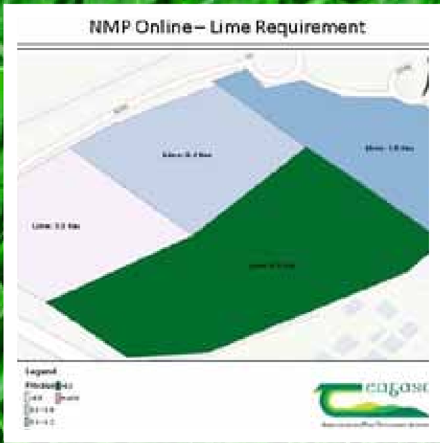
MAJOR & MICRO NUTRIENT ADVICE FOR PRODUCTIVE AGRICULTURAL CROPS



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teagasc
Agriculture and Food Development Authority

MAJOR AND MICRO NUTRIENT ADVICE FOR PRODUCTIVE AGRICULTURAL CROPS

4rd Edition 2016

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Contents

1. Introduction

A major responsibility of the research staff at Johnstown Castle has been the publication of leaflets, booklets and manuals giving nutrient and trace element advice for grassland and crops. This began in the 1940s and was the scientific basis for soil analysis (Coulter 2000), since then, further updates were published by Coulter in 2004 (2nd edition) and by Coulter and Lalor in 2008 (3rd edition). This version has now been enhanced and expanded to produce the present volume (4th edition) published by Wall and Plunkett in 2016. New sections soil types and nutrient cycling, fertilizer ingredients, adaptive nutrient management planning and nutrients for energy crops have been added. Additionally new information and updates based on the latest scientific findings have been made to soil acidity and liming, organic manures, grassland, and crops sections. Many of the chapters have been reorganised to make them easier to consult and the advice and tables have been redesigned to be compliant with the latest European and Irish legislation.

Sixteen elements are essential for plant nutrition and they are classified as major and micro nutrients. The major nutrients are carbon (C), hydrogen (H), oxygen (O), nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulphur (S). The micronutrients (present in much lower concentrations) are iron (Fe), manganese (Mn), copper (Cu), zinc (Zn) boron (B), molybdenum (Mo) and chlorine (Cl). Plants can contain other elements in significant quantities that are not essential for plant growth; for example silicon (Si), aluminium (Al) and sodium (Na). Most of the plant dry matter is made up of C, H, O and N (>95% of the plant dry matter). Plants obtain their requirements of C, H and O (and to some extent N) from air and water. The other essential plant nutrients are supplied from the soil or from fertilizers. The essential plant nutrients are also essential for animal nutrition. In addition, there are other nutrients that are essential for animal nutrition but not for plant nutrition, these include Na, selenium (Se), cobalt (Co), iodine (I) and chromium (Cr) and these are normally supplied to animals by the plants that they eat.

A major objective in this revision was to ensure that it was comprehensive and that it contained sufficient information to allow agricultural and farm advisors and consultants to recommend optimum levels of major and micro nutrients for the most important agricultural and field horticultural crops. The manual sets out to minimise conflicts between the need to ensure an economic return from grassland and tillage farming on the one hand, and growing concerns about losses of nutrients to water or gaseous emissions to the atmosphere on the other.

Many of the changes in this fourth edition were made necessary by legally binding requirements of the EU Nitrates Directive - National Action Programme (NAP) regulations, statutory instrument (SI) 31 of 2014 – the European Communities (Good Agricultural Practice for Protection of Waters) Regulations 2014. These NAP regulations have major implication for use of N and P in farming, both for the farmer and for organisations and advisers recommending levels of nutrient use for agriculture. Before the NAP regulations were enacted, Teagasc nutrient advice involving N and P was determined by the level of these nutrients that gave the economic optimum yield of the crop or grazing livestock in question, having regard to other factors such as the risk and consequences of losses to the environment and/or the needs of subsequent crops in the rotation. It has been the intention of Teagasc that fertilizer advice, if followed carefully, should have the desirable effect of optimising yield, protecting the environment, as well as saving money for the farmer. In revising this document, this policy has been continued, within the constraints of the NAP, particularly when dealing with the environmental consequences of N and P use.

Fertilizer rates for optimum yield may sometimes exceed the maximum allowed under the NAP. In the case of arable crops, Teagasc nutrient advice has always been based on expected crop yields. According to the NAP, N fertilizer rates for high yielding crops require that proof of historic yields is available, although, historic yields are not necessarily a good predictor of expected yields. Where proof of historic yields is not available, achieving high yields may require higher levels of N and P than are legally permissible.

In grassland farming, issues such as the *actual* winter housing period and slurry production on the farm, the amount of land with soil at P Index 4, or the level of concentrates used, could lead to maximum rates of N or P in the NAP being exceeded. In such cases, recommended rates must be modified to comply with the maximum rates.

Nutrient advice tends to be self-correcting when accompanied by frequent soil testing. Thus if soil variation or sampling errors cause nutrient applications to be higher than necessary, this will tend to be corrected following the next soil test. Since soil nutrient levels change slowly under most cropping systems, it is usually safe to base fertilizer advice on soil tests for four to five years from the date of sampling. Where soil analysis suggests that no nutrient applications are needed, or with very light soils which have limited buffering capacity, it is prudent to have soil analysis carried out every three years.

It is mandatory under the NAP that the nutrient value of applied organic fertilizers is taken into account in nutrient advice. Because of the variability of organic fertilizers, it is desirable to have a dry matter and an N, P & K analysis carried out every few years on manure samples from the farm.

In general, these guidelines apply to soils farmed under good conditions. When using the tables however, there is a need for nutrient advisors to consider both agronomic conditions and environmental risk factors such as slope, soil type, distance from water courses and time of application etc. before giving nutrient advice. The guidelines are for conditions of average fertility and growth and may need to be adjusted (within the limits specified in the NAP) according to the professional judgement of the advisor depending on soil conditions, weather, the appearance of the crop and the economic response to application of fertilizer.

Teagasc fertilizer advice is not static but is reviewed constantly in the light of new national and international research findings, changes in farm practices, nutrient regulations and the onset of new grass and crop varieties with different nutrient requirements.

Steps to Managing Soil Fertility

Soil fertility management needs to be managed over a long term basis as soil nutrient levels tend to change slowly. Optimising soil pH and the availability and supply of major nutrients such as P and K needs a planned approach over a numbers of years to ensure production levels are optimised in an environmentally and economically sustainable manner.

The following 5 key steps to good soil fertility management:-

1. Have soil analysis results for the whole farm.
2. Apply lime as recommended to achieve the target pH for the crop.
3. Aim to have soil test P and K in the target Index 3 in all fields.
4. Use organic fertilizers as efficiently as possible.
5. Make sure the fertilizers used are properly balanced.

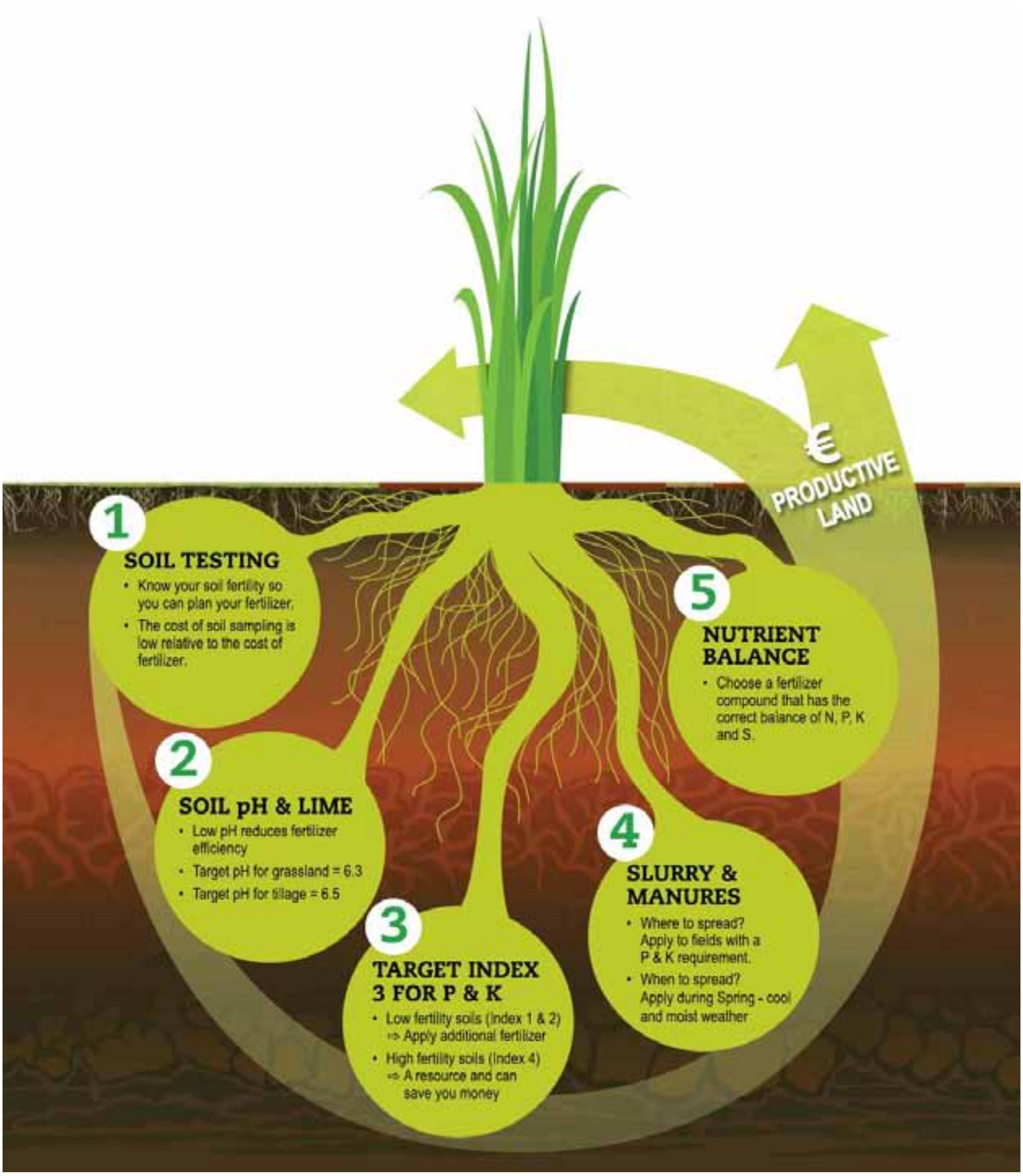


Figure 1.1- Five steps to managing soils fertility

2. Good Agricultural Practice for Protection of Water Quality

In order to maximise the efficiency of nutrient use on farmland and to minimise environmental impacts, application of nutrients should follow a code of good agricultural practice. The major environmental risks from nutrients are (a) leaching of nitrate from the soil to groundwater which can result in the nitrate levels in water supplies being unacceptably high; (b) surface loss or runoff of soluble P from soils or manure, or movement of P enriched clay to drainage channels, ditches or streams increasing the risk of eutrophication of rivers and lakes and (c) losses of ammonia or nitrogen oxides from chemical or organic fertilizers to the atmosphere with possible adverse effects on the upper atmosphere.

Good agricultural practice requires that nutrient supply be matched to crop demand, both in terms of the quantity applied and the time of application relative to the crop yield, soil and climatic conditions.

Nutrients should not be applied to water saturated or frozen soils or if heavy rainfall is expected. This helps to ensure that losses of P to surface water or N to ground water sources do not occur. Also, N fertilizer should not be applied during drought conditions, as it will be utilised less efficiently by the crop, thereby increasing the potential for losses to the environment.

On the 1st February 2006 the government transposed the EU Nitrates Directive – National Action Programme (Anon, 2006) into Irish law. The original legal instrument (SI 378 of 2006), called the Good Agricultural Practice for Protection of Waters Regulations has undergone 3 revisions (SI 101 of 2009, SI 610 of 2010 and SI 31 of 2014). This legally binding statutory instrument deals with the protection of waters from pollution caused by nitrates and phosphates from agricultural sources and is a now part of Irish law. Under the single farm payment scheme there are 13 Statutory Management Requirements (SMRs) of which compliance with the Nitrates Directive is one. Thus Irish farming must comply with the NAP regulations in order to meet cross compliance requirements.

The NAP includes a number of components:

- The livestock manure loading on a holding shall not exceed 170 kg/ha N each year averaged over the farmed area. Livestock farmers can apply each year for derogation to farm up to 250 kg/ha N but this will be granted subject to stringent environmental conditions.
- The country is divided up into zones, each of which has specific manure storage requirements. Each zone also has a specific period during which the application of organic and chemical fertilizers is prohibited. However, fertilizers are generally not required during the closed period, as crop utilization of nutrients is generally low, and there can be a greater risk of nutrient loss at these times.

- Nutrient supply should be matched to crop requirement, both in terms of quantity applied and the time of application relative to the crop yield, soil and climatic conditions.
- Buffer zones must be respected when applying organic or chemical fertilizers in order to prevent the movement of nutrients into water courses, as set out in the regulations.
- To reduce the risk of nutrient loss, organic or chemical fertilizers may not be applied when the soil is:
    - Waterlogged
    - Flooded
    - Frozen or covered with snow
    - Heavy rain is forecast within 48hrs
    - The ground slopes steeply giving a significant risk of water pollution.
- To reduce the risk of nitrate leaching and sediment runoff from tillage soils over the winter period, green cover must be maintained, and where land is ploughed, crops must be established within 6 weeks post ploughing during this winter period.

3. Soil Types and Nutrient Cycling

Plant production and nutrient cycling are two of the key functions that farmed soils must perform. Nutrient cycling is the capacity of soil to provide nutrition for food, fuel and fibre crops that are grown across the landscape. 'Cycling' stands for a movement of matter without getting lost out of an imaginary circle and that is exactly how we want essential plant nutrients to behave (Schroder & Wall *et al.,* 2016). The quality of agricultural soils is deemed to play a role in the cycling of nutrients in residues, indirectly by governing the productivity and harvest ability of crops and thus the effective capture of nutrients from soils, and more directly by its impact on the capacity to accommodate the reception of nutrients in residues and convert these nutrients in forms that can be utilized by crops.

Farmers regularly manage the fertility of the soils on their farms by applying fertilizers and organic manures to build-up or maintain the supply of nutrients required for the grass or crop types they produce. However, experienced farmers will know that not all soils (or fields) have the same production potential (or suitability for certain crop types) or respond in terms of their soil fertility status to the nutrients that are applied. While several factors will determine production potential and fertility status, one major denominator is soil type and most farms will have at least two different soil types, if not more, dispersed within the farm boundary. Given the nature of the Irish landscape and its origins (glaciation) there is often large variability in soils over relatively small spatial areas, even within towns-lands or farms. This poses a challenge for individual farmers and their advisors when planning nutrient and fertilizer management strategies for their farms. A blanket approach, where all fields, even with similar soil test results, receive and "are perceived to respond" to similar nutrient application rates may not happen in reality. This is because different soil types possess different characteristics and qualities. Some of the main characteristics related to soil fertility and nutrient cycling include parent material (rock type, glacial till or mineral deposit) that soil is derived from and its nutrient composition, soil texture (i.e. proportions of sand, silt & clay present), soil organic matter level, water holding capacity and drainage class (i.e. free draining vs. poorly draining).

Across the 11 Great Soil Groups identified in Ireland, the soil nutrient levels will have been influenced by agricultural production to some degree. However, four of these Great Soil Groups are usually found in either upland or mountainous areas. As a result, these soils will; exhibit shorter growing season (Podzols and Lithosols), will be too shallow and have too much rock outcrop (Rendzinas), or are too wet (Ombrotrophic peat soils consisting of raised and blanked bogs) to yield a return on investment in soil fertility. These characteristics limit the use range of these soils from an agricultural perspective and so these soils are therefore more likely to be used for extensive rough grazing by drystock. The more intensively farmed and productive soils such as Brown Earths, Brown Podzolics, Luvisols, Alluvial soils and some drained Surface-water and Groundwater Gleys are more likely to receive active management by farmers to influence their soil fertility status. However, the weathering and soil formation processes under which these have been created and the distinct soil properties that places these soils in each Great Soil Group category has a major influence on their response to fertilizer and manure additions and also how they maintain their long-term soil fertility status. Of the 16 elements essential for plant nutrition, the primary nutrients - nitrogen (N), phosphorus (P), potassium (K), and secondary nutrients, sulphur (S) magnesium (Mg) and calcium (Ca), are required in largest quantities by grassland and crops.

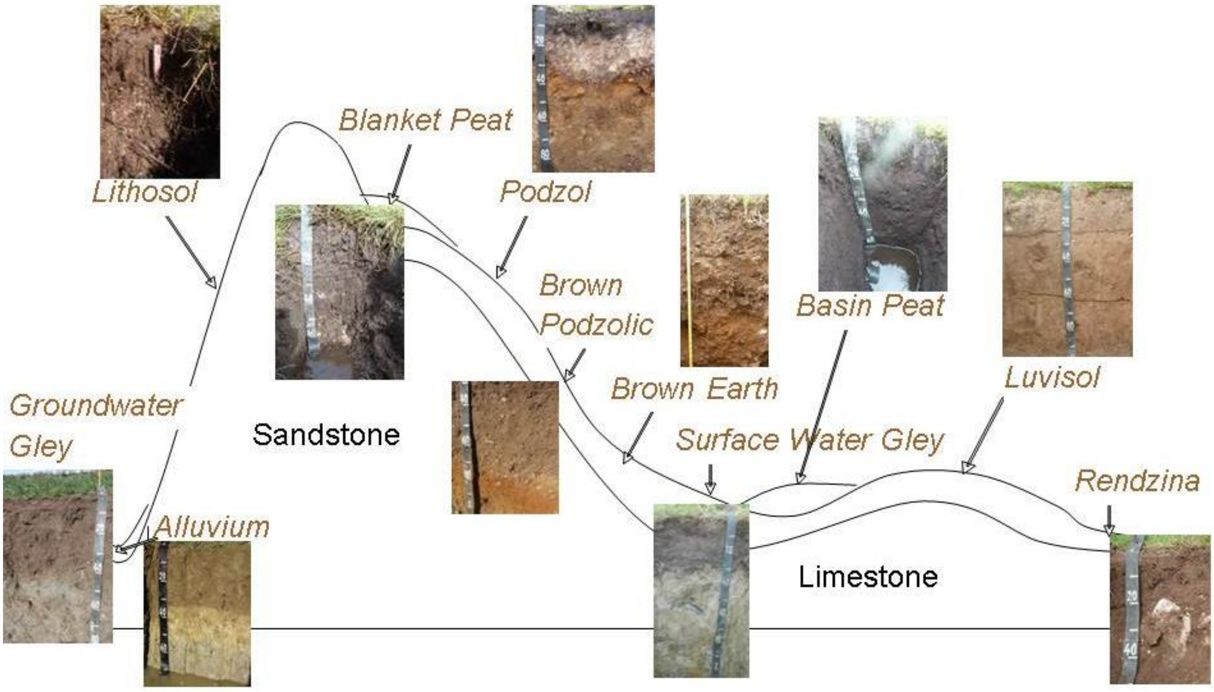


Figure 3.1. Great soil groups found in Ireland and the position that they are typically found within the Irish landscape (Simo *et al.,* 2014).

Soil pH and acidity

Soil pH is the measure of acidity and alkalinity in the soil and the natural pH of the soil is primarily dependent upon soil parent material. For example, soils that are formed from granite parent material will be more acid soils while in contrast, those derived from limestone parent material to produce more alkaline soils with a naturally higher pH. The pH status of the soil is a key factor which regulates nutrient availability in soils and is optimum between the pH range of 6.3 and 7.0. In Ireland soils formed from limestone parent material such as the Calcareous Brown Earths found in the west of Ireland and most Luvisols which are widely found across the midlands, may naturally have high pH status (> 7.0) and therefore do not require lime applications. In contrast Brown Podzolics naturally have inherently low nutrient and pH status (pH < 5.5) due to the leaching of nutrients, in particular iron and aluminium, from the top soil layer. Equally acid Brown Earths may be depleted in Ca and Mg which may have leached out. However, suboptimal soil pH is easy and cost effective to correct with regular applications of lime. On more poorly drained Gley soils, once corrected, the pH status will likely be maintained for longer as leaching of Ca and Mg from the profile is limited. On heavier clay rich soils Ca helps to keep soil particles apart and to increase soil aeration and drainage. Under acid conditions, where Ca levels are low Mg will have a more dominant role on soil structure making particles stick together. Hence, a balance between Ca & Mg is important: where soil is already high in Mg soil pH should be adjusted with calcium limestone.

Nitrogen

Nitrogen is the main driver of plant growth and is the cornerstone of all plant protein production. Organic matter (OM) is the main store of N in soils (can be in excess of 5000 kg/ha), therefore soils with higher soil organic matter such as Peats and Gley soils, have the potential to release more N to the growing crop. The rate at which N is released is dependent upon the ratio of C:N (10-12:1 is optimum) and soil conditions such, temperature, moisture and oxygen. Generally, the highest N release from the soil occurs in late spring and early autumn when soil temperature and moisture levels are favourable. However, N is a volatile nutrient, and moves freely through soils, plant, water and air. It exists in many different compound forms, some of which are available for uptake by plants (e.g. ammonium and nitrate), some of which are a potent greenhouse gas (e.g. nitrous oxide) and some of which can be lost in drainage water (e.g. nitrate). Grassland and crops grown on lighter and well drained soils such as Brown Earths and Brown Podzolics are likely to be very responsive to N fertilizer inputs. However, care must be taken when applying N to these soils, especially during wetter months, as there is a higher risk of the N being leached with draining water. In contrast Gley soils are more poorly drained due to either impermeable clay rich layer which stops water and nutrients from draining through (Surface water Gley) or from the up-welling of water from below (Groundwater Gley). When conditions are favourable, these Gley soils can release N from their organic matter reserves such as, during periods when they are drying out or beginning to wet-up. During prolonged wetter periods when Surface water and Groundwater Gleys and Alluvium soils (which are prone to flooding) become water logged there is a risk of denitrification where N will be lost to the atmosphere as nitrous oxide gas. Many Gley soils have artificial drainage systems which help these soils to dry out more quickly in spring increasing the grass growing season and reducing the risk of N loss.

Different soils have variable capacity to produce grass and crops due to their intrinsic physical and chemical properties, their biology and the climatic environment in which they occur. It is considered that Irish grassland soils have the capacity to supply large quantities of N (17 kg to 131 kg N ha^{-1} over a 5 week growth period) when conditions are favourable in the absence of fertilizer inputs (McDonald *et al.,* 2014) through biological N mineralisation processes. This highlights the importance of customised nutrient management plans that will facilitate efficiencies to be achieved by increasing the efficiency with which nutrients are acquired by crops and also economically through a reduction in the requirement for external inputs (Wall and McDonald, 2014).

