance on leaf analysis for substrate-grown strawberries is given.

Checklist for decision making

Individual decisions for fertiliser use must be made separately for every field. Where more than one crop is grown in a field, these areas must be considered individually.

1. Confirm the crop to be grown and the intended market. Identify any crop quality requirements for this market.
2. Identify the dominant soil type in the cropped area **(Section 1: Principles of nutrient management and fertiliser use)**.
3. Assess soil structure and take action to remove compaction and improve drainage if necessary. Poor structure and drainage can restrict crop growth, resulting in poor nutrient use efficiency.
4. Carry out soil analysis for pH, P, K and Mg before planting and every 3–5 years **(Section 1: Principles of nutrient management and fertiliser use).** Target values to maintain when growing fruit, hops or vines are:
   - **Soil pH 6.0–6.5 (6.5–6.8 before planting)**
   - **Soil P Index 2**
   - **Soil K Index 2 (cider apples respond to soil K Index 3)**
   - **Soil Mg Index 2 (cider apples respond to soil Mg Index 3)**
5. Calculate the total and crop available nutrients from organic materials that have been applied since harvest of the previous crop, or which will be applied to the crop being grown **(Section 2: Organic materials).** Deduct these nutrients from the recommended rates given in the tables.
6. Use regular leaf and fruit analysis to help make fertiliser decisions. Soil levels are not always reflected in the nutrient concentrations in the leaf and fruit.
7. Decide on the strategy for phosphate, potash and magnesium use. This will be either building up, maintaining or running down the soil Index levels **(Section 1: Principles of nutrient management and fertiliser use)**. Allow for any surplus or deficit of phosphate, potash or magnesium applied to previous crops.
8. Using the tables, decide on the required rate of each nutrient. Decide the optimum timings for fertiliser application, then find the best match for these applications using available fertilisers.
9. Check that the fertiliser spreader or sprayer is in good working order and has been recently calibrated **(Section 1: Principles of nutrient management and fertiliser use)**.
10. Keep an accurate record of the fertilisers and organic materials applied.

Further information

Soil management
horticulture.ahdb.org.uk/greatsoils

Simply Sustainable Soils
www.leafuk.org/leaf/farmers/simplysustainablesoils

Identification of soil type

Careful identification of the soil category in each field is very important. The whole soil profile should be assessed to rooting depth. Where the soil varies, and nitrogen is to be applied uniformly, select the soil type that occupies the largest part of the field.

The soil category can be identified using Figure 7.1 which categorises soils on their ability to supply and retain mineral nitrogen. The initial selection can then be checked using Table 7.1.

Carefully assess the soil organic matter content when deciding if the soil is organic (10–20% organic matter for the purposes of this guide) or peaty (more than 20% organic matter). If necessary, seek professional advice on soil type assessments, remembering this will need to be done only once.