Phosphorus

In the soil, the vast majority of P is bound so tightly that it is unavailable to plants. In organic systems, with no input of water-soluble P fertilizers, plants rely on their symbiosis to "mine" P from the soil particles and in return, the plants supply the fungi with sugars. Phosphorus plays a central role in the energy regulation of all organisms and its availability is likely to be most limited early in the season when soils are cold and wet. However, the "behaviour" of P is completely opposite to that of N, as it is easily bound to the soil or in soil organic matter. When mining soil P for plant growth, we need to keep an eye on the total P reserves that remain in the soils. There are dramatic variations in the total P reserves between soils and this can simply be the result of the geology of the soil (derived from limestone vs. acidic rock) and its mineral makeup (e.g. the presence of aluminium, iron oxides or calcium) which affects its storage and of past nutrient management. For example, aluminium rich acid Brown Earths (e.g. Clonroche soil series) have the potential to store more P than typical Brown Earths found elsewhere.

Plant available P in the soil is a much smaller proportion of these total P reserves (usually less than 1%) and is measured using the Morgan's P soil test to indicate how much immediately available P can be supplied by these reserves. However, the supply of available P can differ between soil types and some soils will retain or 'lock-up' P if they are prone to becoming acidic or have high clay content with high quantities of aluminium. This if often why soil type can influence how soil test P levels respond to P fertilizer applications and why some soils (especially those with higher clay content and those over shale bedrock) have the potential to "lock up" fertilizer P and may be more difficult to build-up soil test P levels. Therefore, farmers need to adopt different fertilizer management strategies to overcome this issue such as applying the recommended P fertilizer for crop using a "little and often" approach rather than all at once.

Where soil P levels are in continual decline over a number of years due to large crop, milk and meat off-takes, it will result in P-reserves being eventually exhausted resulting ultimately in P-deficiency in grass and other crop production. In such circumstances, the response in terms of plant available P (i.e. soil test P) of different soil types to fertilizer P, rock phosphate, manures or compost applications for successive seasons, may be different due to their physical, chemical and biological characteristics. In contrast, if a soil test P levels are high/excessive, it may be important to discontinue P applications for two to three years and re-test the soil at that stage to monitor soil P levels after that time as P decline rates may also be different across soil types. Care should also be taken when applying P fertilizers and slurries on more poorly drained Gley soils as they pose a higher risk for P loss after heavy rainfall if water flows off the surface, representing a loss on investment.

Potassium

Potassium (K) is another essential nutrient required in large quantities by plants for plant health including reproduction and growth. It is necessary to regulate the opening and closing of stomata during photosynthesis and is therefore essential to regulate CO_2 uptake. The behaviour of K lies somewhere in between that of nitrogen and phosphorus: it can be bound, but also move quite freely through soil, water and plants. Brown Earth and Brown Podzolic soils may have high K reserves and supply for crop production, derived from their parent material, especially if formed from shale and mud stone geology. However, significant quantities of K can be removed from sandier soils (lighter textured soils) such as sandy loams and loamy sands. Lighter soils may also have lower cation exchange capacity (CEC) and poor ability to store or build K reserves over a longer period, and will require regular K applications in fertilizers or organic manures to maintain K supply. In contrast Luvisols with limestone parent material are the most prominent K-fixing soils which are more likely to occur when organic matter levels are low and when these soils are used for tillage. On K-fixing soils it is difficult to build-up soil test K levels as these soils naturally maintain low soil K in soil solution (i.e. in a plant available form).

More frequent applications of K fertilizers or manures within the growing season are warranted on these soils to maintain rather than build-up soil K supply. On Peat soils both K and Mg are easily released and they are less likely to strongly bind K fertilizer applications. Where K concentrations in soils are suboptimal for grass or crop production, it is often called the "hidden" deficiency with the main effect of a K-deficiency in grassland associated with a change in the botanical composition of grasslands – changing from productive species, such as ryegrass, to unproductive or unpalatable species such as bentgrass or cocksfoot.

Sulphur

Sulphur (S) is an important constituent of a number of amino acids, the building blocks of proteins, and vitamins that are vital to both plants and animals. In plants, S is required for photosynthesis, and is also closely associated with nitrogen in many plant processes. There is no soil test available to accurately predict S deficiency in soils. The S content and the N to S (N:S) ratio in plants are useful guides to assessing the likelihood of a response to S fertilizers. The S content should be greater than 0.2% in dry matter, and the N:S ratio should be less than 15:1.

In Ireland, sulphur levels in the soil tend to be lower than in many parts of Europe, because we lack of heavy industry and the associated S depositions from the atmosphere are low (typically 1-2 kg/ha). In sandier textured and well-drained soils (Brown Podzolics, and Brown Earths) crops can be very responsive to S applications as S can be leached with drainage water from the topsoil. Sulphur deficiencies may be more apparent on these soil types when high levels of N fertilizers are being used, or where high yielding tillage and silage crops are removing large quantities of S. Therefore, applications of N+S fertilizers are required to meet crop demand. More poorly drained, heavier textured and high OM soils (such as Gley soils, Peats, or Brown Earths under long term grassland) have greater potential to release S from OM reserves, making it available to meet the demands of crop uptake.

Excess S may affect the trace element nutrition of plants and animals. Copper (Cu) deficiency in Irish soils is generally caused either by low Cu levels in soils, or more commonly by high soil Molybdenum (Mo) levels. Sulphur, Cu, and Mo can interact in the rumen and make Cu less available to the animal. Sulphur applications have also been associated with reduced selenium uptake in herbage.

Soil Specific Nutrient Management

As not all soils are created equal it is appropriate that nutrient applications need to be tailored to the particular soil type in order to achieve the correct nutrient balance required for the growing crop. To implement soil fertility advice for individual soil types at farm level knowledge of the soils present is required. Teagasc has mapped our soils at a regional scale, with soils information available through the Irish Soil Information System (http://gis.teagasc.ie/soils/index.php). This is a major step towards identifying the typical soil types and soil properties a farmer could expect to find on his farm within a region on the map. The future challenge is to achieve improved nutrient management and increased profitability and sustainability of farming systems by linking soil fertility knowledge to these different soil types and to train and support professional advisors and farmers to identify and manage soil appropriately.

Agriculture cannot be sustained without the replenishment of nutrients removed by crops, as plant growth is dependent upon a continuous supply of mineral nutrients from the soil. Getting the balance right is critical. Fertilizers are applied to grassland and crops to produce an appropriate level of soil fertility that supports adequate crop growth (and animal performance) and maintain an adequate level of soil fertility by replacing all nutrient off-takes, be they in the forms of milk, meat or crops. Nutrient deficiency, particularly N, P, K and S will dramatically reduce agricultural output from land based enterprizes. Poor soil fertility may also lead to inefficient use of fertilizer and manure nutrient applications by grassland and crops potentially increasing nutrient losses to the environment. In order for Ireland to meet its obligations under the Water Framework Directive (WFD), and Green House Gas (GHG) Emission Targets coherent action by all sectors, including agriculture, to reduce nutrient losses to the environment will be required.

4. Soil Sampling

The results of a soil analysis are only as good as the sample on which it is based. To give reliable advice, a soil sample must be representative of the area sampled and be taken to a uniform depth.

Since soil nutrient levels tend to change slowly under most cropping systems, it is usually safe to base fertilizer advice on soil tests for up to four to five years from the date of sampling. On very light soils or soils where P or K fixation is known to occur, it is prudent to have soil analysis carried out every three years. More frequent soil sampling may also be needed to monitor whether the chemical balance between inputs and offtakes of nutrients is being maintained and to ensure that soil P, K or Mg levels have not dropped below the advised Soil Index.

The principle of soil analysis is to determine the average nutrient status of an area and to give a measure of the available nutrients in the soil. A sample normally consists of 0.25 – 0.5 kg of soil and this is taken to represent the entire area or field. As land contains approximately 2,000 tonnes of soil per hectare to a depth of 100 mm, it is imperative to obtain as representative a sample as possible so that the results will accurately reflect the soil nutrient status.

1) To take a soil sample it is essential to have a suitable soil corer, screw auger, etc. that will facilitate taking a soil sample to the desired sampling depth of 100 mm.

2) Ensure all soil sampling equipment is clean and free of rust or old soil residues to avoid contaminating the soil sample. Galvanised, brass or bronze sampling tools should not be used to collect soil samples that will be tested for micronutrients, e.g. for Zn.

3) Divide the farm into fields or areas and as a guide, take one sample to represent about 2 hectares. If the area is very uniform a sample maybe taken to represent up to 4 ha. Draw a plan of the farm showing all fields and giving each a permanent number e.g. Field No. 1, No. 2, etc. Keep the farm plan safely for future use.

4) Take separate samples from areas that are different in soil type, previous cropping history, slope, drainage or persistent poor yields, even if the areas of these are less than 2 ha.

5) Avoid any unusual spots such as old fences, ditches, drinking troughs, dung or urine patches or where fertilizer / manures or lime has been heaped or spilled in the past.

6) Do not sample a field until 3 to 6 months after the last application of P and K. Where lime has been applied allow a time lag of up to 2 years before sampling for lime requirements.

7) Where possible take a minimum of 20 soil cores, mix them together, and take a representative sub-sample for analysis, making sure the soil sample box is full.

8) Take a representative soil sample from the field either by walking in a W shaped pattern. Alternatively, a grid pattern may also be used; this is more representative of the area. See figures 4-1 and 4-2 below.

9) When taking a sample, avoid walking in the lines of normal fertilizer and lime spreading operations on the field.

10) Sample at the same time of the year to aid comparisons of soil sample results.

11) Avoid sampling under extremes of soil conditions e.g. waterlogged or very dry soils.

12) Place the soil sample in a soil box / container to avoid contamination and write the sample number on the soil box/ container with a black permanent marker.

Soil sampling patterns

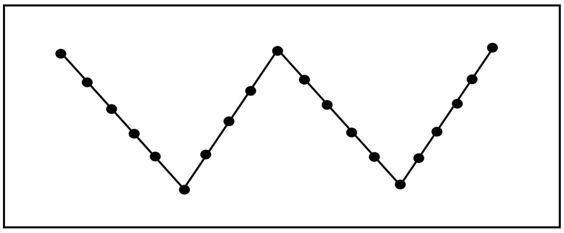


Figure 4-1. Sampling using a W shaped (or M shaped) path is most convenient

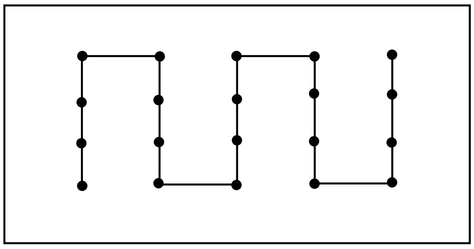


Figure 4-2. Sampling using a grid pattern better represents the field area

Client, spatial and agronomic information about the soil sample is required by the laboratory before analysis can be performed. The soil information must be entered into a Laboratory Information Management System (LIMS) so that it can be tracked and verified as an official soil sample record.

Soil sample location

The soil sample location can be assigned to the soil sample when inputted through the NMP On-line system. The sample location can be submitted as a Department of Agriculture, Food and the Marine (DAFM) Land Parcel Identification Number (LPIN), which is accurate to the location of a field or land parcel; or as a herd number, which specifies the DED that the sample originates from or as a 10 km grid reference number. If there is any doubt about the location of a particular farm on the grid map then the appropriate 1:127,000 (half-inch) Ordnance Survey Map may be consulted.

The sample location information aids the laboratory in producing more reliable advice and guidelines for use of lime, major and micro nutrients.

Texture

The texture code is a number from 1 to 4 that distinguishes between mineral soils and peat, and between heavy and light soils. Texture 1 is sand or gravel, 2 is loam, 3 clay soil and 4 is used to denote peat. This information is essential for reliable lime and nutrient advice. In addition, both lime requirement advice and P nutrient advice are critically dependent on whether the sample is a peat or a mineral soil, so this information must also be given to the laboratory. When taking soil samples across a farm, it is important to classify each soil type into one of the above 4 categories to ensure correct nutrient advice.

Appendix 2 (Diamond, 2001) gives a quick guide to texture classes, as an aid to deciding the texture category. The definition of peats is discussed further in Chapter 7. Peats have a different Index system for nutrients and have very different properties to mineral soils. In particular, many nutrient ions are not strongly bonded to peat and can be lost to ground and surface water during heavy rains and fallow periods. The classification of soil as peat on the sample form should be decided carefully because of these considerations.

Soil type identification

Information on the soil type or soil association is not required for soil analysis but it may be useful for the advisor or consultant to decide on nutrient strategies. Detailed and general soil information may be obtained from the Irish Soil Identification System (http://gis.teagasc.ie/soils/index.php) and from Teagasc Soil Survey county reports and detailed soil maps for counties that have been surveyed.

5. Nutrient Management Planning (NMP Online)

5.1 Introduction

Over the last decade, since the introduction of environmental legislation on farms, nutrient planning has changed from being a relatively straightforward field by field process to being a complex whole farm nutrient balance based system. To deal with the new complexity a variety of nutrient planning tools have been prepared to aid farmers in meeting statutory requirements. However, the complexity of the statutory requirement provided plans which were not suitable for guiding farmers to apply chemical and organic fertilizers.

Teagasc undertook a process of consultation with farmers. The outcome of this process was a request for a divergence in output within a nutrient management planning system with tabulation based outputs for regulators but a much more visual output for farmers integrating mapping and graphical outputs that support the day to day actions at farm level. In developing NMP On-line Teagasc had three main objectives:

- To improve nutrient management at farm level in support of more efficient, competitive and profitable farming systems
- To improve the efficiency and quality of plans produced to meet the statutory requirements
- To improve environmental outcomes, particularly in relation to water quality and gaseous emissions

NMP On-line is available to all advisers and consultants working in Ireland. It facilitates the efficient production of high quality nutrient management plans and provides a basis for improving soil fertility management on Irish farms.

5.2 How NMP On-line Works

NMP On-line utilises a data-set of farm information to allow a consultant to work with a farmer to create a nutrient management plan. Much of the required data is available from other sources and the system integrates with a number of databases to speed up the planning process. Connected databases include Department of Agriculture Food and the Marine (DAFM) land parcel data, DAFM livestock information, and soil analysis results. Completion of the plan involves a sequential process; some components are optional (mapping and winter housing and storage). The tasks involved include;

1. Plan Setup
2. Importation or entry of soil analysis results
3. Entry of land parcels and mapping
4. Importation or entry of animal information
5. Entry of concentrate feed usage
6. Entry of animal housing information (Optional)
7. Entry of manure and soiled water storage (Optional)
8. Preparation of lime plan
9. Preparation of organic manure plan
10. Producing soil fertility and nutrient applications maps
11. Producing reports (Dependent on requirement)

The NMP On-line planning system is based on two main rule sets. The first is the European Union - National Action Programme (NAP) (Good Agricultural Practice for Protection of Waters) regulations. This provides the regulatory rules which set the limits for fertilizer use at farm level. The Teagasc Green Book (Major and Micro Nutrient Advice for Productive Agricultural Crops) provides the basis for the recommendation for field by field application of organic and chemical nutrient based on crop and animal requirements.

5.3 NMP On-line Outputs

A nutrient management plan needs to satisfy two basic requirements:-

1. To provide a plan to the farmer in a comprehensible format that will act as a guide to the application of organic and chemical fertilizer and which will support the achievement of a good soil fertility status and targeted crop output on the farm
2. To provide a plan to show compliance with regulation and to be in a format required by the statutory authorities

5.4 Fertilizer plans / Nutrient management plans

The system provides a number of NMP report types.

Farm Fertilizer Plans: All farmers require a nutrient management plan to help match nutrient applications to soil requirements as per soil test results, crop type and/or stocking rate etc. NMP On-line offers two main types of farm fertiliser plans;

<u>(1) Simple fertilizer plan -</u> this plan provides a report which focuses on the core nutrient management component of the plan.

<u>(2) Detailed fertilizer plan -</u> This plan provides a comprehensive output from the system including nutrient management, manure production and storage.

GLAS NMP Report: For farmers who are participating in the GLAS Agri-environmental scheme there is a report format which can be produced by the system. This report can be printed by the system for the farmer but is uploaded NMP Online directly into DAFM systems. This saves the requirement of interfacing with a GLAS system upload system.

Derogation NMP Report: For farmers who are applying for derogation to farm more intensively (i.e. up to a stocking rate of 250 kg/ha organic N) under the EU Nitrates Directive NAP there is a requirement to develop a detailed nutrient management plan which includes a comprehensive computation of organic manure storage.

5.5 NMP On-line; How the System Works

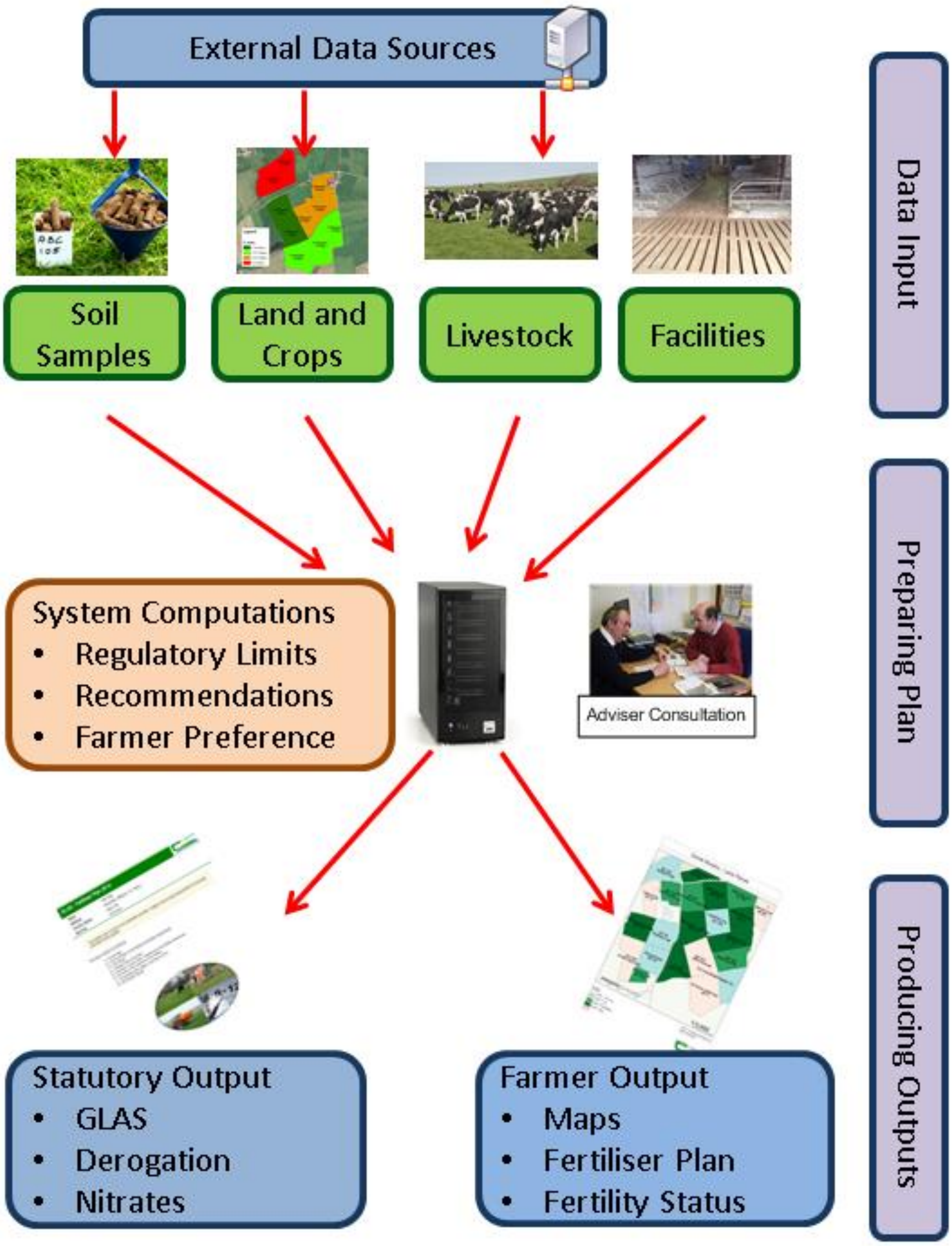
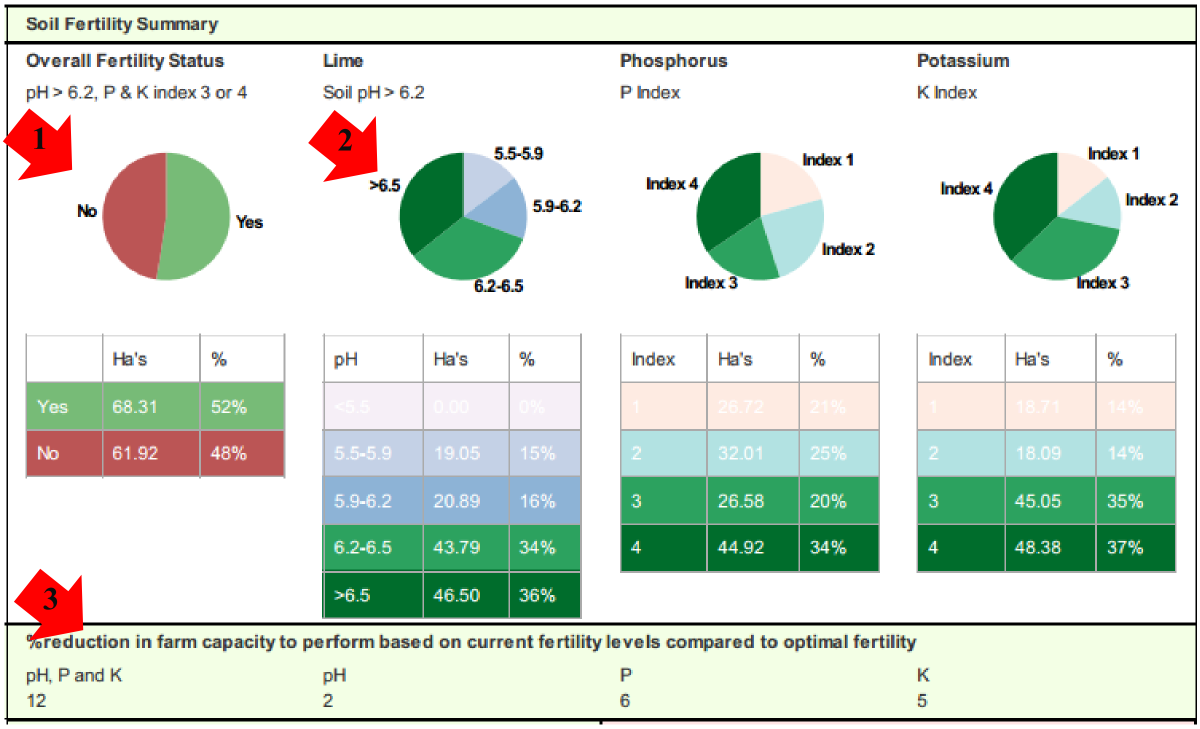


Figure 5-1. Overview of data inputs, plan preparation and outputs using NMP On-line

5.5.1 Soil Fertility Summary

All reports contain a Soil Fertility Summary (Figure 5-2) which highlights graphically the key soil fertility challenges and requirement on the farm. The purpose of the soil fertility summary is to allow the adviser and farmer to quickly assess overall soil fertility status and get an indication of the key priorities for action going forward. Highlighting the losses in production is intended to provide an incentive to deal with the problem.



	Ha's	%
Yes	68.31	52%
No	61.92	48%

pH	Ha's	%
<5.5	0.00	0%
5.5-5.9	19.05	15%
5.9-6.2	20.89	16%
6.2-6.5	43.79	34%
>6.5	46.50	36%

Index	Ha's	%
1	26.72	21%
2	32.01	25%
3	26.58	20%
4	44.92	34%

Index	Ha's	%
1	18.71	14%
2	18.09	14%
3	45.05	35%
4	48.38	37%

pH, P and K	pH	P	K
12	2	6	5

Figure 5-2. Soil fertility summary showing (1) overall soil fertility status, (2) proportions of farm in each index range for lime, P & K and (3) an estimate of the reduction in farm production capacity based on current soil fertility status.

5.5.2 Soil Fertility Report

1. **Overall fertility status -** How much of the farm achieves an overall high fertility status
2. **Component fertility status (Lime, P and K)** - Provides a quick overview of fertility status and the key issues to be addressed
3. **% reduction in crop production capacity across the farm due to low soil fertility -** This estimates the potential losses in crop production relative to optimal soil fertility and indicates the impact of each of the component nutrients.

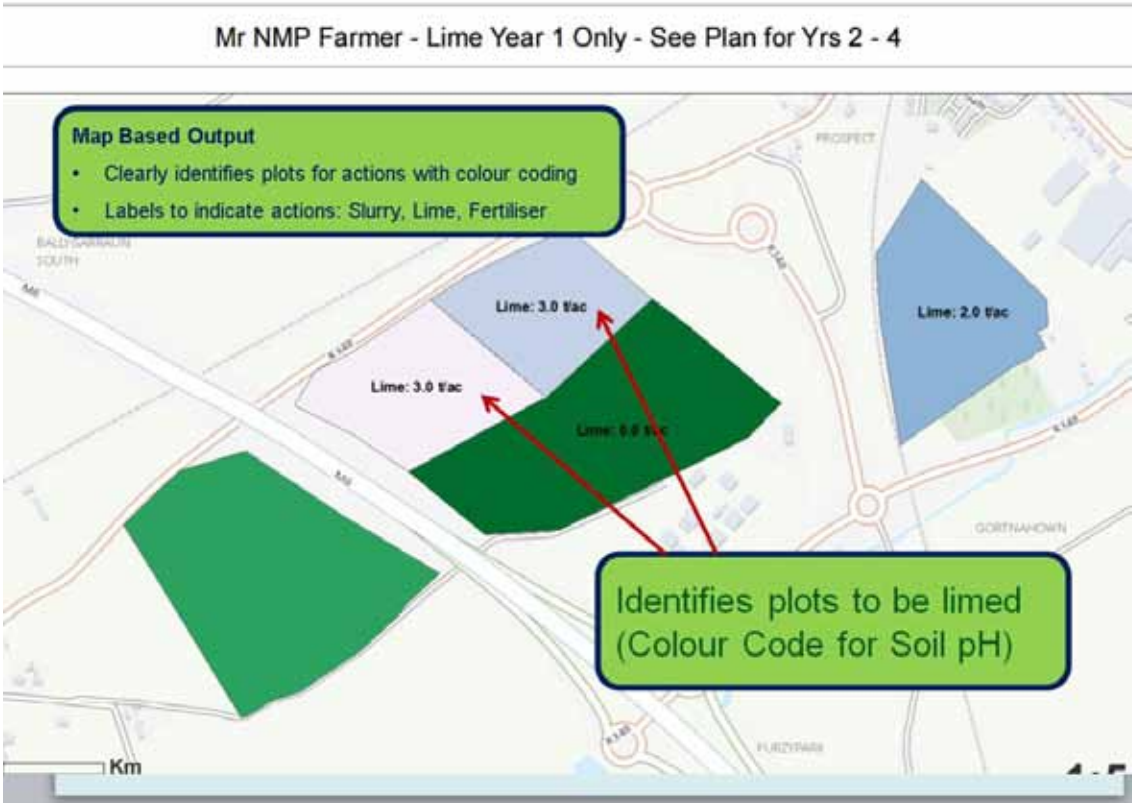
5.5.3 NMP Maps

NMP On-line provides a flexible map production system which gives the user a free hand to produce a range of maps which can support the farmer. The mapped plots are colour coded for a variety of criteria and can have a wide variety of labels and information specified on the plots.

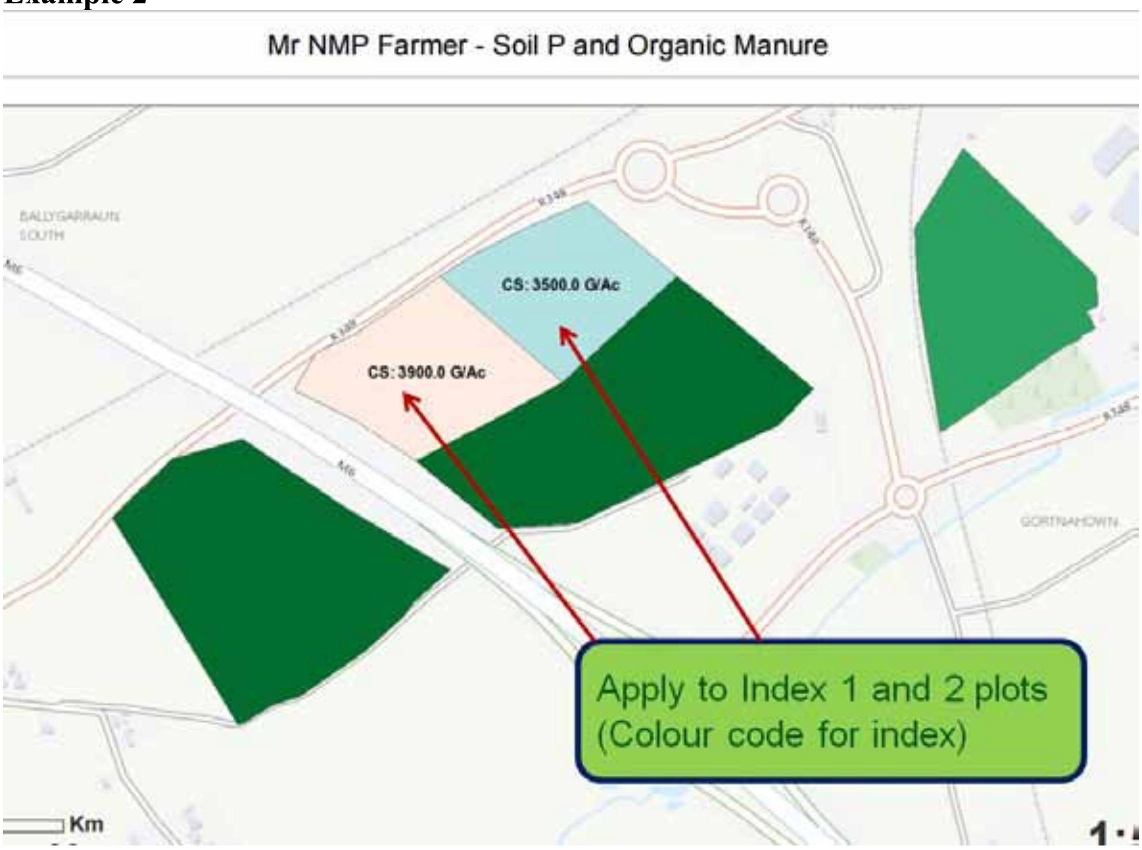
Example 1- Colour code: pH — Label: Annual Lime Spreading Plan

Example 2 - Colour Code: Soil P Index — Label: Organic manure application

Example 1



Example 2



6. The Soil Index System for Major and Micro Nutrients

6.1 Introduction

Advice on major and micro nutrient application rates must depend on the quantity of the element in the soil that is available to the crop. Apart from N and S, this is determined by soil analysis. For most elements, the soil is extracted with a suitable reagent and the amount extracted is deemed to be or is related to the amount available to the plant. For elements that are extracted, the analysis unit is milligrams per litre of soil (mg/l). For elements that are digested in strong reagents, the analysis units are mg/kg. These include cobalt, total manganese, sulphur and iodine.

In order to simplify advice tables, it is normal to classify soil available levels of major and micro nutrients into classes. The class is referred to as the Soil Index. At Johnstown Castle, soil analysis levels are classified into Index levels 1 – 4. The exact interpretation of the Soil Index varies somewhat with the element and the crop but the definitions in Table 6-1 apply in most circumstances.

Table 6-1: The Soil Index system

Soil Index	Index description	Response to fertilizers
1	Very low	Definite
2	Low	Likely
3	Medium / Adequate	Unlikely / Tenuous
4	Sufficient / High	None

6.2 Nitrogen

There is, as yet, no satisfactory Irish laboratory test for N in soils at farm level. Therefore, the nutrient N advice for grassland systems (grazing and conservation) depends mainly on land use and farming system, and particularly on the stocking rate. Consideration is given to native soil N supply in the advice for individual crops and grassland systems through the N index system and in the research that underpins these recommendations.

For crops requiring cultivation, the available soil N can be deduced from the previous cropping and manurial history, and the type of soil. Thus, N fertilizer advice is determined by the soil N supply status. This depends in turn on the previous cropping history. The supply status is categorised into an Index system for grass establishment and tillage crops. Account is also taken of previous applications of livestock manure N, the requirement of the crop and the likely crop yield.

Tables 6-2 and 6-3 show how the N Index takes into account the past farm management history and reflects the likely rate of release of N from the soil.

Table 6-2: N Index for tillage crops that follow short leys or tillage. This table can also be used for grass establishment.

Index 1	Index 2	Index 3	Index 4
Previous crop			
Cereals, Maize	Sugar beet, Fodder beet, Potatoes, Mangels, Kale, Oil seed rape Peas, Beans,		
	Leys (1 - 4 years) grazed or cut and grazed.	Swedes grazed in situ.	
	Swedes removed.		
Vegetables receiving less than 200 kg/ha N.	Vegetables receiving more than 200 kg/ha N.		

In continuous tillage it is usually only necessary to consider the last crop grown to estimate N Index (Table 6-2). However, where long leys or permanent pasture occur in the rotation, it is necessary to consider the field history for longer than one year (Table 6-3). Previous applications of animal manures must also be taken into account.

Table 6-3: N Index for pasture establishment or tillage crops that follow long leys (5 years or more) or permanent pasture

Index 1	Index 2	Index 3	Index 4
Previous crop			
Any crop sown as the 5th tillage crop following long leys or permanent pasture. For subsequent tillage crops use Table 6-2.	Any crop sown as the 3rd or 4th tillage crop following long leys or permanent pasture. If original long ley or permanent pasture was cut only use Index 1.	Any crop sown as the 1st or 2nd tillage crop following long leys or permanent pasture (see also Index 4). If original long ley or permanent pasture was cut only use Index 2.	Any crop sown as the 1st or 2nd tillage crop following very good long leys or permanent pasture which was grazed only.

6.3 Phosphorus

The P Index depends on the level of available P in soil. This is determined by measuring the amount of the element that is extracted by Morgan's solution (10% sodium acetate at pH 4.8). The ranges are shown in Table 6-4. The ranges for grassland crops are different from other crops as many tillage and vegetable crops require higher P levels for optimum production.

In the past, similar ranges were used for grassland and crops. The agronomic optimum range for grassland (Index 3) was revised downwards in 2006. However, recent research across a more complete range of Irish soil types indicates that somewhat higher critical soil test P levels may be warranted on certain soils types depending on their inherent soil properties. To minimise possible losses of nutrients to the environment, the NAP regulations requires that the fertilization rates for soils which have more than 20% organic matter shall not exceed the amounts permitted for Index 3 soils. P tends to be leached or washed out of peat soils. This was particularly important in deep peats where the P could be lost to the drainage water instead of being trapped by the mineral layer underneath as happens in shallow peats. The effect of this is that a peat soil at P Index 1 or 2 should be fertilized as if it were at soil P Index 3 (i.e. P requirements of the crop should be applied annually).

Table 6-4: The P Index system

Soil P Index	Soil P ranges (mg/l)	
	Grassland crops	Other crops
1	0.0 – 3.0	0.0 – 3.0
2	3.1 – 5.0	3.1 – 6.0
3	5.1 – 8.0	6.1 – 10.0
4	Above 8.0	Above 10.0

6.4 Potassium

The K Index depends on the available level of potassium in soil which is determined by measuring the amount of K extracted by Morgan's solution. Because peat soils do not contain clay minerals they do not store or buffer fertilizer K, so the level at each Index point is greater than for mineral soils. The K Index system for mineral soils is shown in Table 6-5.

Table 6-5: The K Index system

Soil K Index	Soil K ranges (mg/l)
1	0 – 50
2	51 – 100
3	101 – 150
4	Above 150

6.5 Magnesium

The Mg Index depends on the available level of those elements in soil as determined by the amount of the element that is extracted by Morgan's solution. The Index system for Mg is given in Table 6-6.

Table 6-6: The Mg Index system

Soil Mg Index	Soil Mg ranges (mg/l)
1	0 – 25
2	26 – 50
3	51 – 100
4	Above 100

6.6 Copper, zinc and easily reducible manganese

The available levels of Cu, Zn in soil are determined by EDTA extraction. The level of easily reducible manganese (ER-Mn) is determined in EDTA/quinnol reagent. The Index systems for Cu, Zn and ER-Mn are given in Tables 6-7 to 6-9.

Table 6-7: The Cu Index system

Soil Cu Index	Soil Cu ranges (mg/l)[1]
1[1]	< 1.00
2	1.01 – 1.50
3	1.51 – 3.00
4	> 3.00

1. Extractant for Cu: 0.5 M EDTA – pH 7.0.

Table 6-8: The Zn Index system

Soil Zn Index	Soil Zn ranges (mg/l)[1]
1[1]	< 1.00
2	1.01 – 1.50[2]
3	1.51 – 3.00
4	> 3.00

1. Extractant for Zn: 0.5 M EDTA – pH 7.0.
2. At soil pH greater than 7.0, Zn deficiency may be severe when the soil contains less than 1.50 mg/l Zn.

Table 6-9: The ER-Mn Index system

Soil ER-Mn Index	Soil ER-Mn ranges (mg/l)[1]
1[1]	< 90.0
2	90.1 – 120
3	> 120

1. Extractant for ER-Mn: 0.5 M EDTA – pH 7.0

6.7 Cobalt

Cobalt is not an essential element for crops, and testing for Co is mainly relevant to animal nutrition, particularly to sheep. Cobalt is measured by dissolving soil in aqua regia. Total Mn is measured at the same time. The effect on sheep of Co deficiency in the soil depends also on the total Mn in soil; (Micronutrients for grassland). Table 6-10 is given only for completeness.

Table 6-10: The Co Index system[1]

Soil Co Index	Soil Co ranges (mg/kg)
1	0 – 3.0
2	3.1 – 5.0
3	5.1 – 10.0
4	Above 10

1. See Table 11-2 for Co/total Mn treatment options for sheep on grassland

6.8 Boron

Soil B is measured after extraction in boiling water. The B Index (Table 6-11) applies only to boron-responsive crops, i.e. swedes, turnips, oil seed rape, sugar beet, fodder beet, mangels, all horticultural brassicae, carrots and celery. Boron can be toxic to other crops. Potatoes and legumes are particularly sensitive to high soil B and high B levels should be avoided for cereals.

Table 6-11: The B Index system

Soil B Index	Soil B ranges (mg/kg)[1]
1	< 0.5
2	0.5 – 1.0
3	1.1 – 1.5
4	1.6 – 2.0

1. Extractant for B is boiling water

7. Peats

For a soil sample to be treated as a peat it must be organic, i.e. there should be no mineral soil in the upper 10 cm throughout the sampled area. From a legal point of view, peat is defined as soil having more than 20% organic matter to a depth of more than 100 mm throughout the sample. Shallow peatland has a variable and high mineral content and must be treated differently from deep peat.

Nitrogen

As in the case of mineral soils, the amount of N to use depends mainly on stocking rate and potential yield. Peat releases N on liming, consequently N rates should be reduced on limed peats. The amount of N released varies from 80 kg/ha on deep peat to none on very shallow peat. Generally N rates should be reduced by 40 kg/ha on limed peat soil.

Phosphorus

The minimum amounts of P necessary for crop growth should be applied on peats to reduce the risk of loss to water. This is because peats have little capacity to retain P, unlike mineral soils in which P can bond with iron and aluminium compounds in the clay mineral structure. Because P tends not to accumulate in peats but is washed out in late autumn, winter or early spring, building up the soil P level is not advised. Therefore, P fertilizer should be applied only when the crop needs it, i.e. in the growing season and then preferably in a number of small applications.

The NAP regulations require that the fertilization rates for peat soils shall not exceed the amounts permitted for Index 3 soils. There is currently no soil P index for peats, so on soil with OM > 20%, it is more efficient to apply maintenance rates only of P fertilizer to meet crop requirement annually.

Potassium and magnesium

The K and Mg Index levels for peats and the corresponding soil test ranges are shown in Table 7-1. The soil test ranges are different than those for mineral soils. This is because K and Mg are released easily from peat to Morgan's extract, so the Index relates more to the total content than to the available fraction in contrast with mineral soils.

Table 7-1: The Index system for K and Mg in peats

Soil Index	K (mg/l)	Mg (mg/l)
1	0 – 100	0 – 50
2	101 – 175	51 – 100
3	176 – 250	101 – 150
4	> 250	> 150

The nutrient advice for crops grown on mineral soils may be used for peats, using the Indices and nutrient ranges shown in Table 7-1 and 7-2. However, if the crop yields are expected to be lower than those expected from mineral soils, the rates should be reduced proportionally and pro rata.

Copper, zinc and easily reducible manganese

Copper and ER-Mn deficiencies are common in crops grown on peats. This is because these nutrients have inherently lower concentrations in peats. Moreover, the organic matter binds Cu in forms that plants cannot utilise. The Cu, Zn and ER-Mn Index for peats and the corresponding soil test ranges are shown in Table 7-2.

The Index System on peats is different from that in mineral soils. There are several reasons for this, e.g. the lower pH values of peats, the presence of antagonists to trace element uptake or absorption, and the higher buffer capacity of mineral soils to Cu and Zn adsorption (Coulter *et al*., 1999).

Table 7-2: The Index system for Cu, Zn and ER-Mn in peats

Soil Index	Cu (mg/l)	Zn (mg/l)	ER-Mn (mg/l)
1	0 – 3	0 – 2.5	0 – 60
2	3.1 – 6.5	2.5 – 4.0	61 – 100
3	6.6 – 10	4.1 – 5.0	101 – 150
4	> 10	> 5	> 150

Mn is freely available in peat due to its high organic matter content, but becomes increasingly unavailable to crops at pH values above 5.5. Shallow peats and fen peat types usually have a high pH and require a high soil concentration of Mn. In deep peat (more than 1 m), the Mn concentration ranges from 10 to 100 mg/kg. In shallow peat (less than 0.5 m), soil Mn is typically between 60 and 320 mg/kg.

8. Soil Acidity and Liming

8.1 Introduction

Soil pH is a measure of the acidity or alkalinity of a soil. Soil pH is defined as the negative logarithm of the hydrogen ion concentration. The pH scale ranges from 0 to 14. A pH of 7 is neutral, which is neither acid nor alkaline. Below 7 is acid and above 7 is alkaline. A pH of 5.5 is 10 times more acidic than a pH of 6.5. Conversely, a pH of 8.5 is 10 times more alkaline than a pH of 7.5. A soil test will determine pH levels and lime advice. In soils, pH usually varies from below 5.0 (acid), where crops may give reduced yields or fail due to high levels of aluminium (Al) or manganese (Mn) at the root/soil interface, to about 8.0 (alkaline) for over-limed soils.

Soils tend to become acidic as a result of: (1) rainwater leaching away basic ions (calcium, magnesium, potassium and sodium); (2) carbon dioxide from decomposing organic matter and root respiration dissolving in soil water to form a weak organic acid; (3) formation of strong organic and inorganic acids, such as nitric and sulfuric acid, from decaying organic matter and oxidation of ammonium and sulfur fertilizers.

Crops differ in their sensitivity to soil pH. In addition, the optimum use of fertilizers containing N, P and K is obtained when soil pH is between about 6.2 and 7.0. The availability of some micronutrients, especially Mn and B is decreased when pH is above 7.0. A deficiency of Mn is quite common in cereals that follow sugar beet in the rotation, due to the high rates of lime used for the beet production.

In Ireland the majority of soils naturally have a requirement for lime due to the acid bedrock and to control acid conditions generated by our high annual rainfall. Some counties for e.g. (Kildare and Offaly) have a higher percentage of soils above pH 6.5; this is due to the underlining parent material which is limestone. Naturally high soil pH levels (>7.0) or fields that are over limed will result in reduced availability of both major (e.g. P) and minor nutrients (e.g. Mn). Rainfall is the biggest driver of increased soil acidity resulting in low soil pH levels; however, chemical fertilizer and manure applications and plant root exudates also contribute to acid build up in soils. Soil acidity is a major limitation to the productivity of our soils as it reduces the availability of major soil nutrients (N, P & K) and the uptake and efficiency of applied nutrients in manures or fertilizers.

Lime is a soil conditioner. It corrects soil acidity by neutralising the acids in soils so that the micro-organisms can thrive, break down plant and animal residues and liberates the elements necessary for healthy plant growth. It helps in the release of N and other nutrients from organic matter; it increases earthworm activity which improves soil structure and it assists the growth of rye grasses and clover and the activity of N fixing bacteria.

In mineral soils, nutrients occur in a form most readily available to plants below or near neutral conditions, (pH 6.2 - 7.0), and in peats under strongly acid conditions (pH 5.2 - 5.8). In the case of mixed peat/mineral soils, the most favourable conditions occur at intermediate levels and depend on the proportion of peat to mineral soil. Liming soils improves the availability of: N, P, K, S, Ca, Mg and many micronutrients. Acid soils often contain high levels of available Al and Mn, which can be harmful, in varying degrees, to many plants. These effects can be ameliorated by liming.