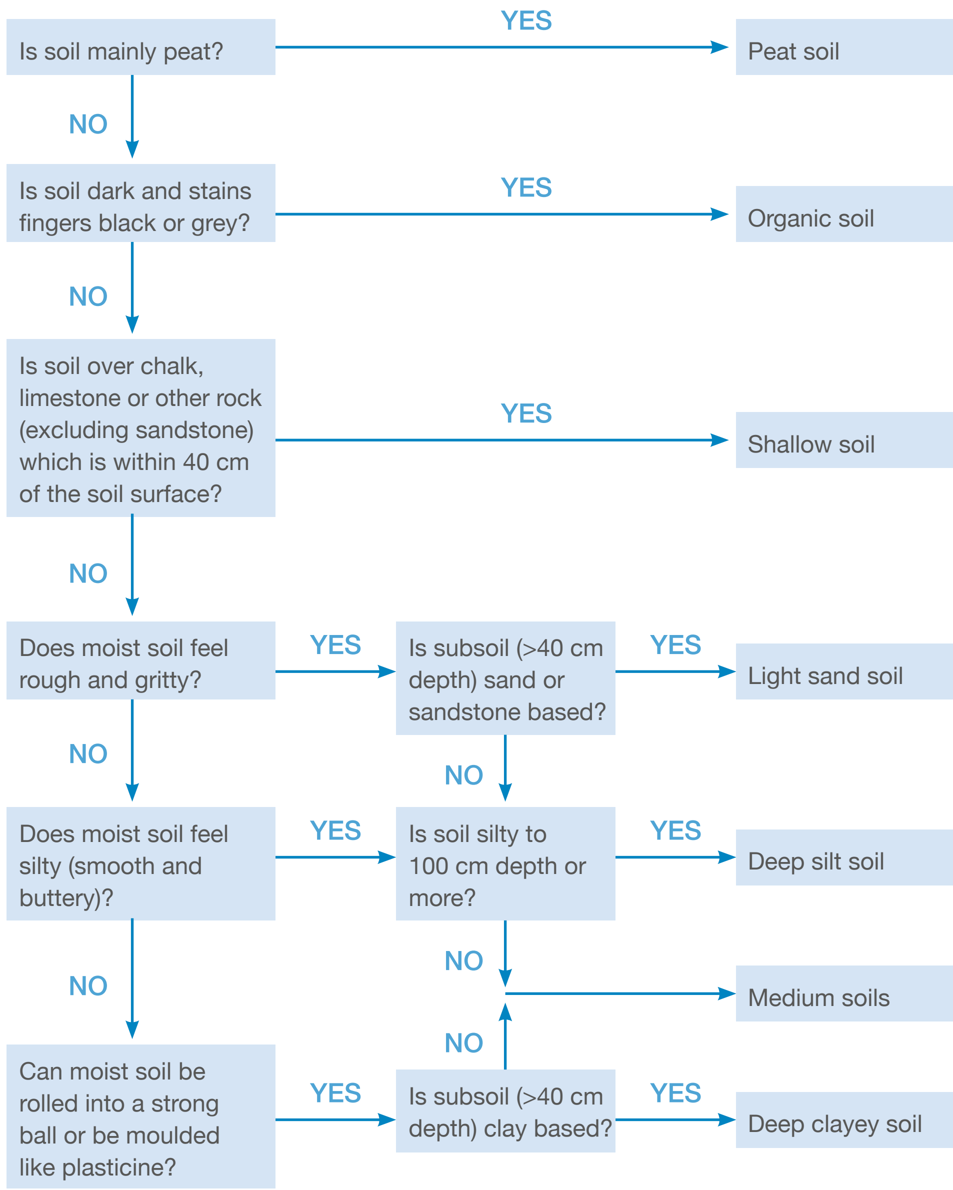

Figure 7.1 Soil category assessment

Table 7.1 Soil category assessment

Soil category	Description of soil types within category	Properties
Light sand soils	Soils which are sand, loamy sand or sandy loam to 40 cm depth and are sand or loamy sand between 40–80 cm, or over sandstone rock.	Soils in this category have poor water holding capacity and retain little nitrogen.
Shallow soils	Soils over impermeable subsoils and those where the parent rock (chalk, limestone or other rock) is within 40 cm of the soil surface. Sandy soils developed over sandstone rock should be regarded as light sand soils.	Soils in this category are less able to retain or supply nitrogen at depth.
Medium soils	Mostly medium-textured mineral soils that do not fall into any other soil category. This includes sandy loams over clay, deep loams, and silty or clayey topsoils that have sandy or loamy subsoils.	Soils in this category have moderate ability to retain nitrogen and allow average rooting depth.
Deep clayey soils	Soils with predominantly sandy clay loam, silty clay loam, clay loam, sandy clay, silty clay or clay topsoil overlying clay subsoil to more than 40 cm depth. Deep clayey soils normally need artificial field drainage.	Soils in this category are able to retain more nitrogen than lighter soils.
Deep silty soils	Soils of sandy silt loam, silt loam or silty clay loam textures to 100 cm depth or more. Silt soils formed on marine alluvium, warp soils (river alluvium) and brickearth soils are in this category. Silty clays of low fertility should be regarded as other mineral soils.	Soils in this category are able to retain more nitrogen than lighter soils and allow rooting to greater depth.
Organic soils	Soils that are predominantly mineral but with between 10–20% organic matter to depth. These can be distinguished by darker colouring that stains the fingers black or grey.	Soils in this category are able to retain more nitrogen than lighter soils and have higher nitrogen mineralisation potential.
Peat soils	Soils that contain more than 20% organic matter derived from sedge or similar peat material.	Soils in this category have very high nitrogen mineralisation potential.

Phosphate, potash and magnesium recommendations

For soil-grown crops, the current phosphate, potash and magnesium recommendations are based on achieving and maintaining target soil Indices. Soil analysis should be done before planting and every 3–5 years in established crops. The use of soil analysis as a basis for making fertiliser decisions and the procedure for taking soil samples is described below.

The phosphate and potash recommendations given in the tables are sufficient to replace the crop offtake of established crops at the target soil Index and therefore, to maintain the target soil Index. The amount of phosphate and potash needed to supply maintenance needs will depend on crop uptake and nutrient offtake. Where the soil is below the target phosphate or potash Index, the recommendations given in the tables are higher, to allow the soil to 'build up' to the target Index over time.

When the soil also needs liming, magnesium can often be supplied cost-effectively by using magnesian limestone. When liming is not required, a magnesium fertiliser should be used. Where magnesium deficiency has been diagnosed, foliar sprays of agricultural magnesium sulphate (Epsom salts) or other proprietary materials are likely to give a more rapid effect than a soil application of a magnesium fertiliser.

Points to consider

- Recommendations assume good soil structure, water supply, and pest and disease control
- Recommendations are given as phosphate (P_2O_5), potash (K_2O) and magnesium oxide (MgO). Conversion tables (metric–imperial, oxide–element) are given on page 25
- Organic materials supply phosphate and potash which contribute to crop requirements. Don't forget to make allowance for the phosphate and potash applied in organic materials **(Section 2: Organic materials)**

- All recommendations are given for the mid-point of each Index. Where a soil analysis value (as given by the laboratory) is close to the ranage of an adjacent Index, the recommendation may be reduced or increased slightly, taking account of the recommendation given for the adjacent Index. Small adjustments of less than 10 kg/ha are generally not justified
- Where more or less phosphate and potash are applied than suggested in the tables, adjustments can be made later in the rotation

Taking soil samples for pH, phosphate, potassium and magnesium

Soil sampling must be done well to avoid misleading results and expensive mistakes.

- The soil in each field should be sampled before planting and every 3–5 years thereafter
- Ideally, samples should be collected in the spring
- Do not sample within six months of a lime or fertiliser application (except nitrogen) and avoid sampling when the soil is very dry
- Do not take samples in headlands, or in the immediate vicinity of hedges, trees or other unusual features
- Before planting, samples should be collected before ploughing so that if lime and/or fertiliser is needed, it can be applied and then ploughed down
- The soil sample must be representative of the area sampled. Areas of land known to differ in some important respects (eg soil type, previous cropping, applications of manure, fertiliser or lime) should be sampled separately

- Small areas known to differ from the majority of a field should be excluded from the sample
- Before planting in old herbicide strip orchards, separate samples should be taken from the grass alley and the strip, especially where previous lime and fertiliser applications have been applied to the strip only
- Established orchards in overall grass management, or very weedy orchards, should be sampled within the spread of the tree branches
- In established orchards with herbicide strip management, sampling should be restricted to the strip, excluding the grass area
- Samples from soft fruit plantations and hops should be taken from within the area of rooting
- Clean tools before starting and before sampling a new area
- Walk a 'W' pattern across the sampling area, stopping at least 25 times
- At each point, collect a subsample (core) using a gouge corer or screw auger
- Fields intended for planting should be sampled to a depth 0–15 cm and 15–30 cm, this is particularly important on land previously in fruit, vines, hops or grass where a depth gradient in nutrient content and acidity will probably have developed
- The 15–30 cm sample is not essential on land that has been ploughed regularly to a depth of 25 cm or more
- For all established crops sample to 15 cm depth
- An even depth of sampling is important and when necessary both the top and bottom portions of the soil core should be included in the subsample
- The subsamples should be bulked to form a representative sample and sent to the laboratory for analysis. As a rule of thumb, take one bulk sample for every 4 hectares of land under the same management
- Use appropriate packaging (normally available from the laboratory) and label samples clearly, providing as much information about the field and crop as possible

Classification of soil analysis results into Indices

The laboratory soil analysis results for P, K and Mg (in mg/kg dry soil) can be converted into soil Indices using Table 7.2.

Table 7.2 Classification of soil P, K and Mg analysis results into Indices

Index	Phosphorus (P)	Potassium (K)	Magnesium (Mg)
	Olsen P	Ammonium nitrate extract	
	mg/litre		
0	0–9	0–60	0–25
1	10–15	61–120	26–50
2	16–25	121–240	51–100
3	26–45	241–400	101–175
4	46–70	401–600	176–250
5	71–100	601–900	251–350
6	101–140	901–1,500	351–600
7	141–200	1,501–2,400	601–1,000
8	201–280	2,401–3,600	1,001–1,500
9	Over 280	Over 3,600	Over 1,500

Soil acidity and liming

Most fruit crops are tolerant of slight acidity and grow best at around pH 6.0–6.5. Soil pH levels below about 5.5 can give rise to manganese toxicity, causing 'measley' bark in apples and purple veining in some strawberry varieties. Blackcurrants are more susceptible to soil acidity and a pH of at least 6.5 should be maintained.

Blueberries are an exception to other fruit, as they require a soil pH of 4.5–5.5. Where soil pH is higher than this, ammonium sulphate can be used to lower the pH, providing the soil does not contain free calcium carbonate.

Mature hops can tolerate a considerable degree of soil acidity but some varieties may suffer from manganese toxicity if the soil becomes too acidic. Young hop plants are more sensitive to acidity.

It is important that soils used for fruit, vines and hops are not over limed as this may lead to micronutrient deficiencies such as iron and manganese.

Liming before planting

Any lime required should be applied and incorporated before planting, see Section 1: Principles of nutrient management and fertiliser use. Because acidity problems occur in patches and acidity can develop rapidly when herbicides are used, the whole plough layer should be limed to maintain a pH value of 6.5 in the early years of fruit or hops. It will be impossible to correct any acidity at depth by later lime incorporation so the quantity of lime applied before planting should be calculated to correct the pH of the top 40 cm of soil.