8.2 Liming sources

Ground Limestone

- Ground limestone (calcium limestone, 100% $CaCO_3$) is the most suitable liming material where soil pH is low (<6.0) and a large quantity of lime is required to neutralise the acid and increase soil pH to the target range
- Magnesium lime (40 % $MgCO_3$ & 60% $CaCO_3$) applications are appropriate where soil Mg levels are low (Index 1 or 2) to replenish soil Mg reserves. Magnesium limestone serves as a source of Mg, and is the most effective way to improve soil Mg levels where lime is required

Ground Limestone Specification (SI 248 of 1978)

- Product must have a Total Neutralising Value (TNV) greater than 90 per cent. Variability in the nature of the limestone rock type and impurities will influence the TNV (pure $CaCO_3$ has a TNV of 100%)
- 100% lime products must pass through a 3.35 mm sieve (i.e. very course limestone is less effective at increasing pH due to lower reactivity, needs additional time to break down and dissolve). The porosity and mineral content of the limestone rock type will also influence lime reactivity
- Not less than 35% must pass through a 0.15 mm sieve (i.e. is finely ground). Therefore, a minimum of 350 kg/tonne of ground limestone is fine, very reactive and will begin to work immediately
- The moisture content must be less than 3.0% specification

Fine Limes

Granulated limes

- Granulated is composed of fine lime (i.e. ≤0.1 mm sieve) and therefore all very reactive due in part to its high surface area.
- Where soil pH is close to the target level, granulated lime could be considered for minor pH adjustment and maintenance. The rate of application from pH maintenance will depend on the level of lime loss and acid production. One would expect increased acid production in regions with high rainfall and where higher annual N fertilizers and manure applications occur.
- Where soil pH is <6.0 consult the soil analysis report to determine an appropriate lime application rate (ground limestone is more appropriate for low pH soils). Where soil pH is >6.0 reduced application rates of granulated lime could be considered for annual pH maintenance.

- Granulated lime needs to be applied frequently (i.e. annually) as it has a short reaction time and therefore reduced longevity in the soil (i.e. ~ 100% will react within the year of application).

Other limes

- Calcium oxide (CaO) (also called quicklime or burned lime) is ground limestone that has been exposed to high temperatures to remove carbon dioxide. Pure calcium oxide has a TNV of 178% and reacts quickly (very fine powdery lime material). Calcium oxide must be handled carefully as it quickly reacts with water creating hydrated lime and releasing large amounts of heat.
- Calcium hydroxide ($Ca(OH)_2$) (also called hydrated lime) is also a very fast acting and fine powdery lime material. Care should be taken when using calcium hydroxide as is caustic and can burn plants when applying to soils where crops are already established. Finely ground hydrated lime can have a TNV of 120-135% and can quickly rise soil pH.

8.3 Liming of grassland

The optimum soil pH for grassland is at or above 6.3. To achieve this, Teagasc advice sets the target pH for grassland at 6.5. This allows for the slow pH changes that occur after liming and the gradual loss of lime after the target is reached. It assumes that the period between lime applications is not long. Short-term leys should be limed to the required level of the most sensitive crop in the rotation.

Liming of grassland should be done at least every 5 years based on recent soil analysis. For reseeding pastures, best results are achieved by spreading lime at the time of reseeding, when the lime can be well worked into the soil. Surface acidity often occurs in the top 50 mm in grassland due to high rainfall and heavy usage of nitrogenous fertilizers; this reduces the availability of soil and fertilizer P and K. For this reason it is better to have frequent small applications of lime than one large application. Keeping the pH above 6.0 in grassland improves N recycling and reduces total N requirements.

Very acid land should be limed immediately. There is no best time to apply lime, provided it is spread evenly on the surface of the soil. Thus, ground limestone can be spread at any time and pasture fields can be limed in rotation. Grass can be grazed as soon as the lime has been washed off the leaves by rain. If the lime advice for grassland exceeds 7.5 t/ha; initially only this amount should be applied, and the remainder applied after two years.

In grassland soils that are high in molybdenum (Mo), it is important not to raise the pH above about 6.2, as increasing the pH above this level increases the availability of Mo and this in turn induces copper (Cu) deficiency in animals by reducing Cu absorption. High Mo soils often occur on carboniferous black shales and calp limestone. Therefore, lime application rates on such land should be reduced by 5 t/ha.

Lime breaks down the tough sod of old pastures on very heavy wet soils giving rise to a greater risk of poaching. A 'little and often' approach to liming should be used in such cases.

8.4 Liming of tillage crops

Where high levels are advised for tillage, half should be applied pre-ploughing and the remainder post-ploughing and then worked in. As lime takes up to two years to have its full neutralising effect on soil acidity, it should be applied well before sowing for acid sensitive crops such as beet. Lime should not be applied within two years preceding a potato crop because it can increase the risk of common scab. At least 4 years should intervene between liming and sowing a seed potato crop.

Although potatoes can grow very well below pH 6.0 it is necessary to maintain the soil at a pH suitable for the rotation. The pH levels to aim for in mineral soils are 6.5 for most cereals and pH 7.0 for beet, beans and peas.

Where lime has not already been applied, it should be spread after ploughing so that it can react with the soil and can be thoroughly mixed with the soil during cultivation. Where lime is spread to prevent finger and toe in brassicas, it should be spread at least twelve months before sowing the crop. Over-liming can cause problems mainly in the form of induced micronutrient deficiencies e.g. of Mn in sugar beet and oats, B in root crops, Fe in fruit plantations, and Mo induced Cu deficiency in animals. Too much lime can also prevent plant roots from taking up P and K and other nutrients from the soil. It can also decrease Mg availability.

Where dolomitic limestone is used as a liming material, it is important that it is not used repeatedly without monitoring the soil Mg levels. The release of such Mg can be very slow, and frequent use of dolomitic limestone can cause soil Mg to rise to very high levels where it can impede the availability and uptake of other nutrients such as K.

The effect of soil pH on different crops is summarised in table 8-1.

Table 8-1: Soil acidity effects on grassland and tillage crops

	pH	Effect
Optimum range for efficient use of N, P & K fertilizer	8.0	Over limed: low availability of micronutrients, especially of Mg, Mn and B
	7.2	Top of optimum range for efficient use of N, P and K fertilizer
	7.0	Optimum pH for white clover, beet (sugar and fodder), beans, peas, and oil seed rape.
	6.5	Optimum pH for cereals.
	6.3	Optimum pH for grass.
	6.2	Maximum pH for grass on high Mo soils Bottom of optimum range for efficient use of N, P and K fertilizer for most crops
	6.0	Optimum pH for potatoes.
	5.5	Optimum pH for peats.
	5.0	Very acid. Possibility of Al and Mn toxicity.

8.5 Liming peats

Peats have a high pH buffering capacity and require twice the lime rate to achieve the same increase in pH compared with mineral soils. A dressing of 2.5 t/ha of lime will usually increase the pH of peat soil by 0.1 units. The ideal pH for peat soil is 5.5. The pH of unlimed peat ranges from 3.8 to 4.5, and therefore to achieve a target pH of 5.5, a large quantity of lime may be required initially on unlimed peat with a depth greater than 1 m. In shallow peat (less than 450 mm), the pH may be variable, ranging from more than 8.0 on mineral outcrops down to 4.5 in deeper peat areas. The rate of lime application must be carefully adjusted in these situations. Many fen soils have a pH in excess of 5.5 and do not require lime. It is important to classify soils correctly in order to calculate the correct lime advice. This is especially true for peats as there optimum soil pH level is lower compared to mineral soils. In peatland, liming will cause the pH value to rise sharply over a period of 4-5 years. Lime is less likely to be leached from peat soils than from mineral soils because of the high cation exchange capacity of peat. Once the pH has been increased to the required level, additional applications of lime are not normally required as a result.

8.6 Determining lime advice

Soil testing is the most reliable method for determining the lime requirement for a soil to reach the target soil pH. Soil testing provides two critical pieces of information required to establish the quantity of lime required;

1. Soil pH level (soil pH in water); this indicates the current pH level of the soil.
2. SMP buffer pH (soil pH following extraction with a buffered solution); this indicates how much latent acidity is present in the soil and how buffered the soil pH is (i.e. what quantity of acidity is present in the soil to react with lime that will be applied). In general, the more highly buffered a soil higher the quantity of lime will be needed to adjust soil pH.

This soil test information (SMP buffer pH) is then used to calculate the lime requirement for the soil based on the target soil pH specified (e.g. 6.3 for grassland or 6.5 for tillage crops).

8.7 Planning of lime applications

Lime may need to be applied to a percentage of the farm on an annual basis depending on recent soil analysis so a 3-5 year liming plan is essential for best results. This will ensure that soil pH is maintained within the optimum range for both grassland and tillage crops. Correcting soil acidity is the first step in nutrient management planning and goes hand in hand with efficient management of fertilizer and manure applications.

A planned approach to lime applications on the farm will ensure the following:-

- A more systematic approach to liming and maintenance of soil pH levels
- Lime application programme (right time, right place, right rate, and right product) to address fields with large lime requirements over a number of years
- Identification of appropriate opportunities to apply lime based on weather and soil conditions and to avoid negative interactions with other fertilizers and nutrients
- Quantification of farm lime requirements over a 5 years liming period
- Planned financing for lime and spread costs over a number of years

9. Nutrients from Organic Materials

9.1 Introduction

There are many forms of organic fertilizer that can be land spread to supply nutrients to crops. The most common of these are animal manures, with over 40 million tonnes available nationally. Another organic fertilizer is spent mushroom compost which is often used to provide N, P and K. Organic materials from industrial and municipal sources may also be considered, under certain circumstances, as these can have a valuable nutrient contribution when applied to land. The aim when land spreading organic fertilizer is to optimise nutrient uptake by the crop and to minimise losses to water and air resources. Understanding the manure composition and timing of application are critical to achieving these objectives.

The storage and application of organic fertilizers should be managed in accordance with the legal requirements specified in the NAP regulations.

9.2 Livestock Manures

Livestock manures are the product of the animal production systems. Slurries, litters and farmyard manures are common forms of animal manures. These manures are typically concentrated in areas of animal housing. Redistribution of livestock manures onto lands from which feed is produced is a key part of optimising how these manures are recycled in agricultural systems.

Information on the N, P and K content of the organic fertilizer is a pre-requisite for optimising crop uptake of the nutrients. This information, combined with soil test results and the details of the crop to be grown, are critical to ensuring that crop nutrient demands are met and legislation is complied with.

The nutrient content of organic fertilizers can vary considerably. Nutrient content is affected by the animal type, the diet fed, the bedding material and the extent of dilution with water. Surveys on manure composition suggest that the dry matter and nutrient contents of manure may vary up to tenfold even from the same type of animal. The typical dry matter and nutrient content of cattle slurry are shown in table 9-1.

Table 9-1: Dry Matter and N, P and K levels in cattle slurry samples from Irish farms[1,2]

Cattle slurry	DM %	N kg/t	NH_4-N kg/t	P kg/t	K kg/t
Average values	6.3	2.4	1.4	0.5	3.5
Range in values	0.4 - 11.9	0.2 -5.2	0.2 -3.4	0.1 -1.1	0.5 – 7.7

1. Surveys of cattle slurry (dairy and beef farms) conducted by Berry *et al.,* 2013.
2. 1 tonne slurry = 1000 litres = 1 m^3. 1000 gallons = 4.5 tonnes. 1000 gallons/acre = 11 tonnes/ha. (See Appendix 1).

9.3 Fertilizer replacement value

In addition to the variation that exists between manures regarding the total nutrient content, the proportion of the total nutrient content that is actually available for plant uptake is also variable due to timing and method of application. In the season of application the fertilizer replacement value of N, P and K is lower than the total quantities applied and farmers may need to adopt strategies that improve the nutrient uptake from organic fertilizers as a result.

The following principles should be adopted in order to maximise the fertilizer replacement value levels in cattle slurry.

9.4 Optimising N fertilizer replacement value

The fertilizer replacement value of N from organic fertilizer is determined by the composition, the time of application and the method of application. The N contained in organic fertilizer is present in two forms: (i) ammonium–N, which is available for plant uptake, and (ii) organic–N which is not available at time of application. The release of the organic–N fraction is slow, and as such, is not normally considered to be agronomically significant in the year of application. Capture of the ammonium–N component of manure is the key determinant of N fertilizer replacement value of organic fertilizer in the year of application. Organic fertilizers with higher proportions of ammonium–N, such as pig manure, will have a higher total N fertilizer replacement value than those with lower ammonium–N proportions, such as stored farmyard manure (with about 10% of total N present as ammonium) (DEFRA, 2006).

Ammonium–N, the principal plant-available N source in organic fertilizers, is also susceptible to losses. The ammonium–N is readily converted to ammonia gas (NH_3), which can be lost from the surface of the organic fertilizer to the atmosphere. Animal slurries account for approximately 80% of organic fertilizers used in Ireland. Land application of slurry and manure is also susceptible to ammonia loss. Exposure of slurry or manure to warm, windy and sunny conditions at the time of application promotes high ammonia losses. Therefore, applying manure or slurry in a manner that minimises ammonia losses will maximise the N fertilizer replacement value. Adherence to the following guidelines will help to maximise the N fertilizer replacement value.

1. Timing of application:

   - Apply at a time when crop demand is high in spring. Where soil conditions allow, aim to have 70% applied by the end of April. Opportunity for spring application on heavy soils may be increased by using application methods that reduce soil compaction, e.g. umbilical system.
   - Application in dull, cool, overcast or misty conditions will result in lower ammonia losses compared to application in warm, dry, sunny weather.

2. Slurry management to reduce N losses:

- Slurry dry matter: slurries with lower dry matter contents will percolate and wash into the soil more quickly than material with higher dry matter, thus reducing the duration of exposure to the air. Dilution of slurry with soiled water increases the volume to be managed; however, a 1% decrease in slurry DM% will decrease ammonia losses by approximately 5 - 8%.

- Slurry application method: 'low emission' application methods, have been shown to increase the N fertilizer replacement value of slurry under Irish conditions (Lalor *et al.,* 2010). Methods such as band spreading and trailing shoe, place the slurry in bands or lines rather than on the entire surface of the soil or crop as with the conventional splashplate method. Slurry applied with a low emission method has reduced ammonia losses compared to splashplate applied slurry. For example, ≥25% reduction in ammonia losses for a trailing shoe technique compared to splashplate under Irish grassland conditions.

- Speed of incorporation: where organic fertilizers are applied to tillage land prior to or during the cultivation process, incorporation is beneficial for reducing ammonia losses, as this will reduce the length of time for which the manure is exposed to the air. Immediate incorporation (or at least within 3 - 6 hours of application) is recommended.

Table 9-2: Nitrogen fertilizer replacement value (NFRV)[1] in cattle slurry according to application timing and method

Timing	Method	NFRV (%)[2]
Spring	Splashplate	30
	Trailing shoe	40
Summer	Splashplate	15
	Trailing shoe	25

1. Nitrogen fertilizer replacement values (NFRV) is the percentage of the total slurry N available for plant uptake from Lalor *et al.,* 2014.
2. Refers to the total NFRV in the year of application, and is the sum of the short term NFRV after slurry application and the residual NFRV over the remainder of the year.

Across the whole farm it is mandatory that any strategy devised for organic manure management should comply with the NAP regulations (Tables 9-9 and 9-10).

9.5 P fertilizer replacement value

Although the NAP assumes that P fertilizer replacement value of organic fertilizers applied on Index 3 soils will be 100%, the actual P fertilizer replacement value of an organic fertilizer will depend on the proportion of total P that is present in the mineral form.

Approximately 50-60% of the total P content of organic fertilizers is present in the inorganic form (DEFRA, 2006), with the remaining P being mineralised into an available form over time. Crops will have an immediate demand for P in an available form. It is therefore advised that if the P level is below the required Index and organic fertilizer is the sole source of P; one should ensure that there is sufficient mineral P available to supply the immediate crop P demand. Therefore, on low P (Index 1 and 2) soils the P fertilizer replacement value in organic manures can be assumed as 50%, allowing more scope to meet the crop P requirements with organic fertilizer sources during the growing season. Where limited slurry is available the inclusion of chemical P fertilizer combined with organic fertilizers may be necessary in order to ensure that the immediate demand for available P by the crop is met. On soils with P levels equal to the required Index, organic fertilizers can be used to supply the entire P demand. However, it is mandatory that any strategy devised for organic fertilizer management should comply with the NAP regulations (Tables 9-9 and 9-10).

9.6 K fertilizer replacement value

Unlike P, the K in livestock manure is not bound up in organic forms. According to DEFRA (2006), the proportion of readily available K in organic fertilizers is 90%. Therefore, organic fertilizers can be used to supply the entire crop K demand on soils, provided that the amount of N and P also present in the manure does not exceed that permitted under NAP regulations.

9.7 Available N, P and K in cattle slurry

Tables 9-3 and 9-4 shows the average N, P and K levels available in cattle slurry applied to low soil fertility soils (Index 1 & 2) and medium to high fertility soils (Index 3 & 4), respectively. The timing of cattle slurry application and application method used will affect the NFRV which is also reflected in table 9-3 and 9-4. For soils with very low and low soil P and K fertility (Index 1 and 2) use the N, P and K availability values from cattle slurry shown in table 9-3.

Table 9-3: Average available N, P and K in cattle slurry applied to soils with low P and K Index (1 or 2) in either spring or summer[1,2]

Slurry application timing	N kg/t[2] Spring	N kg/t[2] Summer	P kg/t[2]	K kg/t[2]
Splashplate	0.7	0.4	0.3	3.2
Trailing shoe / hose	1.0	0.6	0.3	3.2

1. Values based on average cattle slurry nutrient concentrations as shown in table 9-1. Dry matter and nutrient contents of slurry can vary widely between farms and testing of slurry is advised to determine actual nutrient content (See section 9.10 and Table 9-8).
2. 1 tonne slurry = 1000 litres = 1 m^3. 1000 gallons = 4.5 tonnes. 1000 gallons/acre = 11 tonnes/ha. (See Appendix 1).

For soils with medium and high P and K fertility (Index 3 and 4) use the cattle slurry N, P and K availability values shown in table 9-4.

Table 9-4: Average available N, P and K in cattle slurry applied to soils with medium or high P and K Index (3 or 4) in either spring or summer[1,2,3]

Slurry application timing	N kg/t[3] Spring	N kg/t[3] Summer	P kg/t[2,3]	K kg/t[3]
Splashplate	0.7	0.4	0.5	3.5
Trailing shoe / hose	1.0	0.6	0.5	3.5

1. Values based on average cattle slurry nutrient concentrations as shown in table 9-1. Dry matter and nutrient contents of slurry can vary widely between farms and testing of slurry is advised to determine actual nutrient content (See section 9.10 and Table 9-8).
2. No slurry should be applied to P Index 4 soils where other land is available on a farm to receive slurry and in compliance with the NAP.
3. 1 tonne slurry = 1000 litres = 1 m^3. 1000 gallons = 4.5 tonnes. 1000 gallons/acre = 11 tonnes/ha. (See Appendix 1).

Across the whole farm it is mandatory that any strategy devised for organic manure management should comply with the NAP regulations (Tables 9-9 and 9-10).

9.8 Available N, P and K in other organic manures

Table 9-5 shows the average N, P and K levels available in other organic fertilizers applied to low soil fertility soils (P & K Index 1 and 2).

Table 9-5: Average available N, P and K in organic fertilizers applied to soils with low P and K Index (1 or 2)

Organic Fertilizer Type		DM %[1]	N kg/t[2,3]	P kg/t[2]	K kg/t[2]
Pig slurry		3.2	2.1	0.4	2.0
Sheep slurry			5.1	0.8	4.9
Dungstead manure (cattle)		17	1.1	0.5	3.6
Farmyard manure		20	1.4	0.6	5.4
Poultry:	Slurry (layers)	30	6.9	1.5	5.4
	Broilers / deep litter	60	14	3.0	16.0
	Layers	55	11.5	2.8	11.0
	Turkeys		14	6.9	11.0
Spent mushroom compost		35	1.6	0.8	6.9

1. Dry matter and nutrient contents can vary widely between farms and testing of manures is advised to determine actual nutrient content.
2. 1 tonne slurry = 1000 litres = 1 m^3. 1000 gallons = 4.5 tonnes. 1000 gallons/acre = 11 tonnes/ha. (See Appendix 1).
3. Apply manures in a manner to maximise NFRV at time of application as discussed in section 9.4.

On soils with medium and high P and K fertility soils (Index 3 and 4) use organic manure N, P and K availability values shown in table 9-6.

Table 9-6: Average available N, P and K in organic fertilizers applied to soils with medium to high P and K Index (3 or 4)

Organic Fertilizer Type		DM %[1]	N kg/t[2,2]	P kg/t[2]	K kg/t[2]
Pig slurry		3.2	2.1	0.8	2.2
Sheep slurry			5.1	0.8	5.4
Dungstead manure (cattle)		17	1.1	0.9	4.0
Farmyard manure		20	1.4	1.2	6.0
Poultry:	Slurry (layers)	30	6.9	3.0	6.0
	Broilers / deep litter	60	14	6.0	18.0
	Layers	55	11.5	5.5	12.0
	Turkeys		14	13.8	12.0
Spent mushroom compost		35	1.6	1.5	7.7

1. Dry matter and nutrient contents can vary widely between farms and testing of manures is advised to determine actual nutrient content.
2. 1 tonne slurry = 1000 litres = 1 m^3. 1000 gallons = 4.5 tonnes. 1000 gallons/acre = 11 tonnes/ha. (See Appendix 1).
3. Apply manures in a manner to maximise NFRV at time of application as discussed in section 9.4.

Across the whole farm it is mandatory that any strategy devised for organic manure management should comply with the NAP regulations (Tables 9-9 and 9-10).

9.9 Sulphur & magnesium in organic manures

Manures are a useful source of sulphur and magnesium. Table 9-7 below shows guideline total values for a range of manures. Manure analysis will provide a better indication of the nutrient actual content of such nutrients.

Table 9-7: Total Sulphur and Magnesium levels in organic fertilizers

Organic Fertilizer Type		S kg/t[1]	Mg kg/t[1]
Cattle slurry		0.3	0.4
Pig slurry		0.4	0.4
Sheep slurry		--	--
Dungstead manure (cattle)		--	--
Farmyard manure		0.9	1.1
Poultry:	Slurry (layers 30% DM)	1.4	1.3
	Broilers / deep litter	3.2	2.6
	Layers (55% DM)	2.5	2.5
	Turkeys	--	--
Spent mushroom compost (35% DM)		6.6	2.1

1. 1 tonne slurry = 1000 litres = 1 m^3. 1000 gallons = 4.5 tonnes. 1000 gallons/acre = 11 tonnes/ha. (See Appendix 1).