Where lime is needed to correct acidity in the subsoil, it should be ploughed down. Where sampling has only been carried out to 15 cm depth, the lime requirement using this pH result should be doubled. If the total lime requirement is more than 7.5 t/ha, half should be deeply cultivated into the soil and ploughed down, with the remainder applied and worked in after ploughing. If less than 7.5 t/ha of lime is needed, the whole requirement should be applied after ploughing and cultivated in.

On soils where acidity is known to occur, soil may need to be tested more frequently than the four year cycle used for phosphate, potash and magnesium. Since acidity can occur in patches, spot testing with a soil indicator across the field is often useful. Soil indicators can also be useful on soils which contain fragments of free lime, since these can give a misleadingly high pH when analysed following grinding in the laboratory.

Where there is significant variability of soil pH, lime should be applied at different rates in different areas so that the whole field reaches the same pH. If testing with a coloured indicator or a pH meter shows that the soil pH is less than 5.0 below plough depth, seek further advice before liming or planting.

Liming established crops

Under herbicide strip management, the strip will generally become acid more quickly than the grass alley and may require more frequent liming than the alley. The correction of acidity in undisturbed soil is slow, so it is important to check soil pH regularly and apply lime when necessary before the soil becomes too acidic and a severe problem builds up.

Liming materials

Acid soils deficient in magnesium may be limed with magnesian limestone, particularly before planting. One tonne of magnesian limestone contains at least 150 kg MgO. However, over application of magnesian limestone can reduce the availability of soil potash. Where soil magnesium levels are satisfactory, ground chalk or limestone should be used. The use of coarse grades of limestone or chalk should be avoided.

See Section 1: Principles of nutrient management and fertiliser use for more information on liming rates.

Sulphur recommendations

Fruit crops are not generally thought to respond to sulphur. However, atmospheric sulphur emissions have declined significantly and a yield response to sulphur is possible in some circumstances. Where sulphur deficiency has been recognised or is expected, apply 15–25 kg/ha SO_3. Sulphur should be applied as a sulphate-containing fertiliser in the spring. Crops are most at risk of sulphur deficiency where they are grown on light sandy soils, soils with a low organic matter content and in high rainfall areas.

Points to consider

- Recommendations are given as sulphur trioxide (SO_3). Conversion tables (metric–imperial, oxide–element) are given on page 25
- Organic materials supply crop-available sulphur which contributes to crop requirements
- Don't forget to make allowances for the crop-available sulphur applied in organic materials **(Section 2: Organic materials)**
- Further guidance on sulphur can be found in Section 1: Principles of nutrient management and fertiliser use

Micronutrients recommendations

Micronutrient deficiencies may occur in fruit, vine and hop crops, especially where the soil pH is over 7.0. These deficiencies can often be identified by visual symptoms but the diagnosis should be checked by leaf analysis. Iron deficiency cannot reliably be confirmed by leaf analysis.

- Boron (B): Boron deficiency in fruit crops is uncommon but can occur in hot dry summers, with pears being most susceptible. Where confirmed, the deficiency can be corrected by foliar application of boron
- Copper (Cu): Copper deficiency in pears has been diagnosed on occasion particularly in orchards on sandy soils. It can be corrected by applying a foliar spray of copper
- Iron (Fe): Iron deficiency occurs commonly in fruit crops grown on shallow calcareous soils. Either soil or foliar application of a suitable iron chelate can be used for treatment
- Manganese (Mn): Manganese deficiency can occur in fruit crops grown on calcareous soils or soils with a high pH. It is best controlled by foliar application of manganese
- Zinc (Zn): Zinc deficiency has very occasionally been found to reduce growth and cropping of apple trees on sandy soils. This deficiency can be corrected by foliar application of zinc but applying excessive amounts during blossom or cell division may decrease the number of fruitlets

Fruit, vines and hops – before planting

Nitrogen is not required before planting fruit crops but can be beneficial before planting potted hop cuttings. Where soil analysis before planting shows soil acidity or low soil P, K or Mg Indices, it is important to correct these shortages by thorough incorporation of appropriate amounts of lime and fertilisers.

After planting, the downward movement of all nutrients from the soil surface is slow, except for nitrogen. This applies particularly for phosphate and to a lesser extent for potash and magnesium. In organic production systems, soil fertility must be built up prior to planting.

Where previously ploughed land has been sampled to 15 cm depth only, the recommended amounts of phosphate, potash and magnesium should be thoroughly incorporated in the autumn before planting. Before planting top fruit, vines or hops, if soil analysis shows the field to be at P, K or Mg Index 0 or 1, the appropriate nutrient quantities should be ploughed down. Then the same amount of nutrients should be applied again and thoroughly incorporated before planting. If the plough depth is less than 20 cm, the amount ploughed down should be halved.

Where samples have been taken from 0–15 cm and 15–30 cm depths, the recommended rate based on the 15–30 cm sample should be ploughed down before top fruit, vines or hops are planted if the soil P, K or Mg Index is 0 or 1. After ploughing, the amount based on the 0–15 cm sample should be applied and thoroughly incorporated. If the plough depth is less than 20 cm, the amount ploughed down should be halved.

Where it is not possible to plough fertiliser down, the application should be limited to the amount recommended for one sampling depth only. Composted green waste and green manure crops can be incorporated to increase soil organic matter content.

Table 7.3 Nitrogen, phosphate, potash and magnesium for fruit, vines and hops before planting

	SNS, P, K, or Mg Index[c]					
	0	1	2	3	4	5 and over
	kg/ha					
Fruit and vines						
Nitrogen (N)	0	0	0	0	0	0
Phosphate (P_2O_5)	200	100	50	50	0	0
Potash (K_2O)[a]	200	100	50	0	0	0
Magnesium (MgO)	165	125	85	0	0	0
Hops						
Nitrogen (N) [b]	0	0	0	0	0	0
Phosphate (P_2O_5)	250	175	125	100	50	0
Potash (K_2O) [a]	300	250	200	150	100	0
Magnesium (MgO)	250	165	85	0	0	0

a. Apply potash in the autumn and thoroughly incorporate it into the soil to avoid root scorch of the newly planted crop.

b. Potted hop plants benefit from 70–80 kg N/ha applied in the spring before planting.

c. The recommendations in Table 7.3 are based on samples taken from a 15 cm depth of soil.

Points to consider

- Make allowance for nutrients applied in organic materials **(Section 2: Organic materials)**

Top fruit, established orchards

Nitrogen recommendations are based on the soil management system and soil type. The recommendations are intended as a guide and should be varied according to variety, rootstock, vigour, leaf or fruit analysis and appearance of foliage.

Nitrogen dressings can be split across the growing season. The largest demand for nitrogen is between blossom and late-July, which corresponds with the rapid shoot growth phase and nitrogen applications should reflect this. No application should be made during or after leaf drop.