Source: (DEFRA, 2006)

9.10 Determining slurry nutrient content

Knowing the nutrient content of slurry is important as it helps to ensure that crops receive the targeted levels of N, P and K to maximise crop growth. The nutrient content of cattle slurry varies on farms depending on animal type and diet, and especially with the dilution effect of water i.e. how watery the slurry is (dry matter content).

Research has shown that the nutrient content of slurry increases as the dry matter content of the slurry increases (Berry *et al.,* 2013). Laboratory analysis of slurry can be used to get a direct estimate of the nutrient values for different slurries on farms. However, in practice this is rarely done due to the time and cost of the analysis. A more practical approach may be to estimate the slurry dry matter on-farm using a slurry hydrometer and then use the conversion Table 9-8, which illustrates the typical amounts of available N, P and K applied in both cattle and pig slurry depending on the slurry dry matter content and slurry application rate. The slurry hydrometer is a relatively quick, cheap and easy on farm tool to use.

The steps to use the hydrometer are as follows:

1. Collect freshly mixed slurry (fully agitated) in a bucket or container which has a depth of at least 30cm (12 inches).

2. Place the hydrometer in the container of slurry slowly and allow it to sink and then settle to find its own level.

3. Read the value on the hydrometer which is at the slurry surface. This value is the dry matter of the slurry which can then be used with either Table 9-8 below to estimate how much nutrients you are applying depending of the slurry dry matter and your slurry application rate.

4. Where the slurry is very thick (high dry matter) the hydrometer will not sink in the slurry and will not give a correct reading. In these cases dilute half the slurry with an equal volume of water and mix thoroughly. Place the hydrometer in the slurry again and read as above. The value you read will then have to be doubled e.g. if the hydrometer reads 5% dry matter after diluting with 50% water the actual dry matter value is 10%.

5. A slurry hydrometer can be used repeatedly once it is cleaned after use. Take care when clearing / washing the slurry hydrometer after use as they can be very fragile, being normally made of glass.

Table 9-8: Typical available N, P, and K applied (kg/ha)[1, 2, 3, 4] depending on cattle slurry dry matter content and application rate[4]

Slurry Application Rate	4% DM Slurry			6 % DM Slurry			8% DM Slurry			10% DM Slurry		
	---kg/ha---											
	N[2]	P[3]	K[3]	N[2]	P[3]	K[3]	N[2]	P[3]	K[3]	N[2]	P[3]	K[3]
11 t/ha	5	4	23	8	5	32	10	7	40	12	8	49
22 t/ha	11	7	47	15	10	64	20	13	80	24	16	97
33 t/ha	16	11	70	23	15	95	30	20	121	37	25	146
44 t/ha	21	15	93	31	21	127	40	27	161	49	33	195
55 t/ha	27	18	116	38	26	159	50	33	201	61	41	244

1. Cattle slurry nutrient values are based on Table 9-1 from an on-farm survey of cattle slurry on Irish dairy and beef farms (Berry *et al.,* 2013). Note that total nutrient content in slurry can vary between farms.
2. N availability values are based on spring application using splashplate assuming 30% NFRV as per table 9-2.
3. P and K are calculated at 100% availability (i.e. fertilizer replacement value) as per soil P Index 3. However, where slurry is applied to low P and K fertility soils (Index 1 and 2) the P fertilizer replacement value can be assumed to be 50% and K fertilizer replacement value can be assumed to be 90% and application rates should be adjusted accordingly.
4. 1 tonne slurry = 1000 litres = 1 m^3. 1000 gallons = 4.5 tonnes. 1000 gallons/acre = 11 tonnes/ha. Kg/ha x 0.8 = units/ac (See Appendix 1).

9.11 Total N and P content of animal manures as specified in the NAP regulations

The total N and P contents specified by the NAP of common animal manure types and spent mushroom compost are shown in Table 9-9. The total N and P contents shown here are those tabulated in the NAP regulations.

Table 9-9: Total N, P and K levels in organic fertilizers as specified under the NAP regulatons[1,2]

Organic Fertilizer Type		N kg/t[3]	P kg/t[3]
Cattle slurry		5.0	0.8
Pig slurry		4.2	0.8
Sheep slurry		10.2	1.5
Dungstead manure (cattle)		3.5	0.9
Farmyard manure		4.5	1.2
Poultry:	Slurry (layers 30% DM)	13.7	2.9
	Broilers / deep litter	11.0	6.0
	Layers (55% DM)	23.0	5.5
	Turkeys	28.0	13.8
Spent mushroom compost		8.0	1.5

1. Values shown for N and P content are those specified in the NAP regulations (SI 31 of 2014).
2. Dry matter and nutrient contents can vary widely between farms.
3. 1 tonne slurry = 1000 litres = 1 m^3. 1000 gallons = 4.5 tonnes. 1000 gallons/acre = 11 tonnes/ha. (See Appendix 1).

The values for the percentage fertilizer replacement value (availability) of the total nutrient content of each manure type that are set out in the NAP are shown in Table 9-9. These values must be used when calculating the contribution of organic fertilizers to available fertilizer supply for compliance with the regulations.

The standard fertilizer replacement value of P in manures, assigned in the NAP, is 100% for soils with a P Index ≥3 but reduced to 50% for soils with P index 1 & 2. This is to facilitate better utilization and distribution of organic manure P (and K) resources across the farm and on the soils that require them the most. This emphasises the importance of regular soil testing in order to ensure that the fertilizer value of organic manures are not over-estimated on soils that are P Index 1 and 2. The standard fertilizer replacement value of N in manures, assigned in the NAP, varies according to manure type (Table 9-10). Farmers need to adopt strategies that improve the uptake of N from organic fertilizers as a result.

While it is legally required to base the calculation of slurry nutrient (N & P) fertilizer replacement value on the values shown in Table 9-10, the achievable fertilizer replacement value will often be lower.

Table 9-10-Nutrient availability in organic fertilizers according to the NAP regulations

Organic Fertilizer Type	Fertilizer replacement value %[1]		
	Nitrogen	Phosphorus	
		Soil test P Index 1 & 2	Soil test P Index ≥3
Pig and poultry manure	50	50	100
Farmyard manure	30	50	100
Spent mushroom compost	20	50	100
Cattle and other livestock manure (including that produced on the holding)	40	50	100

1. Fertilizer replacement value % refers to the percentage of the total nutrient content that will potentially replace chemical fertilizer application to the crop following application.

9.12 Biosolids

Sewage sludges (commonly called biosolids) from waste water treatment plants can be treated in various ways to produce a material which can be used as a soil conditioner and as a source of plant available nutrients. The rules and requirements set out in the '*Code of Good Practice for the use of Biosolids in Agriculture*' must be followed where biosolids are applied to agricultural land. This code of practice was developed to ensure the proper use of biosolids so as to prevent the build-up of heavy metals in soils and to reduce the risk to human and livestock health. Table 9-11 below indicates the typical characteristics and nutrient values of biosolids which have received different treatment processes. The quantity of available N in biosolids is low compared to the total N content. Typically, up to 50% of the total P in biosolids is available to the crop in the first year after application with the remainder becoming available over future years. Application of lime stabilised biosolids also have the potential to increase soil pH.

Table 9-11: Typical characteristics and total nutrient values of differently treated biosolids[1,2]

Type of biosolids	DM%	pH	N kg/t	NH_4-N kg/t[3]	P kg/t	K kg/t
Anaerobically digested liquid	4	-	2	1.2	1.2	-
Anaerobically digested solid	24-25	8	7-13	0.8-1	6-14	0.5
Thermally dried	87-94	7	35-45	0.5	15-35	1.8
Lime stabilised	34-60	13	4-6	0.2	1.3-2.4	0.8
Composted[4]	65	-	10.4	1[3]	6.5	-

1. Nutrient values shown are a combination of data from Peyton *et al.*, 2016 and the '*Code of Good Practice for the use of Biosolids in Agriculture*'.
2. Nutrient contents may vary widely between biosolid sources.
3. Immediately available form of N (ammonium).
4. Woodchips used as a bulking agent.

9.13 Composts

Composts made from green waste and source separated domestic and commercial biodegradable inputs are valuable sources of plant available nutrients and organic matter. Composts termed 'green wastes' are generally composed of feedstocks such as landscaping and gardening wastes, whereas composts with a significant proportion of their feedstock being derived from catering/food/kitchen combined with a green waste component are generally termed biowastes.

Composts that are made from source separated biodegrable materials must conform to a compost quality Irish standard (IS) 441(NSAI, 2011) which incorporate a number of specifications the compost must comply with before it can be termed a 'compost' and spread onto land. IS 441 is a specification that controls which materials may be used as primary feedstocks, as well as specific temperature, microbiological and stability thresholds which the material must achieve before it is deemed in compliance with the quality standard. The standard defines the point when the material ceases to be categorised as a waste and becomes a definable product. Before application to land, it is advisable that users consult their produce purchasers and refer to their quality produce schemes; to ensure there are no possible crop specific restrictions which may need to be taken into consideration.

9.13.1 Nutrient content of compost

Composts are a valuable source of stable organic matter and crop available nutrients, which can be used by growers to meet crop nutrient requirements and to maintain soil fertility. With the advent of domestic source separation and collection of biodegradable waste, it is envisaged that increasing amounts of green and food waste composts will be produced and available for use. Composts, by their nature are variable, depending on their feedstock and composting process. Some typical nutrient contents of composts are displayed in the table below, however composts should be supplied with specific nutrient content data. Typical total nutrient concentrations in fresh compost are shown in table 9-12.

Table 9-12: Typical total nutrient values of compost'[1]

Type of biosolids	DM%	N kg/t	NH_4-N kg/t[2]	P kg/t	K kg/t
Green	60	7.5	<0.2	1.3	4.6
Green/food	60	11	0.6	1.7	6.6

1. Source Teagasc and DEFRA 2010. Nutrient contents may vary widely between biosolid sources.
2. Immediately available form of N (ammonium).

9.13.2 Nutrient supply from compost

Available field data indicates that only small amounts of crop available nitrogen are supplied by green composts (approx. 2% of total N). In general, during the composting process, readily plant available forms of N are converted to less available forms of N. For composts with a significant food waste feedstock, available data indicates that between 5 and 8% of the total N is available to the next crop. It should also be noted that the physical presence of compost applied to soil can also result in a significant increase in plant biomass, particularly with shallow rooting horticultural crops. Repeated applications of composts can, increase soil N supply and soil organic matter levels over time.

In general the availability of P to crops from compost sources is extrapolated from work conducted with livestock manures and sewage sludge. This suggests that approx. 50% of the P will be available within the year of application, with the remainder released over time. Compost also contains other agronomically important nutrients such as K (80% in soluble form) as well as calcium, magnesium and sulphur. Teagasc research indicates that, in general green/food waste composts have a significantly higher sulphur and calcium content than green waste only composts.

10. Chemical Fertilizer Ingredients

10.1 Nitrogen Fertilizers

The main sources of artificial nitrogen fertilizers are as follows:

Calcium Ammonium Nitrate (C.A.N.)

Calcium ammonium nitrate is the most widely used straight nitrogen source presently used in Ireland. It is made by reacting gaseous ammonia and aqueous nitric acid to form an ammonium nitrate solution which is subsequently mixed with calcium carbonate or magnesium carbonate to form CAN. This product can then be either granulated or prilled. CAN contains 26-27% N, half of which is in ammonium form and half is in nitrate form. Both ammonium and nitrate are taken up directly by plant roots. Ammonium is less vulnerable to leaching and denitrification losses compared with nitrate. Ammonium contributes to soil acidification by net release of H^+. Nitrate delivered in fertilizer has no soil acidification potential. The calcium carbonate content of CAN can contribute to offsetting the acidifying effect of the ammonium content of CAN.

Urea 46% N

Globally urea is the main source of N used for meeting crop N requirements. In Ireland, urea use is currently relatively low compared to CAN. Urea is formed by reacting ammonia and carbon dioxide. Urea contains 46% N. Urea can be taken up directly by plant roots. However, in practice urea uptake by plants is limited because urea is converted to ammonium when applied to soil in a process catalysed by the enzyme urease. Ammonium can be taken up by plant roots, but it can also be converted to nitrate. However, as these conversions take place the plants can continue to take up N as required in urea, ammonium and nitrate forms. The speed of these conversions is generally dependent on both moisture and temperature.

Urea has lower acidification potential than ammonium because one H^+ is consumed during the conversion from ammonia to ammonium. It is during the conversion to ammonium that N applied as urea is at greatest risk of loss as ammonia gas. Irish research (Forrestal *et al.,* 2016) shows that maximum ammonia loss rates in Irish grassland are reached generally reached within 24-48 hours of urea application. N losses as ammonia from urea fertilizer can be reduced by rapid incorporation of fertilizer into the soil, by applying before rainfall and by applying low rate applications. Additionally, ammonia loss is reduced when urea is protected with a urease inhibitor.

Urease inhibitor

A urease inhibitor is an active ingredient which is coated or incorporated into the fertilizer granule to protect urea against ammonia loss. In Teagasc trials the active ingredient commonly known as NBPT (N-(*n*-butyl) thiophosphoric triamide) reduced ammonia losses from urea to levels comparable to CAN (Forrestal *et al.,* 2016) and allowed urea to consistently equal the agronomic performance of CAN while reducing losses of greenhouse gases compared with CAN (Harty *et al.,* 2016; Roche *et al.,* 2016).

Sulphate of Ammonia

Sulphate of ammonia can be granular or cystaline and contains 21% N and 24% sulphur (S) and is often formed by mixing of ammonia and sulphuric acid. It is useful in areas where S deficiency is expected or for high S demanding crops such as brassicas. Sulphate of ammonia is often used for blending with other fertilizers, including urea, to produce fertiliser products containing S. The sulphate form of S is available for plant uptake. However, like nitrate, S as sulphate is susceptible to leaching loss.

Ammonium sulphate nitrate (ASN) contains 26% N and 14% S. It is a mixture of ammonium nitrate and ammonium sulphate. ASN provides ammonium, nitrate and sulphate all of which are readily plant available.

10.2 Phosphorus (P) Fertilizers

There are two types of P fertilizer available depending on the degree of chemical processing that has been done on the original rock phosphate. These types can be described as "fast acting" and "slow acting" (Table 10-1).

Table 10-1: Phosphate fertilizer types

Fast Acting	Slow Acting
Super Phosphate, Triple Super Phosphate Mono & Diammonium Phosphate	Rock Phosphate, Basic Slag

'Fast Acting' means water soluble. Water soluble phosphorus is the most readily available to plants. The phosphorus in "Super Phosphate" is all soluble in water. 'Slow Acting' means the phosphorus needs to be dissolved by some other method, e.g. by soil acids or soil micro-organisms. Historically basic slag a by-product of ore production was a good source of P (~7%) and widely used to improve soil P levels, the basic slag of today is now more refined and contains less P (~1%).

Superphosphate is produced by treating rock phosphate with acid. Depending on the level of treatment, Single Super Phosphate (8% P) or Triple Super Phosphate (16% P) is produced. It is highly water soluble (over 90%) and is quick acting. Agronomic trials have shown that there is no significant difference in P nutrition from various “fast acting” phosphate fertilizers under most conditions.

Triple Super Phosphate (TSP)

Triple super phosphate is a water soluble source of P produced by treating finely ground rock phosphate with phosphoric acid. TSP is generally >90% water soluble. TSP contains 16% P as phosphate along with 15% calcium. It is used either as a raw material for complex fertilizer or for direct application. TSP has the highest P concentration of any non N containing granular fertilizer.

Mono Ammonium Phosphate (MAP) or Diammonium Phosphate (DAP) is formed when phosphoric acid is reacted with ammonia. These P sources are commonly used to produce blended N, P & K fertilizers.

Mono Ammonium Phosphate (MAP)

Mono ammonium phosphate is a water soluble granular fertilizer containing 11% N and 22% P. Rock phosphate is reacted with sulphuric acid to form phosphoric acid. The phosphoric acid is reacted with ammonia to form mono ammonium phosphate. On dissolution, MAP provides plant available phosphate and ammonium. The pH of the solution surrounding the granule becomes moderately acidic on dissolution, which is particularly beneficial in neutral or alkaline soils. It is not widely used in Ireland as it tends to be more suitable for alkaline soils.

Diammonium Phosphate (DAP)

Diammonium phosphate is a water soluble granular fertilizer containing 18% N and 20% P. It is the most widely used sources of P fertilizer, both globally and in Ireland. Rock phosphate is reacted with sulphuric acid to form phosphoric acid. The phosphoric acid is reacted with ammonia to form DAP. The product of this reaction produces highly plant available source of P. On dissolution, DAP provides plant available phosphate and ammonium. The pH of the solution surrounding the granule becomes alkaline. As a result, ammonia can be produced and caution should be taken on alkaline soils if applying high concentrations of DAP near germinating seeds.

10.3 Potassium (K) Fertilizers

Potassium Chloride (KCl) also known as Muriate of Potash (MOP)

Muriate of potash (MOP) is the most commonly used K fertilizer in agriculture. It contains 50% potassium (K). It is available in many colours and sizes as traces of iron oxide give some particles a reddish colour. Dissolving MOP will increase the soluble salt concentration and as a result it is often banded to the side of seed to avoid damage to germinating seeds. MOP is widely used in Ireland for the production of blended fertilizers and is commonly applied as a straight K source to improve soil K levels.

Potassium Sulphate also known as Sulphate of Potash (SOP)

Sulphate of potash (SOP) contains 42% potassium (K) and 18% sulphur (S). SOP can be used when both K and S are required. It contains very low levels of chloride and is used for chloride sensitive crops. SOP is more expensive than MOP.

11. Magnesium, Sulphur and Micronutrients

When advising on micronutrients for crops and animals, their concentration in the soil cannot be considered in isolation. Many soil properties and the levels of major and micro nutrients in soil and herbage can interact with the availability of the element in question. These effects can also vary with the crop or animal being considered. Table 11-1 illustrates some of these interactions. It should also be noted that use of proprietary micronutrient mixtures when only one element is required is not advisable; both because it represents a waste of money and because the one that is required may not be supplied in adequate amounts by the mixture.

Table 11-1. Mutual interactions of major nutrients, micronutrients and soil characteristics for agricultural crops

	Cause of Interaction: ++ Indicates high levels, -- indicates low level													
Element affected	Sandy Soils	++ OM[2]	++ pH	++ Al	++ Fe	++ K	++ Mn	++ Mo	++ N	++ P	++ S	-- Zn	++ Zn	Crops affected
B		–	–			–								beet, brassicas
Co		–	–				–							grass
Cu	–				–			–	–		–		–	cereals, grass
Mg	–		+			–			–					grass, beet, potatoes
Mn	–	–	–											cereals, beet, potatoes
Mo			+											grass, legumes
N												–		all crops
P				–	–									all crops
S	–								–					grass, arable crops
Se								–			–			grass
Zn	–	–	–							–				grass, arable crops, maize

1. A hyphen indicates a negative effect on the element in the second column; a plus symbol indicates an elevating effect
2. OM = soil organic matter content

The soil texture can be important factor in trace element availability. Appendix A2 gives a quick guide to determining texture (Diamond, 2001).

11.1 Magnesium, Sulphur and Micronutrients for Grassland

Responses in pasture growth to micronutrient application are rare under Irish conditions. Therefore, the importance of micronutrient levels in pastures relates principally to the needs of animals rather than plants. The micronutrients that are associated directly with clinical deficiency in animals are Co, Cu, I, Mn, Se and Zn. Molybdenum is also important because at high levels in the herbage it reduces the availability of Cu to animals. Soil analysis is a better indicator of availability than herbage analysis for Co and I, whereas herbage analysis is more reliable for Cu, Mn, Se and Zn.

Magnesium

Where the soil test for Mg is low (Table 6-6), and liming is necessary, magnesium limestone should be used if possible. However, a herbage test is more reliable than a soil test to check the Mg that is available to the animals. It is often necessary to supply a source of Mg (e.g. calcined magnesite), to animals, particularly dairy cows, in spring to prevent hypomagnesaemia (grass tetany). This is mainly because there is a low absorption of Mg from the lush spring grass as it passes rapidly through the animal's digestive tract. Magnesium concentration in herbage is lowest in the spring.

Sulphur

More than 30% of Irish soils require S for optimum yields, mainly because high S containing fertilizers such as sulphate of ammonia (24% S) and single superphosphate (12% S) have become less common in recent years. Sulphur deficiencies are usually more prevalent in lighter to moderate textured soils (e.g. more sandy soils) with lower soil OM levels. Where fields are being regularly cut for silage or have been in tillage for a longer period the contribution of available S from soil organic matter can be reduced. Typically, deficiencies in S have been shown to arise in 1st cut and to a lesser degree in 2nd cut silage grown on lighter soils.

Soil analysis for S is a poor predictor of the likely response to S fertilizer. This is because most of the S in soils occurs in the organic matter, which must be broken-down to release the S for root uptake. The rate of break down, or mineralisation, is influenced by the soil moisture and temperature. These factors are extremely difficult to predict accurately. Hence, soil test results for S can vary in the same soil from one week to the next.

The soils most likely to show deficiencies are sandy, free draining soils with low organic matter content. As the sulphate ion leaches readily from soils, it is not worthwhile to attempt to build up soil S levels. Organic manures are a valuable source of S and can help maintain soil S levels see table 9-7 in organic sources (*Chapter 9*).

Plant S content and plant N:S ratios are useful guides in assessing the likelihood of a response to S fertilizers. The plant S level should be greater than 0.2% of DM, and the N:S ratio should be less than 15:1. Where S deficiency occurs in silage, an application of 15-20 kg/ha S should be applied to all grass silage swards in mid spring prior to closing. A subsequent application of may be require for 2nd or subsequent silage cuts on lighter textured soils only. For grazing, one dressing of 20 kg/ha S should suffice.

It is important not to oversupply S where it is not required, as excess S can depress the uptake of Se in herbage and reduce the absorption of Cu by animals.

Cobalt

Soils giving rise to low Co in herbage are typically formed from granite and sandstones. However, low herbage Co levels can occur even on soils rich in Co, if the total Mn content of the soil is high. Hence, when determining the level of Co in a soil, it is also necessary to analyse for total Mn in order to determine whether Co deficiency can occur. It also determines whether Co can be applied to the soil, or if it must be fed directly to the animals.

Most of the soils which respond to pasture treatments are located in Mayo and Kerry; and to a lesser extent in Limerick, Carlow, Waterford and Galway. Cobalt deficiency causes pine and poor thrift in sheep. A concentration of 0.1 mg/kg Co in herbage is required to supply sufficient Co for animal needs. Total Mn concentrations in soil greater then 600 mg/kg can reduce the plant uptake of Co by pasture species to below 0.1 mg/kg. Investigations have shown that up to 25% of the stomach contents of sheep may be ingested soil. Cobalt deficiency rarely occurs in pastures with soil Co greater than 6 mg/kg and total Mn above 600 mg/kg, due to Co intake by soil ingestion.