The results of leaf and fruit analysis are particularly important. The width of the herbicide strip, the effectiveness of the herbicide programme and use of mulches (eg straw) can also influence nitrogen requirements. Straw and composted green waste mulches release potash which can antagonise calcium uptake. In extreme cases, this can cause physiological fruit disorders where soil calcium availability is low. Guidance on the use of leaf and fruit analysis to modify recommendations is given on pages 19 and 22, respectively.

Applying excess nitrogen encourages vegetative growth, causing large, dark green leaves. This may adversely affect fruit quality, especially taste, firmness and storage quality. Increasing nitrogen reduces the amount of red colour and intensifies the green colour of apples. This effect is detrimental to crop appearance and value in red coloured varieties, but can be beneficial in culinary varieties such as Bramley. Excess nitrogen can also reduce the storage life of fruit. However, autumn foliar application of nitrogen can improve blossom quality in the following spring.

When nitrogen is deficient, the leaves of fruit crops tend to be small and pale green, the bark of fruit trees may be reddish in colour and shoot growth restricted. Yields are reduced due to the decrease in the number and size of fruit, which may also be highly coloured.

In grass alley herbicide strip orchards, the tree roots are largely confined to the strip and fertiliser should be applied to the herbicide strip only. The nutrient recommendations given in Table 7.4 are for the complete orchard area and can be reduced where nitrogen is applied to the bare soil area only.

Further information
Apple Best Practice Guide
apples.ahdb.org.uk

Fertigation of young trees

The addition of nutrients to the irrigation water (fertigation) can improve the growth and nutrient use efficiency of trees.

Fertigation may be particularly beneficial for early cropping of young apple trees planted on sites previously cropped with apples, and may help overcome replanting problems. A benefit is more likely where the soil organic matter level and nitrogen reserves have been depleted by long-term use of herbicides, intended to maintain a bare soil surface.

The rate of nitrogen addition should be about 10 g N/tree in the first growing year, increasing to 15–20 g N/tree in the second and third years. Fertigation will allow fertiliser rates to be reduced by up to 50% of that used for broadcast applications in orchards older than three years. It can also help correct nutrient deficiencies, such as phosphate, because nutrients in solution are more rapidly moved down the soil profile. Again, leaf analysis should be used regularly to provide feedback on adjusting nutrition to appropriate levels.

Points to consider

- Care should be taken to ensure soils are not completely wetted, to minimise the risk of nitrate leaching

Table 7.4 Nitrogen for established top fruit

Crop	Grass/herbicide strip[a]	Overall grass
	kg N/ha	
Dessert apples[b]		
Light sand and shallow soils	80	120
Deep silty soils	30	70
Clays	40	80
Other mineral soils	60	100
Culinary and cider apples		
Light sand and shallow soils	110	150
Deep silty soils	60	100
Clays	70	110
Other mineral soils	90	130
Pears, cherries and plums		
Light sand and shallow soils	140	180
Deep silty soils	90	130
Clays	100	140
Other mineral soils	120	160

a. In grass alley/herbicide strip orchards the tree roots are largely confined to the strip and fertiliser can be applied to the herbicide strip only. The nitrogen recommendations given here are for the complete orchard area and can be reduced where nitrogen is applied to the herbicide strip area only. Nitrogen rates can also be adjusted depending on plant vigour and the results of leaf nitrogen analysis.

b. Larger nitrogen rates may be needed on varieties with regular heavy cropping potential (ie >40 t/ha)

Table 7.5 Phosphate, potash and magnesium for established top fruit

	P, K or Mg Index				
	0	1	2	3	4 and over
	kg/ha				
All top fruit, annually					
Phosphate (P_2O_5)	80	40	20	20	0
Potash (K_2O) [a]	220	150	80	0	0
Magnesium (MgO)	100	65	50	0	0

a. Pears require approximately an additional 70 kg K_2O/ha up to Index 3 but no addition at Index 4. Cider apples also respond to larger applications rates of potash.

For apples, soil K Index should not be built up above 2 because excessively large potash applications can adversely affect storage quality. To avoid inducing magnesium deficiency, the soil K:Mg ratio (based on soil mg/litre K and Mg) should be no greater than 3:1. Where the yields of apples and pears are regularly above 40 t/ha, maintenance applications of potash may need to be increased by 20 kg K_2O/ha for every additional 10 t/ha in yield.

For established crops, the timing of phosphate, potash and magnesium application is not critical. If the nutrient Index is 2 or over, the nutrients may be applied at twice the recommended rate every second year.

Points to consider

- Make allowance for nutrients applied in organic materials **(Section 2: Organic materials)**

Soft fruit and vines, established plantations

For bush and cane fruits, nitrogen rates may need to be modified depending on the amount of annual growth required for a particular production system. When nitrogen is deficient, leaves tend to be small and pale green.

For blackcurrants, apply nitrogen in two or three applications, either split across three approximately equal applications timed for late-dormant, May and post-harvest or apply 66% at leafing-out and the remainder post-harvest.

The nitrogen recommendations for raspberries are for both floricane and primocane varieties. For floricane varieties, nitrogen should be applied between the onset of floricane growth and the end of July. Avoid applying nitrogen after the end of July to avoid excessive growth of soft cane, unless nitrogen is applied at lower rates through fertigation, where nitrogen applications may continue until the end of August.

For primocane varieties, nitrogen should be applied between emergence and early October. Avoid applying nitrogen after the beginning of October to avoid excessive growth of soft cane.

For crops that are establishing prior to reaching full crop potential, smaller rates of nitrogen are usually adequate. The rate should be adjusted according to the amount of growth required and the results of leaf nitrogen analysis.

Points to consider

- Under Nitrate Vulnerable Zone (NVZ) rules, no fertiliser nitrogen should be applied to field-grown crops during the closed period, unless supported by written advice from a FACTS Qualified Adviser

Table 7.6 Nitrogen for soft fruit and vines

	N kg/ha
Blackcurrants[a b]	
Light sand and shallow soils	160
Deep silty soils	110
Clays	120
Other mineral soils	140
Redcurrants, gooseberries, raspberries, loganberries, tayberries, blackberries[a]	
Light sand and shallow soils	120
Deep silty soils	70
Clays	80
Other mineral soils	100
Vines[c]	
Light sand and shallow soils	60
Deep silty soils	0
Clays	20
Other mineral soils	40

a. With continuing change in varieties, adjust nitrogen rates depending on plant vigour.

b. For blackcurrants, varieties developed by James Hutton Ltd in the 'Ben' series, typically require 70–120 kg N/ha. Higher nitrogen rates may reduce fruit quality for processing.

c. Excessive growth of vines will cause wood to ripen slowly and a yield reduction in the following crop. Reduce nitrogen rates where growth is excessive.

Table 7.7 Phosphate and potash for soft fruit and vines

	P, K or Mg Index				
	0	1	2	3	4 and over
	kg/ha				
Blackcurrants, redcurrants, gooseberries, raspberries, loganberries, tayberries					
Phosphate (P_2O_5)	110	70	40	40	0
Potash (K_2O)[b]	250[a]	180[a]	120	60	0
Blackberries and vines					
Phosphate (P_2O_5)	110	70	40	40	0
Potash (K_2O)[b]	220	150	80	0	0
All crops					
Magnesium (MgO)[b]	100	65	50	0	0

a. Sulphate of potash should be used for raspberries, redcurrants and gooseberries where more than 120 kg K_2O/ha is applied.

b. To avoid inducing magnesium deficiency, the soil K:Mg ratio (based on soil mg/litre K and Mg) should be no greater than 3:1. For established crops, the timing of phosphate, potash and magnesium applications is not critical.

Points to consider

- Make allowance for nutrients applied in organic materials **(Section 2: Organic materials)**
- Under NVZ rules, no fertiliser nitrogen should be applied to field grown crops during the closed period unless supported by written advice from a FACTS Qualified Adviser

Table 7.8 Nitrogen for soil-grown strawberries

	SNS Index					
	0	1	2	3	4	5 and over
	kg/ha					
Strawberries – main season						
Light sand and shallow soils	60	50	40	30	20	0
Deep silty soils	0	0	0	0	0	0
Other mineral soils	40	40	30	20	0	0
Strawberries – everbearers						
Light sand and shallow soils	80	70	60	40	20	0
Deep silty soils	40	30	30	20	0	0
Other mineral soils	60	50	40	20	0	0

Nitrogen recommendations for strawberries are based on the Soil Nitrogen Supply (SNS) Index. For information on determining the SNS Index, refer to **Section 6: Vegetables and bulbs**. With continued change in varieties, adjust nitrogen rates depending on plant vigour and the results of leaf analysis.

Table 7.9 Phosphate, potash and magnesium for soil-grown strawberries

	P, K or Mg Index				
	0	1	2	3	4 and over
	kg/ha				
Phosphate (P_2O_5)	110	70	40	40	0
Potash (K_2O)	220	150	80	0	0
Magnesium (MgO)	100	65	50	0	0

To avoid induced magnesium deficiency, the soil K:Mg ratio (based on soil mg/litre K and Mg) should be no greater than 3:1.

Fertigation

Where strawberries or raspberries are grown under a polythene mulch with sub-irrigation, nutrients can be applied in the irrigation system (fertigation). On soils that encourage vigorous growth, it may be beneficial to reduce nitrogen rates when applied by fertigation. Where growth is not excessive, the nitrogen rates for the whole season should be the same as those recommended for soil applications but with less being applied during the fruiting period.

At P and K Index 2 or above, maintenance rates of phosphate and potash can be applied by fertigation. However, where the soil P, K or Mg Index is 0 or 1, the recommended amounts of phosphate and potash should be cultivated into the planting bed before the soil is mulched. Irrigation water may also contain nutrients, particularly calcium, and care should be taken when mixing with fertiliser as insoluble compounds may form which can block emitters.

Points to consider

- Make allowance for nutrients applied in organic materials **(Section 2: Organic materials)**

Substrate strawberry production

When strawberries are grown in an inert substrate, a complete nutrient solution is required. Table 7.10 provides guidelines for the normal range of nutrients in solution. Normally, a conductivity of 1.4 mS/cm is maintained during growth and production for main crop ‘June bearers’ and the value should not exceed 2.0 mS/cm.

High salinity can cause marginal necrosis and stimulate leaf and flower tip burn. During vegetative growth the substrate K:Ca ratio (based on mg/litre K and Ca) should be maintained at 0.65, and at 0.7–0.8 during flowering and fruiting to improve fruit taste and firmness.

Plants grown on substrates are very sensitive to excessive concentrations of zinc, boron and sodium in the nutrient solution. Deficiency of iron and manganese can occur at high (alkaline) pH levels in the substrate.

The nutrients will need to be adjusted depending on whether peat or coir substrates are used. Coir is usually supplied unfertilised and therefore needs wetting up for 2–3 days before planting with a feed solution. It needs more calcium, magnesium and sulphur, but less boron and potassium when used fresh.

Owing to its inherently high pH, coir needs a lower solution pH (5.3–5.8) than for peat (5.6–6.0). Furthermore, feed recipes also depend on the chemical composition of the irrigation water and should be modified during the growing season according to the results of substrate, leaf tissue and drainage solutions analyses.

Careful scheduling of irrigation will help to improve water and nutrient use efficiencies. Recent work has shown savings of 10–20% where irrigation is scheduled to match demand with supply. Monitor substrate moisture content to establish which irrigation events can be reduced to save water and fertiliser.

Table 7.10 Guidelines for nutrient solution for strawberry production on substrate

Nutrient	Normal range
Element	**mg/litre**
Nitrogen (NO_3)	110–140
Nitrogen (NH_4)	7–14
Phosphorus (P)	46
Potassium (K)	140–250
Magnesium (Mg)	30–40
Calcium (Ca)	140–180
Sulphate (SO_4)	50–100
Iron (Fe)	1.1–1.7
Zinc (Zn)	0.46–0.65
Boron (B)	0.11–0.17
Manganese (Mn)	0.55–1.11
Copper (Cu)	0.03
Molybdenum (Mo)	0.05

Further information

Principles of strawberry nutrition in soilless substrates
Understanding and measuring conductivity in soilless substrate grown soft fruit crops
Strawberry analysis chart – optimum ranges
horticulture.ahdb.org.uk/publications-portal

Strawberry feed calculator
horticulture.ahdb.org.uk/strawberry-feed-calculator

Leaf analysis for top and soft fruit

Leaf analysis is an essential technique for general monitoring of nutrient status and the diagnosis of nutritional disorders. Separate samples should be taken in a similar manner from good and poor areas of growth so that the results can be compared.

In addition, knowledge of leaf nutrient concentrations has proved useful for assessing the nutritional status of crops. Satisfactory ranges for optimal growth and cropping are given in Tables 7.11, 7.12 and 7.13. Where analysis results are to be compared to these standards, it is essential that a representative sample is taken in the correct way and at the correct time.

Because there are seasonal and other factors that influence leaf nutrient concentrations, leaf analysis must be interpreted carefully. Leaf nutrient levels can also vary between varieties. Where there is sufficient information, the standard ranges take account of differences between varieties.

Leaf analysis can be used to provide a more complete indication of the adequacy of the orchard fertiliser programme than can be obtained from soil analysis alone. Where leaf nutrient levels are below the satisfactory range, an increase in fertiliser use can be considered. However, before making a change, the cause of the problem should be further investigated to ensure that other factors such as soil compaction or disease are not involved.

Where the leaf nutrient level is consistently above the satisfactory range for several years, there is justification for a reduction in fertiliser use. In particular, high levels of nitrogen and potash can have adverse effects on apple storage quality and application rates can often be reduced.

A high manganese level indicates a need to check soil pH, as it is often associated with increased soil acidity but can also result from use of foliar feeds or fungicides containing manganese.