The Index system for Co (Table 6-10) is given in column 2 of Table 11-2. However, the risk table for Co deficiency in sheep on soils with different levels of cobalt and total Mn is shown in the remaining columns of Table 11-2. Only in two soil categories are animals at high risk; category-1 soils are those with less than 3.0 mg/kg Co and less than 600mg/kg total Mn and category-2 soils are those with 3-6 mg/kg Co and 600-1000 mg/kg total Mn.

Table 11-2: Risk assessment and remedial procedures for sheep on grassland based on Co and total Mn levels in soil

Soil Co Index	Soil Co range (mg/kg)	Total Mn (mg/kg) 0 - 600 Risk	Remedy	601 - 1000 Risk	Remedy	> 1000 Risk	Remedy
1	0.0 – 3.0	High	Soil Treatment[1]	-	-	-	-
2	3.1 – 5.0	Low	Soil Treatment[2]	High	Animal Treatment	-	-
3	5.1 – 10.0	None	None	None	None	Low	Animal Treatment
4	> 10.0	None	None	None	None	None	None

1. Apply 3 kg/ha cobalt sulphate (21% Co) to 25% of grassland area every 4 years
2. Apply 2 kg/ha cobalt sulphate (21% Co) to 25% of grassland area every 4 years

For Index 1 soils, Co deficiency in sheep is controlled by pasture treatment. Pasture treatment is costly and band application is used to reduce the expense. Cobalt treatment applied to 10-20% of the pasture area gives satisfactory results. Hydrated cobalt sulphate mixed with sand or fertilizer can be applied at a rate of 3 kg/ha using a fertilizer spreader. The cobalt sulphate may also be applied using a sprayer. At normal soil pH levels this treatment can last up to 4 years. At high soil pH values it will be necessary to repeat the treatment annually. Animals must be allowed to graze a treated area at every 2-3 weeks.

Direct animal treatment is used in the case of Index 2 and Index 3 soils. This includes oral drenching, Co bullets and injections.

Copper and molybdenum

Soils derived from sandstones, granites and peats are likely to have low Cu levels. The amount of Cu normally absorbed from food by the ruminant is less than 10%. Soil Cu levels of below 5 mg/l in mineral soils are rare north of a line from Galway to Dublin. Low soil concentrations are common on peat land and in the light sandy soils which occur in counties Wexford, Carlow, Waterford, east Wicklow, north Clare and Kerry.

Adequate Cu in the herbage is important for the health of ruminants and horses. Copper deficiency can lead to ill thrift and scour, especially in young cattle. It can also cause swayback in sheep and bone deformity in horses. It is difficult to provide precise data for animal requirements for a number of reasons. The most important factor is high Mo, which prevents Cu absorption within the animal system causing molybdenosis or induced Cu deficiency. High Fe, S and Zn concentrations in herbage can cause similar disorders but are less common. Soil ingestion is another factor which can be involved; grazing animals can ingest large amounts of soil which can reduce Cu availability. The higher the stocking rate the greater the tendency for soil intake by grazing animals. When such induced deficiencies occur, direct treatment of the animal is necessary.

Soil Cu tests are not useful as definitive diagnostic tests owing to the complexity of the problem of Cu availability and utilisation by the ruminant. It is better to use herbage Cu levels together with Mo and S values.

Copper deficiency symptoms occur in grassland when the EDTA extractable levels are below 0.5mg/l. Such low levels are rare and they occur only in peats and in soils derived from sandstone. Soil Cu levels of below 3.0 mg/l are considered to be low. Herbage produced on such soils may have Cu levels that are insufficient for the needs of livestock. Soils with low Cu concentrations may be treated with copper sulphate applied at 20 to 40 kg/ha to the ploughed surface during pasture renewal or sprayed annually with copper sulphate in the case of established grassland. The livestock should be withdrawn for a period of three weeks following treatment. Alternatively the treatment can be applied to the land during the housing period.

When soils that are low in Cu, an application of 20 to 40 kg/ha of copper sulphate at reseeding will maintain reasonable levels of Cu in the herbage for 5 to 10 years depending on soil type. Satisfactory treatment of established pastures is more difficult. Most reports indicate that the small increase in herbage Cu resulting from soil application Cu to permanent pasture often leaves stock still at risk from Cu deficiency.

Iodine

Iodine is readily leached from soils, therefore low I levels are likely in coarse textured, freely drained soils. While there is no completely satisfactory extractant for measuring available I in soils, the extractant used by Teagasc serves mainly as a guide to possible low I levels in pasture. Soil analysis has been found to be better than herbage analysis. Animals should be treated directly rather than by using soil application of I, as these would be readily leached from the soil. Animals have the capacity to store I for only 2-3 weeks. In I deficient pasture, daily oral doses are best but doses at 1-2 week intervals are also effective.

Zinc

Zn deficiency is most likely on sandy soils with high pH. Approximately 23% of Irish soils sampled have soil concentrations of Zn below 2.0 mg/l. The occurrence of soils with Zn levels below 2 mg/l is highest in Donegal (65%), Louth (47%), Carlow (29%), Tipperary (25%), Cork (24%) and Meath (24%). Zinc deficiency in grassland occurs at EDTA extractable soil concentrations below 0.6 mg/l. The main deficiency symptom is reduced grass emergence and stunted pasture growth. Soil concentrations below 0.6 mg/l are rare and the occurrence of pasture affected by Zn deficiency is unusual.

Adequate Zn in the herbage is important for animal health. Low Zn in herbage affects the immune system. Severe deficiency affects hoof and hair growth in cattle and wool growth in sheep. At soil concentrations of less than 2.0 mg/l EDTA extractable Zn, the concentration in grass will normally range from 11.3 to 22.0 mg/l. Herbage concentrations of less than 20 mg/l are regarded as low for livestock.

Nitrogen application has a strong effect on Zn uptake by herbage. At soil Zn concentration above 2.0 mg/l, N application increases uptake of Zn. At low soil Zn concentrations, Zn concentrations in the herbage are reduced. The application of zinc sulphate at 5.0 kg/ha is recommended for grassland when the soil Zn concentrations are less than 2.0 mg/l Zn. Grassland treated with such an application will have adequate Zn for a period of up to 15 years. Zinc is relatively non-toxic to livestock, but livestock should be removed from the pasture for a period of three weeks after treatment. When soil Cu concentrations are low, Zn applications should be delayed until the housing period as high Zn levels can have a depressing effect on Cu availability in soil.

Selenium

Selenium, like Co and I is not required by plants but it is required by animals. The Se content of Irish pastures can vary widely. Some soils, mainly in counties Meath, Limerick and Tipperary have excess Se, which can cause Se toxicity in livestock. Selenium deficiency occurs most frequently in the sandstone soils of south Munster and the clear-water-limestones of west Munster and east Galway.

Selenium toxicity tends to occur at herbage concentrations above 3 mg/kg Se. Soil testing for Se can be used to diagnose Se toxicity; Rogers et al., (1989) found soil Se levels ranging from 3-132 mg/kg in Se-toxic fields. Se toxicity causes loss of hair and extension and sloughing off of the hooves of livestock. On soils with high Se, there is no certain method of avoiding Se toxicity in livestock. The affected areas may be fenced off and used to grow cereals or hay as the Se content of hay is lower than its content in pasture.

Soil testing for Se is not of great value in diagnosing Se deficiency. Analysis of forage or blood is usually used instead. However, McGrath (2000) found that Se in pasture was very variable and that one could not rely on a single determination to diagnose the selenium status of grassland. Selenium deficiency occurs at herbage concentration below 0.1 mg/kg. It causes stillbirth and retention of afterbirth in livestock. Poor conception rates and embryonic mortality are also common. Farmers should consult their advisor or vet on procedures for correction of Se deficiency problems. Pasture treatment of sodium selenite at 0.15 to 0.3 kg/ha as a spray may be effective. Oral applications in concentrate feeds or mineral licks are often advised. In more severe Se deficiency cases injections of Se solutions may be effective.

11.2 Magnesium, Sulphur and Micronutrients for Tillage Crops

Magnesium and sulphur are important elements for nutrition of cereals, potatoes and other tillage crops, but their effect varies with the crop and is discussed in more detail in later chapters dealing with nutrient advice for individual crops. Micronutrient deficiencies in tillage crops can cause a large reduction in the yield in contrast to grassland.

The main micronutrient deficiencies found in crops are B, Mn, Cu and Zn. Boron deficiency occurs in sugar beet, fodder beet, swedes, oil seed rape, kale, and other brassicas and beet crops. Manganese deficiency occurs in cereals, sugar beet, peas and potatoes. Cu deficiency is most common in cereals. Zn deficiency occurs in cereals and broad beans.

The frequency of occurrence of micronutrient deficiencies in tillage crops has been increasing gradually over the past decade. Some of the main reasons for this increase are:

- The increased use of lime and fertilizers over the last number of decades. The extra biomass produced as a results of high fertilizer and lime applications requires higher quantities of micronutrients for sustained growth but the concentration of micronutrients in the soil remains the same or may be reduced. Lime, N, P and K all interact to some degree with micronutrients and high soil application will affect the micronutrient supply.
- Higher yielding crop cultivars demand correspondingly higher quantities of micronutrients for sustained growth. Newer cultivars frequently require higher concentrations in order to produce maximum yields.
- Advanced methods of fertilizer manufacture have resulted in lower contaminant levels in compounds. In the past, some of the contaminants contained in these fertilizers were micronutrients. Their elimination from fertilizer compounds has resulted in the loss of a micronutrient source.

Copper

Copper deficiency occurs mainly in cereals. In the past, this deficiency was found most commonly on the sandstone soils of east Cork and in cultivated peatland. More recently it has been shown to be quite common in light textured soils and in many medium textured soils of the midlands, south, east and southeast. Copper deficiency in cereals is observed less frequently as one moves northwards, and with the exception of the peatlands, only occurs occasionally in soils north of a line drawn from Dublin to Sligo. Copper deficiency is found in soil derived from sandstone, granite, sandstone/granite, limestone/sandstone and limestone/granite mixtures, in light sandy soils, in strongly leached soils and in peat.

The critical soil concentration at which Cu deficiency occurs varies with the soil texture. In heavy soils, growth may not be affected until the EDTA-extractable concentration falls below 1 mg/l but in light sandy soils a yield reduction occurs when the soil concentration falls below 2.5 mg/l. The effect of soil texture and soil type on the concentration at which yield reduction occurs in spring barley due to Cu deficiency or toxicity is given in Table 11-3. The range at which deficiency or toxicity of Cu occurs in tillage crops is largest for peat and smallest for sandy loam soils.

There is considerable variation between the cultivars of the different cereals in their susceptibility to deficiency and toxicity. The variation between cultivars is usually greater than the variation between the different cereal types. The concentration of Cu in the foliage of healthy cereal crops varies from 5-10 mg/l.

Concentrations of less than 3 mg/l are too low for healthy growth and good yields. Foliar concentrations of greater than 20 mg/l are excessive. Grain size is reduced when the concentration in the foliage is excessive.

Table 11-3: The effect of soil texture and soil type on the critical soil concentrations of copper in spring barley

Texture class	Critical copper concentrations (mg/l)	
	Low	High
Peat	< 6.0	> 50.0
Sandy loam	< 2.5	> 15.0
Loam	< 1.5	> 20.0
Clay loam	< 1.0	> 30.0

Copper deficiency in cereals may be treated by soil application or by foliar sprays. Soil application offers the most long-term solution to a copper deficiency problem. The application of copper sulphate at 20 to 40 kg/ha gives good control of Cu deficiency for up to 5 to 10 years. However, Cu has poor mobility in soil and several cultivations are required before the soil application is fully effective. Consequently, foliar applications are required for 1-2 years following the soil dressing to obtain satisfactory control of the deficiency.

The spreading of the copper sulphate presents a problem. Pneumatic spreaders are the most successful type of implement for uniform distribution of the copper sulphate because this machine is designed to spread small quantities of material. The copper sulphate may be mixed with compound fertilizers at spreading but the finer powder is not distributed as widely as the fertilizer prills and the bout width of the spreader must be reduced to obtain a uniform spread. As a result of the finer texture, the Cu powder falls to the base of the distributor and is fully ejected before the fertilizer prills. In some countries, Cu prills are manufactured to facilitate spreading and blending with other fertilizers. Foliar application of Cu gives more short-term control of the deficiency. The recommended rate of application for Copper sulphate is 2.0 kg/ha. Rates greater than 2.0 kg/ha can cause severe foliar scorch. Early application of copper sulphate reduces the risk of foliar scorch. Chelated compounds and inorganic formulations cause less foliar scorch, are more compatible with other spray materials and may be applied in smaller volumes of water.

In summary:

- Copper deficiency is most prevalent on light, sandstone and granite soils, on sandstone/granite/limestone mixtures and on peat
- The main deficient areas are concentrated in the south of the country
- Copper deficiency occurs mainly with cereals
- Deficiency and toxicity of Cu are affected by soil texture
- Long term control is obtained with soil application but uniform application is a problem
- Foliar sprays may be used for in season crop deficiencies

Zinc

Low Zn concentrations are found in several soil types with different textural classifications varying from clay loam to sandy loam. Low Zn occurs most frequently on the following soils:

A. Hill Land:

- Brown podzolics derived from shale with loam to clay loam texture in Tipperary.

B. Rolling Lowlands:

- Acid brown earth soils derived from granite, sandstone and shale with a sandy loam to loam texture in Louth, Meath, Wexford and Cork.
- Acid brown earth soils derived from moranic sands and gravels with a sandy to sandy loam texture in Wexford.
- Brown podzolic soils derived from sandstone with a gravelly loam texture in Cork and Waterford.

C. Flat lowlands:

- Greybrown podzolics derived from limestone glacial till and moranic gravels and sands with a gravelly loam and sandy loam texture in Carlow, Kildare, Tipperary, Galway, Kilkenny and Meath;
- Gley soils derived from a limestone/shale mixture with a clay loam to silty clay loam texture.

D. Peat soils:

- Peat soils with a high phosphorus concentration in the midlands and along the west coast.

Manganese

Manganese deficiency is common in many crops especially beet, cereals and peas. It occurs mostly in sandy and organic soils at high pH, but it can occur on most soils when they are over limed. Leaf analysis is a more reliable means of diagnosis than soil analysis but the easily reducible Mn test (ER-Mn) together with pH is of some use in predicting Mn deficiency.

12. Nitrogen for Grassland

Adequate N nutrition is essential to plant health. Nitrogen is an essential element in amino acids – these are the building blocks of all proteins, including enzymes which control virtually all biological processes. Plants deficient in N usually have a pale yellowish-green colour (chlorosis), particularly on the older leaves. Deficient plants can also have a stunted appearance and develop thin spindly stems (Brady and Weil, 1999).

12.1 N Fertilization Strategy for Grazing and Silage

The quantity of fertilizer N applied to grassland will depend on the quantity of herbage production required, and the background release of nitrogen from the soil. The quantity of herbage production required will depend on the grass sward type (grazed or cut), stocking rate, and animal type. The supply of background N from the soil will depend on the soil, the clover content of the sward and whether the sward is old pasture or newly sown.

Unlike many other elements, there is no reliable method available for determining the background N release from soil. The rates of N fertilizer shown in tables 12-1 to 12-7 are advised for soils of 'average' soil fertility. These rates may need to be adjusted in many instances, based on experience with individual fields or soils.

N fertilizer advice

N-fertilizer advice is based on the following 5 steps:

1. Determine available N rates and timing for grazed swards (tables 12-1, to 12-5,)
2. Determine available N rates for cut swards (table 12-7)
3. Take account of available N in slurry and farmyard manure
4. Calculate chemical fertilizer N
5. Determine maximum N allowance, and confirm that N advice for the holding is compliant with the NAP regulations

(1) Available N fertilizer for grazed swards

Rates of available N application for grazed swards used for dairy, beef and sheep production are shown in Tables 12-1, 12-2 to 12-4 and 12-5, respectively.

These rates are advised for farms of average soil–N fertility. Only fertilize to the stock carrying capacity of the soil. This may vary between different areas within the farm. In this case, the stocking rate for the different sections of the farm should be calculated individually to determine the relevant rate of N for each section from the appropriate table. At stocking rates below 2.3 LU/ha (200 kg/ha Organic N) rates of N greater than those shown in tables 12-1 to 12-5 can be applied on poorer soils under NAP regulations. Lower N rates may be appropriate on soils with above average natural fertility. Where clover is present, management should promote clover growth as a good clover sward will reduce N requirements or in some situations can fully offset the need for chemical N fertilizer applications. An extra 25% N may be used where necessary to aid the establishment of a good ryegrass sward if pasture is less than 3 years old, provided that the rates do not exceed those prescribed in the NAP. Rates which are higher than required should be avoided to reduce potential N losses to the environment, particularly in permeable soils where there is a risk of loss of nitrate to ground water.

N fertilizer for Dairy

Table 12-1 gives guideline rates for N applications on grazed swards used for dairy production. The N timetable depends on several factors including overall farm system, soil, climatic conditions, livestock turnout and housing dates, sward clover content etc.

Table 12-1: Suggested timing of available N applications for swards grazed by dairy cows at various stocking rates

Stocking rate		----------------------- N rates[1] (kg/ha) for approximate application dates ---------------------								Total N Rate[1,6] (kg/ha)
LU/ha[2]	kg/ha N[3]	Jan[4, 5] / Feb	March	April	May	June	July	Aug	Sept[4, 5]	
<1.0	≤85			25			15			40
1.25	106		15	28	15		15			73
1.5	128		28	35	25		23			111
1.75	149		29		26		26		17	142
2.0	170		34	53	42		42		31	202
2.12	180	32	32	48	38		38		28	216
2.25	191	31	41	54	37		37		37	237
3.35	200	30	53	53	37	37		37	27	275
2.47	210	31	54	54	56	37		37	37	306
>2.47	≥210	32	49	55	38	38		38	28	279[6]

1. Rates shown above refer to recommended application of available fertilizer. Chemical fertilizer rates should be calculated by deducting the available N contained in organic fertilizer applications from the rates shown in the table above.
2. Livestock unit (LU) per ha refers to a mature dairy cow.
3. Total annual organic nitrogen (kg) excreted by grazing livestock averaged over the net grassland area (grazing and silage area). Stocking rate refers to grassland area only.
4. Rates shown above refer to grazed swards only, and are not suitable as a guideline value of the N requirement for the entire grassland area. The N requirement for the entire grassland area will depend on the proportions of the area that are grazed, or cut as silage or hay.
5. Chemical or organic fertilizers cannot be applied during periods when application is prohibited by NAP regulations.
6. At stocking rates above 210 kg/ha organic N, fertiliser N advice is constrained by the NAP regulations.
7. Total N use on the farm must comply with NAP regulations.

N fertilizer for Beef systems

Nitrogen fertilizer requirements for beef production systems are related to the demand for grazed grass over the growing season. This demand for grass will vary according to the beef system and the length of the grazing season and grazing intensity. Additionally, grass demand will depend on a number of management factors for the beef production system e.g. calving/turnout dates, silage harvest strategy, animal finishing system, housing dates, etc. A generalised depiction of grass demand for different spring calving beef systems is shown in figure 12-1.

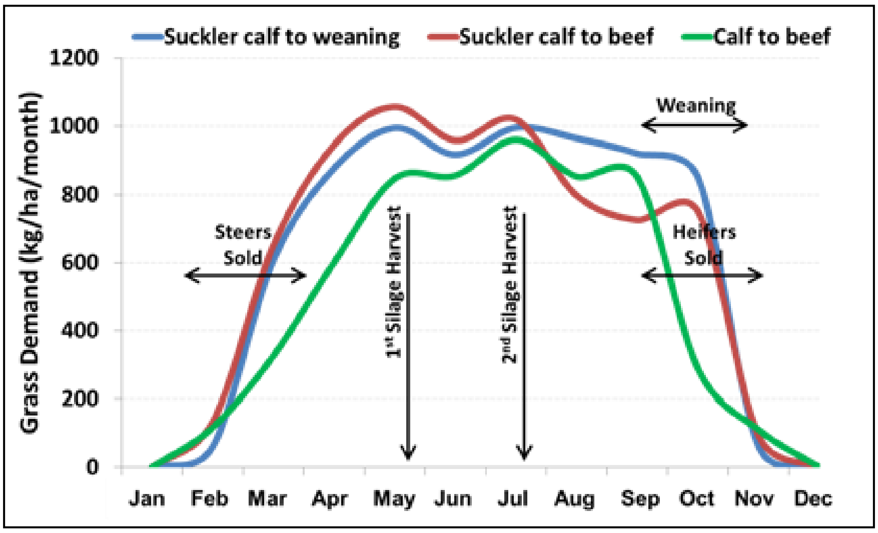


Figure 12-1. Grass demand for different beef systems at a stocking rate of 2 LU/ha over the grazing season.

Nitrogen advice for grazed swards is given for the 3 main beef production systems as follows;

- Suckler calf to weaning, Table 12-2
- Suckler calf to beef, Table 12-3
- Calf to beef, Table 12-4

Suckler calf to weaning

Table 12-3 gives guideline rates for N applications on grazed swards used for calf to beef production with normal to low clover content for a range of stocking rates. The recommendations provided below are based on a production system where: 1) mean calving date is mid-March with cows and calves turned out to pasture shortly thereafter, 2) closing up of grassland for silage harvest occurs in early April with 1st cut silage harvest taking place at the end of May and 2nd cut silage harvest in late July, 3) cattle are sold for slaughter at 20 months of age for heifers and 24 months of age for steers and, 4) housing of animals for winter feeding occurs in November. The suggested timetable of N application assumes low concentrates feeding rates (<0.3 t/LU) at pasture. The N timetable also depends on several factors including overall farm system, soil, climatic conditions, clover content etc.