Table 7.11 Leaf analysis – nutrient ranges of major nutrients expressed as elements

Crop	Leaf sampling position[a]	Nitrogen (N)	Phosphorus (P)	Potassium (K)	Magnesium (Mg)	Sulphur (S)
	% in dry matter					
Apples						
Cox[b]	1	2.6–2.8	0.20–0.25	1.2–1.6	0.20–0.25	0.20–0.40
Bramley	1	2.4–2.8	0.18–0.23	1.2–1.6	0.20–0.30	–
Cherries	1	2.4–2.8	0.20–0.25	1.5–2.0	0.20–0.25	0.13–0.84
Pears						
Comice	1	1.8–2.1	0.15–0.20	1.2–1.6	0.20–0.25	0.17–0.26
Conference	1	2.1–2.6	0.15–0.20	1.2–1.6[c]	0.20–0.25	–
Plums	1	2.0–2.6	0.15–0.20	1.5–2.0	0.20–0.25	0.20–0.70
Blackcurrants	2	2.8–3.0	0.25–0.35	1.5–2.0	0.15–0.20	–
Raspberries	3	2.4–2.8	0.20–0.25	1.5–2.0	0.30–0.35	–
Soil grown strawberries	4	2.6–3.0	0.25–0.30	1.5–2.0	0.15–0.20	0.10–0.20
Vines	5	2.0–3.0	0.25–0.30	1.2–1.6	0.20–0.30	–
Blueberries	6	1.8–2.0	0.08–0.40	0.4–0.7	0.13–0.25	0.12–0.20

a. Leaf sampling position:
   1. Mid third extension growth, sampled mid–late August.
   2. Fully expanded leaves extension growth, sampled prior to harvest.
   3. Fully expanded leaves non-fruiting canes, sampled at fruit ripening.
   4. Lamina of recently matured leaves, sampled at fruit ripening.
   5. Leaf opposite basal fruit cluster, sampled at full bloom.
   6. Fully expanded leaves between late July and mid-August.

b. For Gala and Braeburn, follow Cox, however, the typical average for Gala is 2.3% N, and P content is less than in Cox.

c. Yield benefits are achieved at 1.6% K.

Table 7.12 Leaf analysis – nutrient ranges of micronutrients

Micronutrient	Deficiency	Optimum	High
	mg/kg in dry matter		
Manganese (Mn)	20	30–100	100[a]
Boron (B)[b]	15	20–40	40[c]
Zinc (Zn)	10	15–30	50
Copper (Cu)	5	7–15	15
Iron (Fe)	<45	45–250	

a. Manganese concentrations above 100 mg Mn/kg indicate that the soil is becoming acid. Check the soil pH.

b. Fruit analysis is the most reliable diagnostic technique for boron deficiency. Optimum levels are 1.5 to 4.5 mg B/kg fresh weight. Below 1.5mg B/kg indicates deficiency.

c. Excess boron levels can promote premature ripening and senescence in fruit.

Further information

Principles of strawberry nutrition in soilless substrates
Strawberry analysis chart – optimum ranges
Understanding and measuring conductivity in soilless substrate grown soft fruit crops
horticulture.ahdb.org.uk/publications-portal

Strawberry feed calculator
horticulture.ahdb.org.uk/strawberry-feed-calculator

Table 7.13 Leaf analysis – substrate grown strawberries

	Deficiency	Optimum	High	Notes
	% in dry matter			
Nitrogen (N)	<1.5	2.0–3.5		• Deficiency causes small, yellow or reddish leaves and poor growth • High levels can cause excessive growth
Phosphorus (P)		0.3–0.6		• Deficiency causes small pale leaves, small fruit and lower yields
Potassium (K)		1.5–3.0		• Deficiency causes poorer flavoured fruit and brown leaf margins • Excess levels limit Ca uptake and affect fruit firmness and colour
Magnesium (Mg)		0.3–0.5		• Deficiency causes interveinal reddening of older leaves • Excessive magnesium is not normally a problem but could reduce K uptake
Sulphur (S)		>0.01		
Calcium (Ca)		1.0–2.0		• Deficiency causes tip-burn on the young leaves and soft fruit, particularly when associated with high K or Mg levels • Excessive calcium is not normally a problem
Sodium (Na)			>0.1–0.3	• Substrate grown crops are most susceptible • Excess causes scorch of petioles and sepals and yield reduction at higher levels • Reduce by flushing with calcium nitrate solution
Chloride (Cl)			>0.5	• Excess causes damage to roots and yield reduction but level depends on climate, substrate and plant type • Reduce by flushing with calcium nitrate solution
	mg/kg in dry matter			
Boron (B)	<30	30–50	>65	• Deficiency causes yellowed leaves and small, malformed fruit • Excess causes leaf burn and in extreme cases sepal and calyx scorch
Copper (Cu)	<2	5–20	>25	• Deficiency causes yellowed leaves, shoot die-back and small fruit • Excess symptoms are not normally seen in substrate strawberries
Iron (Fe)	<45	50–200	>350	
Manganese (Mn)	<20	50–250	>250	• Deficiency causes interveinal leaf yellowing, more diffuse than with Fe deficiency • Deficiency can be due to poor root growth or high pH • Excess symptoms are not normally seen in substrate strawberries
Molybdenum (Mo)	<0.3	0.5		• Deficiency or excess symptoms are not normally seen in substrate strawberries
Zinc (Zn)	<20	20–65	>120	• Deficiencies cause pale green leaves with narrow concave blades – some authorities also report poorer flavoured fruit • Excess causes leaf scorch and reduces Fe uptake

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Apple fruit analysis

Analysis of fruit sampled within three weeks of picking is a useful indicator of the risk of some physiological disorders in stored apples. Results can also be used to rank orchards for potential storage quality. During the period between sampling for analysis and harvesting the fruit, the concentration of calcium falls mainly due to dilution as fruit size increases. Analysing fruit too far in advance of harvest may over-estimate the storage potential.

- Fruit samples should be taken as near to harvest as possible but within two weeks of picking
- In each orchard, randomly select at least 20 trees of the same age and variety
- Take one apple at random from each tree, alternating from side to side and at different heights but ignore abnormally large or small fruits
- Try to make the sample representative of the side of trees where most fruit is growing
- Place the 20 apples in a clean polythene bag and label clearly to indicate cultivar, orchard, farm and sampling date
- If areas of the orchard have been managed differently, for example as regards soil or tree management or there are areas differing in terms of growth and cropping, then these should be sampled separately
- It may be necessary to segregate sections of the orchard at picking time and to allocate the fruit to different stores based on the indicated storage potential

If fruit analysis produces consistently high or low concentrations of a particular nutrient over two to three years, modification of fertiliser application should be considered. The most likely change will be a reduction in nitrogen or potash use. Fruit analysis may also show deficiencies of calcium or phosphorus which can reduce fruit storage quality. These deficiencies can be corrected by foliar sprays of calcium and phosphorus or by post-harvest calcium treatments.

Further information
Apple Best Practice Guide
apples.ahdb.org.uk

Table 7.14 Average nutrient concentrations in Cox, Bramley and Gala apples (sampled at harvest)

Crop	Nitrogen (N)	Phosphorus (P)	Potassium (K)	Magnesium (Mg)	Calcium (Ca)
	mg/100g fresh weight				
Cox	50–70	11.0 minimum	130–150	5.0	4.5 minimum[a] 5.0 minimum[b]
Bramley	60 maximum	9.0 minimum	105–115	5.0	4.5 minimum[a] 5.0 minimum[b]
Gala harvest	42	9.3	122	5.0	7.4

a. For controlled atmosphere storage (Cox in 2% oxygen until late February or 1.2% oxygen until late March; Bramley in 8–10% carbon dioxide until June or 5.0% carbon dioxide plus 1.0% oxygen until July).

b. For storage in air at recommended temperature (Cox until mid-October; Bramley until November).

Satisfactory nutrient concentrations have been established for Braeburn, Bramley, Cox and Gala apples at harvest (Table 7.14) and two weeks prior to harvest (Table 7.15). The standards given for calcium and potassium concentrations in Cox also apply to Egremont Russet.

Table 7.15 Average nutrient concentrations in Gala and Braeburn apples (sampled two weeks prior to harvest)

Crop	Nitrogen (N)	Phosphorus (P)	Potassium (K)	Magnesium (Mg)	Calcium (Ca)
	mg/100g fresh weight				
Gala	45	10.2	106	5.3	9.6
Braeburn	52	11.9	102	5.1	6.3

- **Gala is naturally low in P compared to Cox, but this does not affect storage potential**
- **Gala is naturally high in Ca and does not suffer from Ca-dependent storage disorders**
- **Large concentrations of K in Gala fruit may increase the risk of breakdown**
- **Gala fruits higher in Ca and lower in K may be firmer ex-store**
- **Braeburn has a similar composition to Cox, except that K concentration appears lower**
- **Cox calcium threshold concentrations may be used to judge the storage potential of Braeburn apples**

Nitrogen (N) – As the nitrogen content increases, fruit becomes more susceptible to rotting, loss of firmness, poor skin finish and a lack of red colour. Above 80 mg N/100g the risk of disorders in Cox is high. In Bramley, a large nitrogen concentration leads to more green colour but with a risk of lower firmness.

Phosphorus (P) – At phosphorus contents below 11 mg P/100g in Cox, there is an increased risk of fruit losing firmness and developing breakdown, particularly if calcium is also low. In Bramley, the phosphorus threshold for breakdown is lower at 9 mg P/100g.

Potassium (K) – A high potassium content will increase the risk of bitter pit, *Gloeosporium* rotting and core flush. The risk of bitter pit is also greater if the calcium level is low in relation to potassium. Generally, fruit flavour and acidity increase with increasing levels of potassium. Thus, if calcium levels are adequate (over 5.5 mg Ca/100g), large concentrations of potassium may be advantageous in terms of fruit quality.

Magnesium (Mg) – A high magnesium content will increase the risk of bitter pit, especially when calcium levels are marginal.

Calcium (Ca) – Calcium levels of 5.0 mg Ca/100g and above are necessary to maintain high quality throughout long-term storage. However, the storage potential will be modified depending on the content of other elements, especially potassium and phosphorus. Disorders associated with low calcium (bitter pit in particular) are more likely to occur in apples of a given calcium content that are stored in air rather than controlled atmosphere. Thus, fruit which meets the standards for nitrogen, phosphorus, potassium and magnesium and has a calcium concentration in the range of 4–5 mg Ca/100g should not be rejected for mid-term controlled atmosphere storage, as it is unlikely to develop commercially significant levels of bitter pit or breakdown. This much lower risk is reflected by the dual standards for calcium given in the table.

The risk of bitter pit and susceptibility to *Gloeosporium* will depend on the ratio of K:Ca. If the K:Ca ratio is over 30:1 in air-stored Cox or Bramley stored in controlled atmosphere, or over 25:1 in air-stored Bramley, commercially important losses due to bitter pit are likely. Where calcium contents are marginal (3.5–4.0 mg Ca/100g) and fruit phosphorus is also less than 9.0 mg P/100g, both Cox and Bramley are more susceptible to breakdown. In such cases, Cox should be marketed early. Bramley should be stored at a higher temperature (average 4.5°C) and sold earlier than fruit with optimum levels of calcium and phosphorus.

Gloeosporium risk is dependent on the level of inoculum in the orchard and is influenced by skin finish, fungicide programme and rainfall prior to harvest. Fruit analysis can give an indication of fruit susceptibility to *Gloeosporium* but not necessarily the eventual amount of rotting.

The incidence of senescent breakdown is greatest in late-picked fruit for any given content of phosphorus and calcium.

Susceptibility to low temperature breakdown in Cox stored at 3.0°C (air) and 3.5°C (controlled atmosphere), although less common in Bramley at 4.0°C, is also partly due to low calcium and phosphorus contents.

Hops

See page 12 for pre-planting fertiliser recommendations. Fertiliser is not required in the establishment year provided appropriate pre-planting fertilisers have been applied.

Table 7.16 Nitrogen in established hops (second and subsequent years after establishment)

	kg N/ha
Deep silty soils	180
Clay soils	200
Other mineral soils	220

The recommended rates are for maximum yield situations and should be applied annually. Nitrogen can reduce the alpha-acid content of hop cones, though it may produce more alpha-acid per hectare because the crop yield is greater. Where progressive *Verticillium* wilt is present, high nitrogen rates will make hops more susceptible to this disease, so reduce the recommended amount to 125–165 kg N/ha where there is a risk of wilt.

Nitrogen should be split into two or three applications, the first dressing being given in late March or April, the second during May and the third in late June or early July. There is some evidence that late hop varieties especially, respond to a three timing split, with the last application no later than early July. The total rate should be adjusted according to variety, irrigation and soil type.

Where trickle irrigation is used there is a benefit in using fertigation to apply nutrients.

Where large and frequent applications of organic manures have been used in previous years, reduce the nitrogen recommendation by 70 kg N/ha. Farmyard manure is best applied in the early summer to help minimise aggravating the effect of any wilt present, with alleyways treated in alternate years. Where organic manures have been applied in the previous 12 months, the nitrogen rate should be reduced according to the information in **Section 2: Organic materials**.

Table 7.17 Phosphate, potash and magnesium in established hops

	P, K, or Mg Index					
	0	1	2	3	4	5 and over
	kg/ha					
Phosphate (P_2O_5)	250	200	150	100	50	0
Potash (K_2O)	425	350	275	200	100	0
Magnesium (MgO)	150	100	50	0	0	0

Hops require the maintenance of large soil nutrient reserves, P Index 4, K Index 3 and Mg Index 2. Potash is important and care must be taken to ensure that the recommended rates are applied annually. To avoid induced magnesium deficiency, the soil K:Mg ratio (based on soil mg/litre K and Mg) should be no greater than 3:1.

Farmyard manure

Farmyard manure has been traditionally used on hops. As well as supplying nutrients it helps to improve the structure of cultivated soils. Now that few soils growing hops are cultivated, there is less need for regular applications of bulky organic manures. Farmyard manure is recommended where the soil continues to be cultivated and where land is being prepared for planting.

Extreme caution should be exercised in the use of farmyard manure or slurry where *Verticillium* wilt is known or suspected to be present. Heavy applications of manure, in addition to supplying excess nitrogen, can reduce the soil temperature during the critical spring period. Low soil temperatures in the spring are known to make hops more susceptible to the disease.

Points to consider

- Make allowance for nutrients applied in organic materials **(Section 2: Organic materials)**

Conversion tables

Metric to imperial

1 tonne/ha	0.4 tons/acre
100 kg/ha	80 units/acre
1 kg/tonne	2 units/ton
10 cm	4 inches
1 m^3	220 gallons
1 m^3/ha	90 gallons/acre
1 kg/m^3	9 units/1000 gallons
1 kg	2 units

Note: a ‘unit’ is 1% of 1 hundredweight, or 1.12lbs.