Table 12-2: Suggested timing of available N applications for swards grazed by suckler calf to weaning production systems (weaned within 9 months of age) at various stocking rates

Stocking rate		-------------------- N rates[1] (kg/ha) for approximate application dates --------------------								
LU/ha[2]	kg/ha N[3]	Jan[4, 5] / Feb	March	April	May	June	July	Aug	Sept[4, 5]	Total N Rate[1, 6] (kg/ha)
≤1.0	≤ 80			20			15			35
1.25	92		15	17			15			47
1.5	110		20	23			23			66
1.75	129		23	26	13		26		17	105
2.0	148		25	34	17		42		31	14
2.25	166		28	39	25	20		28	25	165
2.5	185		34	44	25	30		33	31	197
2.75	218		37	48	29	37		33	33	217
3.0	238		42	53	39	37		37	37	245

1. Rates shown above refer to recommended application of available fertilizer. Chemical fertilizer rates should be calculated by deducting the available N contained in organic fertilizer applications from the rates shown in the table above.
2. Livestock unit (LU) per ha: 1 suckler cow plus calf weaned within 9 months = 1.1 LU/ha
3. Total annual nitrogen (kg) excreted by grazing livestock averaged over the net grassland area (grazing and silage area). Stocking rate refers to grassland area only.
4. Rates shown above refer to grazed swards only, and are not suitable as a guideline value of the N requirement for the entire grassland area. The N requirement for the entire grassland area will depend on the proportions of the area that are grazed, or cut as silage or hay.
5. Chemical or organic fertilizers cannot be applied during periods when application is prohibited by NAP regulations.
6. Total N use on the farm must comply with NAP regulations.

Suckler calf to beef

Table 12-3 gives guideline rates for N applications on grazed swards used for calf to beef production with normal to low clover content for a range of stocking rates. The recommendations provided below are based on a production system where: 1) mean calving date is mid-March with cows and calves turned out to pasture shortly thereafter, 2) closing up of grassland for silage harvest occurs in early April with 1st cut silage harvest taking place at the end of May and 2nd cut silage harvest in late July, 3) cattle are sold for slaughter at 20 months of age for heifers and 24 months of age for steers and, 4) housing of animals for winter feeding occurs in November. The suggested timetable of N application assumes low concentrates feeding rates (<0.3 t/LU) at pasture. The N timetable also depends on several factors including overall farm system, soil, climatic conditions, clover content etc.

Table 12-3: Suggested timing of available N applications for swards grazed by suckler calf to beef production systems (steers finished at 24 months of age and heifers finished at 20 months of age) at various stocking rates

Stocking rate		-------------------- N rates[1] (kg/ha) for approximate application dates -------------------								Total N
LU/ha[2]	kg/ha N[3]	Jan[4,5] / Feb	March	April	May	June	July	Aug	Sept[4,5]	Rate[1,6] (kg/ha)
≤1.0	≤ 80		23						12	35
1.25	99		23	15					15	53
1.5	118		25	23			10		17	75
1.75	138		34	25	10		15		19	103
2.0	158		42	30	20		20		20	132
2.25	176	13	45	32	20		26		26	162
2.5	196	15	49	36	25	22		24	22	193
2.75	215	15	53	42	25	26		28	26	215
3.0	235	20	57	46	30	28		32	28	241

1. Rates shown above refer to recommended application of available fertilizer. Chemical fertilizer rates should be calculated by deducting the available N contained in organic fertilizer applications from the rates shown in the table above.
2. Livestock unit (LU) per ha: suckler cow = 0.9 LU; calf (0-12 months of age = 0.3 LU; yearling (13-24 months of age) = 0.7 LU; adult cattle (>24 months of age) = 1.0 LU..
3. Total annual nitrogen (kg) excreted by grazing livestock averaged over the net grassland area (grazing and silage area). Stocking rate refers to grassland area only.
4. Rates shown above refer to grazed swards only, and are not suitable as a guideline value of the N requirement for the entire grassland area. The N requirement for the entire grassland area will depend on the proportions of the area that are grazed, or cut as silage or hay.
5. Chemical or organic fertilizers cannot be applied during periods when application is prohibited by NAP regulations.
6. Total N use on the farm must comply with NAP regulations.

Calf to beef

Table 12-4 gives guideline rates for N applications on grazed swards used for calf to beef production with normal to low clover content for a range of stocking rates. The recommendations provided below are based on a production system where: 1) spring-born dairy bred calves are purchased at 2 weeks of age, 2) calves are turned out to pasture for their first grazing season in May, 3) closing up of grassland for silage harvest occurs in early April with 1st cut silage harvest taking place at the end of May and 2nd cut silage harvest in late July, 4) cattle are sold for slaughter as steers at 24 months of age and, 5) housing of animals for winter feeding occurs in November. The suggested timetable of N application assumes low concentrates feeding rates (<0.3 t/LU) at pasture. The N timetable depends on several factors including overall farm system, soil type, climatic conditions, clover content etc.

Table 12-4: Suggested timing of available N applications for swards grazed by calf to beef production systems (finishing steers at 24 months or age) at various stocking rates

Stocking rate		------------------------ N rates[1] (kg/ha) for approximate application dates ------------------------								Total N Rate[1,6] (kg/ha)
LU/ha[2]	kg/ha N[3]	Jan[4,5] / Feb	March	April	May	June	July	Aug	Sept[4,5]	
≤1.0	≤ 80			12					12	24
1.25	99		15	15					15	45
1.5	118		15	20			15		17	67
1.75	138		17	23	15		15		20	90
2.0	158		20	25	20		23		23	111
2.25	176	13	20	25	22		28		26	134
2.5	196	15	25	30	25	15		26	20	156
2.75	215	15	30	30	28	22		30	23	178
3.0	235	20	35	35	30	25		30	25	200

1. Rates shown above refer to recommended application of available fertilizer. Chemical fertilizer rates should be calculated by deducting the available N contained in organic fertilizer applications from the rates shown in the table above.
2. Livestock unit (LU) per ha: calf (0-12 months of age = 0.3 LU; yearling (13-24 months of age) = 0.7 LU.
3. Total annual nitrogen (kg) excreted by grazing livestock averaged over the net grassland area (grazing and silage area). Stocking rate refers to grassland area only.
4. Rates shown above refer to grazed swards only, and are not suitable as a guideline value of the N requirement for the entire grassland area. The N requirement for the entire grassland area will depend on the proportions of the area that are grazed, or cut as silage or hay.
5. Chemical or organic fertilizers cannot be applied during periods when application is prohibited by NAP regulations.
6. Total N use on the farm must comply with NAP regulations.

N Fertilizer for Sheep

Table 12-5 gives guideline rates for N applications on sheep pasture with normal to low clover content for a range of stocking rates. The suggested timetable applies to ewes with high productivity assuming that no concentrates are offered at pasture. The N timetable is for early to mid-March lambing, but depends on several factors including overall farm system, soil, climatic conditions, clover content etc.

The N requirements for sheep grazing are generally lower than for dairy cows or cattle. This is because:

- Less silage is required for sheep than for cattle due to the shorter in-wintering period
- Sheep recycle dung/urine more uniformly to pasture and hence there is less herbage waste around dung-pats and, consequently, more efficient herbage utilisation (more uniform post-grazing height and less high grass left ungrazed)
- There is a better match between feed demand and herbage growth because feed demand is highest from lambing to weaning (March to early July). It decreases post weaning as lambs are drafted for sale and ewes can be restricted to maintenance feeding
- Clover survival can be encouraged by rotational grazing rather than continuous sheep grazing as sheep preferentially graze clover plants

Table 12-5: Suggested timing of available N applications for swards grazed by sheep and lamb production systems (mid-March lambing) at various stocking rates with low to and normal clover content

Stocking rate		N rates[1] (kg/ha) for approximate application dates								Total N
Ewes /ha[2]	kg/ha N[3]	Jan[4,5] / Feb	March	April	May	June	July	Aug	Sept[4,5]	Rate[1,6] (kg/ha)
6	≤ 80		13	13					13	39
8	99		23	19					18	60
10	118		25	20	15				21	81
12	138	13	28	23	15				23	102
14	158	13	33	23	13		15		26	123
16	176	13	41	25	13		22		30	144

1. Rates shown above refer to recommended application of available fertilizer. Chemical fertilizer rates should be calculated by deducting the available N contained in organic fertilizer applications from the rates shown in the table above.
2. Livestock unit (LU) per ha refers to a ewe plus lambs to weaning.
3. Total annual nitrogen (kg) excreted by grazing livestock averaged over the net grassland area (grazing and silage area). Stocking rate refers to grassland area only.
4. Rates shown above refer to grazed swards only, and are not suitable as a guideline value of the N requirement for the entire grassland area. The N requirement for the entire grassland area will depend on the proportions of the area that are grazed, or cut as silage or hay.
5. Chemical or organic fertilizers cannot be applied during periods when application is prohibited by NAP regulations.
6. Total N use on the farm must comply with NAP regulations.

N fertilization strategy for swards with normal to high (> 20% annually) clover content

White clover can be utilised across all enterprises (dairy, beef and sheep) to improve herbage quality and reduce chemical N fertilizer requirements. Typically, clover content in the sward is low in the spring, increases during the summer and peaks in early autumn and therefore fertilizer N application rates should follow this pattern. Fertilizer N applications on swards with normal to high clover content (> 20% annual average) should be similar to swards with normal to low clover content (< 20% annual average) in the spring/early summer (February to April/May) as clover content in the sward is generally low at that time of the year and there is little biological nitrogen fixation occurring (Tables 12-1 to 12-5). From May/June onwards, when clover content has increased and there is a high level of clover in the sward (> 20%) and it is actively contributing N to the sward, N fertilizer applications may be reduced. The amount of N supplied by clover to the sward will vary depending on clover content and N fertilizer application rates but can be in the region of 70 to 150 kg N/ha with the highest rates of biological N fixation occurring at lower N fertilizer application rates and higher sward clover contents (> 40%). Therefore, depending on stocking rate, grass demand and clover content, N fertilizer rates can be reduced by 50% to 100% (i.e. half rates or no N fertilizer may need to be applied (Tables 12-1 to 12-5) on swards with normal to high clover contents from May/June onwards. As a result, total annual N fertilizer applications can vary from 150 to 250 kg N/ha on swards with normal to high clover content.

Timing of N application

The optimum timing of the N applications in Tables 12-1 to 12-5 depends on climatic, topographical and soil factors which impact on grazing conditions and the length of the grazing season. These factors, together with local knowledge, should be considered when planning the N application dates. The timing of N applications in Tables 12-1 to 12-5 assumes that at each stocking rate, the aim is to optimise the area of first cut silage and to minimise the area for second cut.

The application of fertilizer in early spring and autumn will depend on the length of the grass growing season and early grass demand. For soils with a long grass growing season (e.g. more southerly and coastal regions) the first N application should be in mid to late January, with the second application in early March. For soils with a moderate grass growing season, the first application of N should be in mid-February, with the second application in mid-March. For soils with a short grass growing season, the first application of N should be in late February, with the second application in late March. The recommended date for the final application of fertilizer N is mid-September for areas with long or moderate grass growing season, and late August for areas with short grass growing season.

While these dates are recommended, decisions in each individual year will need to be adjusted depending on the prevailing weather conditions. Soils that are either excessively wet or excessively dry will show poor response to applications of N.

Recent research has shown that CAN, urea and protected urea [urea treated with N-(n-butyl) thiophosphoric triamide (NBPT)] are good sources of N for Irish grassland from a yield perspective (Antille et al., 2015; Harty *et al.,* 2016). However, the efficiency of unprotected urea tends to decline with increasing N rate (Forrestal *et al.,* 2016). Urea protected with NBPT has low ammonia loss, comparable to CAN, and as a result is consistently as good as CAN in terms of yield and efficiency (Forrestal *et al.,* 2016). Urea protected with NBPT also has significantly lower losses of the greenhouse gas nitrous oxide compared with CAN (Harty *et al.,* 2016).

For all applications of chemical or organic N fertilizer, the periods during which application is prohibited within the NAP regulations must be observed.

(2) Available N fertilizer for cut swards

The amount of fertilizer N to apply to cut swards is influenced by many factors, especially by whether it is a new ley, and by the number of cuts taken each year and by the grazing history. Table 12-7shows N advice for cut swards.

Table 12-7: Available N rates for cut swards.

Crop	N application rate (kg/ha)[1]
Silage: first cut	125[2,3,4]
Silage: second or subsequent cut[5]	100[2,3,4]
Hay[6]	65 - 80

1. Rates shown above refer to application of available N. Chemical fertilizer rates should be calculated by deducting the available N contained in organic fertilizer applications from the rates shown in the table above.
2. If N is applied for early grazing, assume that 20% of this remains available for first cut silage.
3. An extra 25 kg/ha may be used where necessary for establishment of a good ryegrass sward if pasture is less than 4 years old, provided that the maximum N allowance prescribed in the NAP regulations is complied with.
4. Where silage fields were grazed rather than cut in the previous year, apply 100 kg/ha for first cut, and 85 kg/ha for second and subsequent cuts.
5. Where multiple cuts are taken the total N use on the farm must comply with NAP regulations.
6. Less N is advised when there is a high risk of crop loss due to high rainfall.

12.2 Available N for Pasture Establishment

Nitrogen advice for pasture establishment is shown in Table 12-6. Considerable amounts of N may be released by mineralization, particularly in cases where conventional ploughing and cultivation is carried out for seedbed preparation. The amount of N released will depend on the previous crop. Thus, the N required depends on the soil N Index;

Table 12-6: Nitrogen for pasture establishment without a cover crop[1] (kg/ha)

Tillage soil N Index[2]	Grass only[3]	Grass / legume[3]
1	75	60
2	65	50
3	55	40
4	55	40

1. For undersown crops, reduce the N rates for the cereal by 50 kg/ha to promote good pasture establishment. Immediately after harvesting the cereal apply 40 kg/ha of N.
2. See Tables 6-2 and 6-3 for N Index system.
3. Establish the crop before the end of August, especially for grass/clover. Apply half the N at sowing and the remainder shortly after grass emergence if there are signs of N deficiency in the sward. For all applications of chemical fertilizers or livestock manure, the periods during which application is prohibited under the NAP regulations must be observed.

(3) Take account of available N in slurry and farmyard manure

To calculate the available N contained in slurry and farmyard manure, multiply the quantity of each material that is applied to grassland by the content of available N that is contained in the material (*cf* Chapter 9, Tables 9-3,9-4 & 9-5).

The N fertilizer replacement value of organic fertilizers, particularly slurry, will depend to a large extent on minimizing the potential for gaseous losses of N as ammonia gas at the time of application (*cf* Chapter 9).

(4) Calculate chemical fertilizer N

The application rate of chemical fertilizer N can be calculated as follows:

Chemical fertilizer N (kg/ha)	=	Available N	-	available N applied in organic fertilizers

(5) Determine maximum N fertilizer allowed and compliance with the NAP regulations

Once the application of chemical N fertilizer for the grassland area has been calculated, it must be cross checked to ensure that it complies with the NAP regulations. The application rates of N, as either chemical or organic fertilizer, cannot exceed the maximum available N rates specified in the NAP regulations across the farm (Tables 12-8 and 12-9). It is advised that the lower of the two rates (advised rate or maximum rate allowed) should be used.

For the purposes of checking compliance with the NAP regulations, it is best to calculate both the advised N application and the maximum N allowance on a whole farm basis. In situations where the N advised exceeds the maximum amount of N allowed, it will be necessary to adjust the N application rates in order to comply with the regulations.

The application rates of 'available nitrogen' prescribed in the NAP refer to the total inputs of N as organic fertilizer (including slurry and farmyard manure), in addition to chemical fertilizer. Therefore, the rates per hectare shown in Table 12-8 should be adjusted to account for all sources of N in order to determine the maximum amount of chemical fertilizer N that can be used on a holding.

Table 12-8 shows the maximum total available N that can be applied to grassland on a holding on which grazing livestock are kept. The rates shown are maxima for all the grassland on such a holding, irrespective of whether the area is used for grazing or silage.

Table 12-8: Annual maximum fertilization rates of available N for grassland on holdings on which grazing livestock are kept, as specified in the NAP regulations

Grassland stocking rate [1] (kg/ha/year)	Available nitrogen[2] (kg/ha)
≤ 170	226
Grassland stocking rate > 170 kg/ha/yr[3]	
171-210	306
211-250,	279
and ≥ 250	279[4]

1. Total annual nitrogen (kg) excreted by grazing livestock averaged over the net grassland area (grazing and silage area). Stocking rate refers to grassland area only.
2. The maximum nitrogen fertilization of grassland shall not exceed that specified for stocking rates less than or equal to 170 kg/ha/year unless a minimum of 5% of the net area of the holding is used to grow crops other than grass or a derogation applies in respect of the holding.
3. This table does not imply any departure from Article 20(1) which prohibits the application to land on a holding of livestock manure in amounts which exceed 170kg Nitrogen per hectare per year, including that deposited by the animals themselves (or 250kg in the case of a holding to which a derogation has been granted, in accordance with the Nitrates Directive).
4. The application of Nitrogen from livestock manure (including that deposited by the animals themselves) to the eligible grassland area shall not exceed 250 kg Nitrogen per hectare per year.

Source: (NAP, S.I. 31 of 2014)

Table 12-9 shows the maximum total available N application that can be applied to grassland that is cut only, and where there are no grazing livestock on the holding.

Table 12-9: Annual maximum fertilization rates of available N for grassland (cut only, no grazing livestock on holding) as specified in the NAP regulations

Grassland cutting regime	Available nitrogen (kg/ha)
First cut	125
Subsequent cuts	100
Hay	80

Source: (NAP, S.I. 31 of 2014)

13. Phosphorus for Grassland

Adequate P nutrition is essential to plant and animal health. Phosphorus is an essential component of the plant and animal cell's adenosine triphosphate (ATP) used for energy utilisation, deoxyribonucleic acid (DNA) for genetic inheritance and cell division, and phospholipids in the cell membrane. In animals, P is also a constituent of bone, and deficiency, known as aphosphorosis, can lead to bone malformation, depraved appetite, poor reproductive performance or low liveweight gain.

In plants, P enhances many aspects of physiology, including photosynthesis, root and tiller development, flowering, seed production and maturation. Phosphorus deficiency in plants is often difficult to recognise, and can result in stunted, thin-stemmed and spindly plants, often with dark, bluish-green foliage, particularly on the older leaves (Sims and Sharpley, 2005). Over-application of P will impose unnecessary costs on a farmer. Furthermore, if maximum fertilization rates are exceeded on soils vulnerable to P loss, this may give rise to adverse effects on water quality through eutrophication resulting from P enrichment. Organic fertilizers can be used with or in place of chemical P to supply crop requirements.

13.1 P Fertilization Strategy for Grazing and Silage

Phosphorus fertilizer advice for mineral soils (i.e. soils with $< 20\%$ organic matter content) is based on increasing the soil P reserves to a level at which the amount of available soil P supports the production of herbage of optimum quantity (DM yield) and quality (P content sufficient to satisfy the dietary requirements of grazing animals). This is referred to as "soil P build-up". Once this soil P level has been achieved, the objective is to maintain the soil P level by replacing the P removed in animal products or in hay or silage. This is called "soil P maintenance". Where the soil P level is greater than that required, there is an increased risk of P loss to the environment. In such cases, P application should be avoided so that the soil P level will decline to the optimum level, so that this risk is reduced. It is advised that wherever possible, animal manures should be recycled to minimise chemical fertilizer needs.

Peat soils (i.e. soils with $> 20\%$ organic matter content) need to be considered separately to mineral soils for P fertilizer advice, as the chemistry of P adsorption behaves differently on peat soils. These soils do not have the reserves of elements such as iron and aluminium that retain P. Also, the high organic matter content present in peat soils competes with P for adsorption sites on soil particles. Therefore, the amount of P that peat soils can adsorb is reduced. Phosphorus applied to or present in peat soils is more susceptible to loss to the environment as a result. Therefore, in order to reduce the risk of P loss to the environment, the concept of "P build-up" does not apply to peat soils, and only maintenance rates should be applied to peat soils that have a P requirement. Additionally, regular low rate applications to coincide with maximum plant P uptake are recommended rather than single high rate application each year.

Soil P Index

The Morgan's soil P test (see Chapter 6) is used to estimate "plant available" P levels in the soil. Soil testing is advised at least once every five years so that soil P levels can be monitored. The Soil Index system for nutrient levels is explained in Chapter 6 and the P Index Table (6-4) is reproduced as Table 13-1 below.

Soil P levels at Index 1 will not achieve optimum sward productivity throughout the year without additional P fertilizer above the rate required for soil P maintenance. Soil P levels at Index 2 may restrict grass growth in spring. Where grass demand is low early in the season P index 2 soils mayachieve sufficient dry matter (DM) yields, but the herbage P concentration may not meet the dietary requirements of some grazing animals. In general, soil P levels at Index 3 are advised to ensure that the grass sward will achieve optimum DM yield, encourage growth of clover and early grass, and contain a P concentration that is adequate to meet the dietary requirements of grazing animals.

A recent study of Irish soil types showed that aluminium (Al) in soil had a strong influence on the soil's ability to supply available P for plant uptake (Daly *et al*., 2015). At high Al to P ratios P fixation occurred and soils had difficulty supplying P. For these soils the critical range of Morgan's P at which P was plant available fell between 5.9 and 8.7 mg/l. The current grassland P Index 3 range (5.1 – 8.0 mg/l Morgan's extractable P) may not capture all these high P fixing soils. Therefore, soils within the current Index 3 and Index 4 categories may show additional P responses beyond the generalised recommended rates of P fertilizers.

In addition, the Morgan's soil test may overestimate the available soil P on calcareous soils and those with high soil pH (>7.0) as it was developed for naturally acidic soils where a large proportion of P is bonded to Al, Iron and Manganese in the mineral matter. These high pH soils may require additional P fertilizer, even at optimum soil test P levels, for intensive grassland production to maintain an adequate P supply throughout the growing season

Grassland soils with P levels at Index 4 may pose an increased risk of P loss to the environment, and no P fertilizer is advised until the soil P level reverts to the Index 3 range.

Table 13-1:P Index for grassland

Soil P Index	Soil P range (Morgan's mg/l)	Comments	
		Index description	Response to fertilizer
1	0.0 – 3.0	Very Low	Definite
2	3.1 – 5.0	Low	Likely
3	5.1 – 8.0	Medium / Adequate	Unlikely / Tenuous
4	> 8.0	Sufficient / High	None

Phosphorus for grazing and silage

P-fertilizer advice for grazing is based on the following 5 steps:

1. Determine P required for soil P build-up (Table 13-2)
2. Determine P required for soil P maintenance (Tables 13-3, 13-4, 13-5)
3. Take account of P in slurry and farmyard manure (Chapter 9)
4. Calculate chemical fertilizer P requirements
5. Determine maximum P allowance, and confirm that the P fertilizer requirement of the holding is compliant with the NAP regulations

(1) Soil P build-up

P fertilizer rates advised for build-up to soil P Index 3 are presented in Table 13-2. Note that application of build-up rates may be required over a number of years (Until next soil sample) for P-deficient soils or higher P fixing soils to move from Index 1 to 2, and from Index 2 to 3.

At very extensive stocking rates, or in areas governed by specific legislation such as national heritage areas (NHAs) or special areas of conservation (SACs), it may be appropriate to fertilize soils to a level such that Index 2 is maintained. Therefore maintenance P applications would be applied to these areas only and no build-up where soils are already at index 2.