Imperial to metric

1 ton/acre	2.5 tonnes/ha
100 units/acre	125 kg/ha
1 unit/ton	0.5 kg/tonne
1 inch	2.5 cm
1,000 gallons	4.5 m^3
1,000 gallons/acre	11 m^3/ha
1 unit/1,000 gallons	
1 unit	0.5 kg

Element to oxide

P to P_2O_5	Multiply by 2.291
K to K_2O	Multiply by 1.205
Mg to MgO	Multiply by 1.658
S to SO_3	Multiply by 2.5
Na to Na_2O	Multiply by 1.348
Na to salt	Multiply by 2.542

Oxide to element

P_2O_5 to P	Multiply by 0.436
K_2O to K	Multiply by 0.830
MgO to Mg	Multiply by 0.603
SO_3 to S	Multiply by 0.4
Na_2O to Na	Multiply by 0.742
Salt to Na	Multiply by 0.393

Fluid fertiliser

kg/tonne (w/w basis) to kg/m^3 (w/v basis)	Multiply by specific gravity

Further information

Conversion calculators

cereals.ahdb.org.uk/tools/agronomy-calculators

Glossary

Available (nutrient)	Form of a nutrient that can be taken up by a crop immediately or within a short period so acting as an effective source of that nutrient for the crop.
Calcareous soil	Soil that is alkaline due to the presence of free calcium carbonate or magnesium carbonate or both.
Cation	Positively charged form of an atom or molecule for example potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}) and ammonium (NH_4^+).
Clay	Finely divided inorganic crystalline particles in soils, less than 0.002 mm in diameter.
Closed period	Period of the year when nitrogen fertilisers or certain manures should not be applied unless specifically permitted. Closed periods apply within NVZs.
Compost	Organic material produced by aerobic decomposition of biodegradable organic materials.
Content (nutrient)	Commonly used instead of the more accurate 'concentration' to describe nutrients in fertiliser or organic manure. For example, 6 kg N/t often is described as the nitrogen content of a manure.
Cover crop	A crop sown primarily for the purpose of taking up nitrogen from the soil and which is not harvested. Also called green manure.
FACTS	UK national certification scheme for advisers on crop nutrition and nutrient management. Membership renewable annually. A FACTS Qualified Adviser has a certificate and an identity card.
Farmyard manure (FYM)	Livestock excreta that is mixed with straw bedding material that can be stacked in a heap without slumping.
Fertiliser	See Manufactured fertiliser.
Fluid fertiliser	Pumpable fertiliser in which nutrients are dissolved in water (solutions) or held partly as very finely divided particles in suspension (suspensions).
Green manure	See Cover crop.
Incorporation	A technique (discing, rotovating, ploughing or other methods of cultivation) that achieves some mixing between an organic manure and the soil. Helps to minimise loss of nitrogen to the air through volatilisation and nutrient runoff to surface waters.
Leaching	Process by which soluble materials such as nitrate or sulphate are removed from the soil by drainage water passing through it.
Lime requirement	Amount of standard limestone needed in tonnes/ha to increase soil pH from the measured value to a higher specified value (eg 6.5 for arable crops). Can be determined by a laboratory test or inferred from soil pH.

Livestock manure	Dung and urine excreted by livestock or a mixture of litter, dung and urine excreted by livestock, even in processed organic form. Includes FYM, slurry, poultry litter, poultry manure, separated manures, granular and pelletised manures.
Maintenance application (phosphate or potash)	Amount of phosphate or potash that must be applied to replace the amount removed from a field at harvest (including that in any straw, tops or haulm removed).
Major nutrient	Nitrogen, phosphorus and potassium that are needed in relatively large amounts by crops.
Manufactured fertiliser	Any fertiliser that is manufactured by an industrial process. Includes conventional straight and NPK products (solid or fluid), organo-mineral fertilisers, rock phosphates, slags, ashed poultry manure, liming minerals that contain nutrients.
Manure	See Livestock manure.
Micronutrient	Boron, copper, iron, manganese, molybdenum and zinc that are needed in very small amounts by crops (see also Major nutrients). Cobalt and selenium are taken up in small amounts by crops and are needed in human and livestock diets.
Mineral nitrogen	Nitrogen in ammonium (NH_4) and nitrate (NO_3) forms.
Mineralisation	Microbial breakdown of organic matter in the soil, releasing nutrients in crop-available, inorganic forms.
Nitrate vulnerable zones (NVZs)	Areas designated by Defra as being at risk from agricultural nitrate pollution.
Offtake	Amount of a nutrient contained in the harvested crop (including straw, tops or haulm) and removed from the field. Usually applied to phosphate and potash.
Olsen P	Concentration of available P in soil determined by a standard method (developed by Olsen) involving extraction with sodium bicarbonate solution at pH 8.5. The main method used in England, Wales and Northern Ireland and the basis for the Soil Index for P.
Organic material (manure)	Livestock manures and all other nitrogen-containing organic materials such as sewage sludge, composts, food wastes, and organic wastes (treated and untreated).
Organic soil	Soil containing between 10% and 20% organic matter (in this guide). Elsewhere, it sometimes refers to soils with between 6% and 20% organic matter.
Peat soil	Soil containing more than 20% organic matter.
Run-off	Movement of water across the soil surface which may carry nutrients from applied organic materials or fertilisers and soil particles.
Sand	Soil mineral particles larger than 0.05 mm.
Silt	Soil mineral particles in the 0.002–0.05 mm diameter range.
Slurry	Excreta of livestock (other than poultry), including any bedding, rainwater and washings mixed with it, that can be pumped or discharged by gravity. The liquid fraction of separated slurry is also defined as slurry.

SNS Index	Soil Nitrogen Supply expressed in seven bands or Indices, each associated with a range in kg N/ha.
Soil Index (P, K or Mg)	Concentration of available P, K or Mg, as determined by standard analytical methods, expressed in bands or Indices.
Soil Nitrogen Supply (SNS)	The amount of nitrogen (kg N/ha) in the soil that becomes available for uptake by the crop in the growing season, taking account of nitrogen losses.
Soil organic matter	Often referred to as humus. Composed of organic compounds ranging from undecomposed plant and animal tissues to fairly stable brown or black material with no trace of the anatomical structure of the material from which it was derived.
Soil texture	Description based on the proportions of sand, silt and clay in the soil.
Soil type	Description based on soil texture, depth, chalk content and organic matter content.
Target Soil Index	Lowest soil P or K Index at which there is a high probability crop yield will not be limited by phosphorus or potassium supply. See Soil Index (P, K or Mg).
Trace element	See Micronutrient.
Volatilisation	Loss of nitrogen as ammonia from the soil to the atmosphere.

Notes

Notes

Notes

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Greenhouse Gas Action Plan:
The industry-wide Greenhouse Gas Action Plan (GHGAP) for agriculture focuses on improving resource use efficiency in order to enhance business performance whilst reducing GHG emissions from farming.

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