Table 13-2: Available P rates (kg/ha) for build-up on mineral soils

Soil P Index	Mineral soils[1,2]
1	20
2	10
3	0
4	0

1. Mineral soils are defined as soils with less than or equal to 20% organic matter
2. Peat soils (i.e. soils with more than 20% organic matter) receive only maintenance rates of P

(2) Soil P maintenance

Grazing livestock

Each year, P is removed in either animal produce (meat, milk) or as silage or hay. This P must be replaced by applying "maintenance rates" of P as recycled P from concentrate feeds used, recycled animal manures or chemical fertilizer P.

For soil P maintenance, no distinction is made between mineral soils or peat soils. However, higher P fixing mineral soils, with higher aluminium concentrations and low ratios of Al to P, will require somewhat higher P inputs (than replacement) to maintain soil test P levels over time.

Table 13-3 shows example soil P maintenance rates for grazing that are required for dairy and drystock production systems.

Soil P maintenance rates advised for grazed pasture should, at least, be equal to the amount of P that leaves the holding as product. In general, 1kg of P is required to replace the P removed in either 1000 litres of milk, or 100 kg of liveweight gain (LWG). The soil P maintenance rate will therefore be determined by the milk production or liveweight gain (LWG) being achieved per hectare.

Table 13-3: Grazing: Maintenance rates of available soil P to replace offtakes (kg/ha)[1,2,3]

Grassland stocking rate (kg/ha) of Org N[5]	System[4]	
	Dairy	Drystock
≤ 100	6	4
130	10	7
170	14	10
210	19	13
≥ 210	23	16

1. Rates of P fertilizer are based on concentrate feed usage level of zero.
2. P for soil P build-up, as determined by soil Index, should be added to the rates shown above.
3. Rates shown above refer to maintenance requirements for the grazing area only. P requirements for the whole farm depend on the proportion of grazing, silage and hay areas on the farm.
4. Where a holding contains a mixture of dairy and drystock enterprises, it is advised that the P rate for all the grazing area should be based on the requirements of the more dominant enterprise.
5. Total annual nitrogen (kg) excreted by grazing livestock averaged over the net grassland area (grazing and silage area). Stocking rate refers to grassland area only

P maintenance for silage and hay

Soil P maintenance rates advised for silage and hay crops are shown in Table 13-4. Where two or more cuts of silage are taken in one year on soils with soil P levels at Index 1 or 2, the additional 'soil P build-up' portion of the fertilizer should be applied prior to the first cut.

Table 13-4: Silage and hay: Soil P maintenance requirement to replace offtakes (kg/ha)[1] 5t/ha

Soil P Index	First cut[1]	Second or subsequent cut
1 - 3	20	10
4	Do not apply chemical P	Do not apply chemical P

1. P for soil P build-up, as determined by soil Index, should be added to the rates shown above.
2. Add or subtract 4 kg/t of DM above or below a yield of 5 t/ha

13.2 P Fertilization for Pasture Establishment

Table 13-5 shows the P rates advised for pasture establishment sown without a cover crop. For under-sown cereal crops at soil P Index 1, 20 kg/ha P should be broadcast in addition to the P applied for the cereal crop. For pasture establishment on peat soils, the P fertilization rates should not exceed that advised for Index 3 soils.

Table 13-5: P rates (kg/ha) required for pasture establishment without a cover crop

Soil P Index	P application rate[1]
1	60
2	40
3	30
4	0

1. Establishment of grass/clover Rates of P fertilizer applied for pasture establishment must not result in the fertilizer P allowance for the holding, as determined from NAP regulations being exceeded.

(3) Take account of P in slurry and farmyard manure

To calculate the P contained in slurry and farmyard manure, multiply the quantity of each material that is applied to grassland by the P-content of the material (see Table 9-3 or 9-4). In situations where total P contained in slurry and farmyard manure produced on the holding exceeds the total P application advised, they may be applied to Index 4 soils, but only after all the P requirements of soils in Indices 1, 2 and 3 have been met by slurry and farmyard manure produced on the farm. Where such a necessity arises, organic fertilizer applications that exceed the advised P rates should be confined to areas where the risk of overland flow is small and risk of P loss to water is low.

Organic Manures and P Availability for Index 1 and 2 soils

Crops have an immediate demand for P in an available form. Approximately 50-60% of the total P content of livestock manure is present in the inorganic form (DEFRA, 2006), with the remaining P being mineralised into an available form over time. On Index 1 and 2 soils 50% P fertiliser replacement value (P availability) can be assumed for organic manures based on soil analysis taken with the last 5 years. Where livestock manure is applied to soils with P levels below the required Index; if there is insufficient mineral P available to supply the immediate P demand, it is advised that the organic fertilizer should not be the sole source of P. On such soils, the inclusion of mineral P fertilizer combined with organic fertilizers may be necessary in order to ensure that the immediate demand for available P by the crop is met. On soils with P levels equal to the required Index, livestock manure can be used to supply the entire P demand. However, it is mandatory that any strategy devised for organic fertilizer management should comply with the NAP regulations.

(4) Calculate chemical fertilizer P requirements

The application rate of chemical fertilizer P for each area of the farm can be calculated as follows

Chemical Fertilizer P (kg P/ha)	=	Available P for build-up	+	Available P for maintenance	-	Available P applied in slurry or farmyard manure

(5) Maximum fertilizer P allowed and compliance with NAP regulations

Once the total application of chemical P fertilizer for the grassland area has been calculated, it must be cross checked to ensure that it complies with the NAP regulations. The application rates of P, as either chemical or organic fertilizer, must not exceed the maximum available P rates specified in the NAP regulations (Tables 13-6 and 13-7). It is advised that the lower of the two rates (advised rate or maximum rate allowed) should be used.

For the purposes of checking compliance with NAP regulations, it is best to calculate both the P advice and the maximum P allowance on a whole farm basis. In situations where the P advice exceeds the maximum amount of P allowed, it will be necessary to adjust the P advice in order to comply with the regulations. The following list shows some possible examples of where such situations are likely to arise including:

- where high levels of concentrate feed are used,
- within high intensity systems, such as high yielding dairy cows,
- where a portion of the farm has soil test P levels in Index 4,
- where the actual winter housing period (and resulting slurry and farmyard manure production) on the farm is at variance with that specified in the regulations.

Where the P advice exceeds the maximum allowed under the NAP regulations, *pro rata* reduction to all applications of chemical P is advised.

Table 13-6: Annual maximum fertilization rates of available P for grassland (grazing plus silage) on holdings on which grazing livestock are kept, as specified in the NAP regulations				
Grassland stocking rate (kg/ha) of Org N[1]	Phosphorus Index			
	1	2	3	4
	Available Phosphorus (kg/ha)[2,3,6]			
< 85	31	21	11	0
86 - 130	36	26	16	0
131 - 170	41	31	21	0
Grassland stocking rate > 170 kg/ha[4,5]				
171 - 210	46	36	26	0
211 - 250	51	41	31	0
≥ 250	51	41	31	0

1. Total annual nitrogen (kg) excreted by grazing livestock averaged over the net grassland area (grazing and silage area). Stocking rate refers to grassland area only.
2. The fertilization rates for soils which have more than 20% organic matter (peat soils) shall not exceed the amounts permitted for Index 3 soils.
3. Manure produced by grazing livestock on a holding may be applied to Index 4 soils on that holding in a situation where there is a surplus of such manure remaining after the phosphorus fertilization needs of all crops on soils at P Indices 1, 2 or 3 on the holding have been met by the use only of such manure produced on the holding.
4. The maximum phosphorus fertilization of grassland shall not exceed that specified for stocking rates less than or equal to 170 kg/ha/year unless a minimum of 5% of the net area of the holding is used to grow crops other than grass or a derogation applies in respect of the holding.
5. This table does not imply any departure from Article 20(1) which prohibits the application to land on a holding of livestock manure in amounts which exceed 170kg Nitrogen per hectare per year, including that deposited by the animals themselves (or 250kg in the case of a holding to which a derogation has been granted in accordance with the Nitrates Directive).
6. An additional 15 kg of phosphorus per hectare may be applied on soils at phosphorus indices 1, 2, or 3 for each hectare of pasture establishment undertaken.

Source: (NAP, S.I. 31 of 2014,)

The application rates of 'available phosphorus' prescribed in the NAP refer to the total inputs of P as either concentrate feeds or organic fertilizers (including slurry and farmyard manure deemed to be produced during the required winter storage period), in addition to chemical fertilizer. Therefore, the rates per hectare shown in Table 13-6 should be adjusted to account for such sources of P in order to determine the maximum amount of chemical P fertilizer that can be used on a holding.

Note that Table 13-6 shows the maximum total available P application that can be applied to grassland on a holding on which grazing livestock are kept. The rates shown are maxima for all the grassland on such a holding, irrespective of whether the area is used for grazing or silage.

Table 13-7 shows the maximum total available P application that can be applied to grassland that is cut only, and where there is no grazing livestock on the holding.

Table 13-7: Annual maximum fertilization rates of available P for grassland (cut only, no grazing livestock on holding) as specified in the NAP regulations

	Phosphorus Index			
	1	**2**	**3**	**4**
	Available Phosphorus (kg/ha)[1,2]			
First cut	40	30	20	0
Subsequent cuts	10	10	10	0

1. The fertilization rates for soils which have more than 20% organic matter (peat soils) shall not exceed the amounts permitted for Index 3 soils.
2. The fertilization rates in this table apply to those areas of farms where hay or silage is produced for sale off the holding on farms stocked at < 1 LU/ha (equivalent to < 85 kg organic N grassland stocking rate).

Source: (NAP, S.I. 31 of 2014)

14. Potassium for Grassland

Regular soil analysis should be used to monitor the soil K levels because the K status can drop quite rapidly in some soils. Only regular monitoring, at least every five years, will ensure that the K Index (Table 6-5) is optimal. The appropriate K application rates for grazing and silage are shown in Tables 14-1 and 14-2, respectively. For K fixing soils such as the Athy soil series, K should be applied in the spring and/or throughout the growing season. Potassium fixation is more likely to occur in conditions when organic matter content is low and during reseeding.

14.1 Potassium for Grazing

Table 14-1 gives the available K advice for a grazed sward. Unless the soil is at K Index 1, fertilizer K can be applied in autumn to reduce the risk of hypomagnesaemia i.e. to avoid Mg deficiency in animals arising from luxury uptake of K by grass in the spring.

Table 14-1: Available K for grazing at stocking rate of 2 LU/ha[1,2]

Soil K Index	K Advice (kg/ha)[3]	
	Dairy	Drystock
1	90	75
2	60	45
3	30	15
4	none	none

1. For stocking rates greater than 2 LU/ha (>170 kg/ha Org N), increase rates by 5 kg/ha for each increase in stocking rate of 40 kg/ha.
2. For stocking rates less than 2 LU/ha (170 kg/ha Org N), decrease rates by 5 kg/ha for each decrease in stocking rate of 40 kg/ha.
3. Chemical K application rates can be calculated by deducting the quantity of K applied in organic fertilizers.

14.2 Potassium for Silage and Hay

Table 14-2 gives the available K required for silage and hay crops i.e. K applied both as chemical and organic fertilizers. The chemical K required can be calculated from Table 14-2 by subtracting the amount in applied organic fertilizer using Table 9-1.

Luxury amounts of K may be taken up by grass where more than 90 kg/ha K are applied. This can reduce fertilizer K efficiency and may upset the K:Mg:Na balance in herbage. Where more than 90 kg/ha is advised; only 90 kg should be applied in spring, and the remainder to the aftermath or in late autumn.

Table 14-2: Available K for silage and hay (kg/ha). The advice assumes a dry matter yield of 5 t/ha for first cut and 3 t/ha for 2nd or subsequent cuts[1]		
Soil K Index	First cut silage / hay	2nd and 3rd cut[2,3]
1	185[4]	75
2	155[4]	75
3	125[4]	75
4	0[5]	0[5]

1. Increase K by 25 kg/ha for each extra t/ha of dry matter (or each 5 t/ha of fresh weight).
2. Note that the advice in this column is per cut.
3. Where K build up has already been applied for previous grass silage crop (i.e. first cut) apply K based on crop offtake (i.e. Index 3).
4. Typically no more than 90 kg/ha K should be applied at closing for silage and the remainder should be applied at least 3 months in advance or after silage harvest.
5. No K is required in the year of sampling. For subsequent years use Index 3 advice pending a further soil test.

Table 14-3 gives the calculated chemical K advice for first cut silage, on the assumption that a typical application of 33 t/ha of slurry is applied to the silage ground.

Table 14-3: Chemical K fertilizer advice for silage (kg/ha) where 33 t/ha of cattle slurry is applied to the first cut[1]. The advice assumes a herbage dry matter yield of 5 t/ha[2]	
Soil K Index	**First cut**
1	79
2	49
3	10
4	0[3]

1. Adjust chemical K fertiliser rates based slurry nutrient content and application rate (see table 9-3, 9-4 and 9-8). See Table 9-5 & 9-6 for other types of livestock manures.
2. Increase K by 25 kg/ha for each extra t/ha of dry matter produced (i.e. for each 5 t/ha of fresh weight).
3. No K is required in the year of sampling. For subsequent years use Index 3 advice pending a further soil test.
4. Note the K content in cattle slurry can be variable and lower rates of K than specified in this table may be applied especially where cattle slurry is more dilute i.e. lower dry matter (see table 9-8).

14.3 Potassium for Pasture Establishment

Table 14-4 shows the K rates advised for pasture establishment sown without a cover crop. For under sown crops at soil K Index 1, 40 kg/ha K should be broadcast in addition to cereal requirements.

Table 14-4: Potassium for pasture establishment without a cover crop[1]

Soil K Index[1]	Grass only kg K/ha	Grass/legume kg K/ha
1	110	120
2	75	90
3	50	60
4	30	40

1. See Table 6-5 for K Index system.

15. Soil Fertility for Horse Production

Good grassland management is a key component of horse production as it will ensure good quality grass during the grazing season and the production of quality forage to meet winter feed requirements.

Nitrogen

Low levels of N are required for swards grazed by horses only. Good soil fertility levels (pH, P & K) are required to ensure good grass palatability and persistency of the productive grass species. An application of 25-30 kg/ha N may be sufficient for most horse production systems. Available N advice is shown in table 15-1.

Table 15-1: Available N, advice and P and K (kg/ha) for maintainance on swards grazed by horses at at various stocking rates

Stocking rate LU/ha[1]	N[2,3]	P	K
1.0	25-40	3	4
1.5	25-40	5	6
2.0	25-40	7	8

1. 1 horse = 1 LU/ha
2. Apply 25kgN/ha in springtime
3. Apply additional N based on grass demand during the growing season.

Phosphorus (P) and Potassium (K)

The maintenance requirement for P and K on grazing swards tends to be low compared to other livestock enterprises (Table 15-1). Where there is a high demand for grass on a horse farm aim to maintain soil P and K in the optimum Index 3 range for good grass production. Depending on grass demand maximizing grass production may not be required and maintaining soil Index 2 may be sufficient depending on the annual grass requirements for the production system. Where soils are Index 1 or 2, additional P and K for build-up will be required see table 13-2 and 14-1 for build up rates. Apply build rates of P and K until the next soil test.

16. Cereals

Nutrient advice for cereal crops is sometimes constrained by the rates prescribed in the NAP regulations. While a fertilizer plan should endeavour in so far as is possible to fertilize each crop based on individual crop requirement, the fertilization strategy adopted must not give rise to a farm exceeding the maximum allowed fertilizer N and P rates as prescribed in law by the NAP.

16.1 Nitrogen for Cereals

Nitrogen application rates for cereals should be based on supplying the difference between total crop N requirement, and the amount of that crop requirement supplied by soil nitrogen. The amount of nitrogen supplied by the soil is governed by a range of factors and is difficult to predict accurately. In Ireland, the soil N Index system is used to give an indication of differences in soil nitrogen supply between sites, which can be used to adjust fertilizer nitrogen inputs (Tables 6-2, 6-3). The soil N Index of a particular soil will be largely determined by previous cropping history.

Cereals are very responsive to N, although excess amounts can reduce yield and quality. Most efficient recovery of applied fertilizer N by crops will occur when the N is applied to actively growing crops. Application of N to crops at times when crops are not actively growing or growing only slowly e.g. over the winter period, is likely to lead to poor recovery of applied N and can result in loss of applied N to the environment. The objective of a fertilizer N strategy should therefore be to apply N as close to the period when the crop needs it as possible. The main demand for N by cereal crops will occur between the beginning of stem extension (GS 30) and flowering (GS 65).

Urea may be used as a source of N and in the majority of instances will give similar agronomic performance to that of CAN at a lower cost per kilogram of N. However, under certain conditions a portion of N applied as urea can be lost to the atmosphere through the process of ammonia volatilisation which can lead to inferior yields from urea relative to CAN. Protected urea [urea treated with N-(n-butyl) thiophosphoric trimide (NBPT)] is an alternative source of N to CAN, with reduced risk of N loss compared to urea. Recent research has shown that protected urea reduced ammonia losses compared to urea and consistently produced similar spring barley yields to CAN, with slightly higher N uptake (Roche *et al*., 2016). Using protected urea also reduced N_2O emissions. On soils where conditions are conducive to ammonia volatilisation, which include high pH and drying conditions subsequent to application, protected urea can be used to minimise N loss risk.

Wheat

Table 16-1 shows available N fertilizer rates for wheat having yields classed as moderate or where proof of higher yields is not available.

Table 16-1: Available N[1] for wheat (kg/ha) having moderate yields[2] or where proof of higher yields is not available

Soil N Index[3]	Winter wheat[4,5]	Spring wheat[4,5,6]
1	210	160
2	180	130
3	120	95
4	80	60

1. N rates shown above refer to application rates of available fertilizer. Chemical fertilizer rates should be calculated by deducting the available N contained in organic fertilizer applications from the rates shown in the above table.
2. Winter Wheat up to 9.0 tonnes/ha, Spring Wheat up to 7.5 tonnes/ha.
3. See Tables 6-2 and 6-3 for Soil N Index.
4. Where proof of higher yields is available, an additional 20kg/ha N may be applied for every 1 tonne above reference yield see table 16-2. The higher yields shall be based on the best yield achieved in any of the three previous harvests at 20% moisture content.
5. Where milling wheat is grown under a contract to a purchaser of milling wheat an extra 30 kg/ha N may be applied.
6. To reduce the risk of poor establishment in spring cereals, not more than 75 kg/ha N should be combined drilled.

If proof of higher wheat yields is available (as defined in the NAP regulations) then the N rates from Table 16-2 may be used.

Table 16-2: Available N[1] for wheat (kg/ha) where proof of higher yields is available

Soil N Index[2]	Winter wheat[3,4]			
	9 t/ha	10 t/ha	11 t/ha	12 t/ha
1	210	230	250	270
2	180	200	220	240
3	120	140	160	180
4	80	100	120	140
	Spring wheat[3,4,5]			
	7.5 t/ha	8.5 t/ha	9.5 t/ha	10.5 t/ha
1	160	180	200	220
2	130	150	170	190
3	95	115	135	155
4	60	80	100	120

1. N rates shown above refer to application rates of available fertilizer. Chemical fertilizer rates should be calculated by deducting the available N contained in organic fertilizer applications from the rates shown in the above table.
2. See Tables 6-2 and 6-3 for Soil N Index.
3. Rates shown above are equal to the maximum allowed rates in the NAP regulations. The higher yields shall be based on the best yield achieved in any of the three previous harvests, at 20% moisture content.
4. Where milling wheat is grown under a contract to a purchaser of milling wheat an extra 30 kg/ha N may be applied.
5. To reduce the risk of poor establishment in spring cereals, not more than 75 kg/ha N should be combined drilled.

Timing of application

Nitrogen should not be applied to winter wheat at sowing time. Nitrogen should be applied to winter wheat at the onset of significant growth in early to mid-March. As a general rule, where more than 100 kg/ha N is to be applied, the N should be split into two applications. Where more than 150 kg/ha N is to be applied, three applications can be considered.

For winter wheat the average application timings will be at late tillering to GS 30 for the first application, GS 30- 31 for the second application and GS 37 where a third application is being made. The application at GS 30-31 is the most important application, as it is at the beginning of the rapid uptake phase, and generally 50% or more of the total dose will be applied at this timing.

Where high protein is required application of 40 kg/ha N at GS 37 as CAN can increase protein content by approximately 0.5%. Alternatively foliar application of 30-40 kg/ha N, applied as a 10% urea solution spray at the grain milky ripe stage can be used but there is a risk of leaf scorching. Optimum timing for foliar applied urea is generally 28-42 days after flag leaf emergence (GS 39) for winter wheat and 25-28 days after flag leaf (GS 39) emergence for spring wheat.

Barley

Table 16-3 shows available N fertilizer rates for barley having moderate yields.

Table 16-3: Available N[1] for barley (kg/ha) for moderate yields[2] or where proof of higher yields is not available

Soil N Index[3]	Winter barley[4]	Spring barley[4,5,6]
1	180	135
2	155	100
3	120	75
4	80	40

1. N rates shown above refer to application rates of available fertilizer. Chemical fertilizer rates should be calculated by deducting the available N contained in organic fertilizer applications from the rates shown in the above table.
2. Winter Barley up to 8.5 tonnes/ha, Spring Barley up to 6.5 tonnes/ha.
3. See Tables 6-2 and 6-3 for Soil N Index.
4. Where proof of higher yields is available, an additional 20kg/ha N may be applied for every 1 tonne above reference yield see table 16-4. The higher yields shall be based on the best yield achieved in any of the three previous harvests at 20% moisture content.
5. To reduce the risk of poor establishment in spring cereals, not more than 75 kg/ha N should be combined drilled.
6. Where malting barley is grown under a contract to a purchaser of malting barley an extra 20 kg/ha N may be applied where it is shown on the basis of agronomic advice that additional N is required to address a proven low protein content in the grain.

If proof of higher barley yields is available (as defined in the NAP regulations) then the available N rates from Table 16-4 may be used.

Timing of application

Nitrogen should not be applied to winter barley at sowing. For winter barley the first application will be made at the onset of significant growth between late February and mid-March when the crop is at the late tillering stage, before GS 30. Generally, 25-30% of the total should be applied at this timing. The second application should be made at around GS 31, which will typically be in late March/early April. In general, a third application will not be required.

For spring barley the initial fertilizer N can be applied at sowing, either broadcast before sowing or combine drilled, or alternatively, particularly for early drilled crops (i.e. February sown crops), the initial N application can be made as soon as the crop has emerged. Research has shown little difference between applying the first N at sowing compared to applying the first N at emergence to spring barley. Since the crop demand is very low in the early stages of growth approximately 25-30% of the total planned N application is sufficient at the first application. The second application should be made during tillering (GS22-25). At this stage the remainder of the fertilizer N can be applied, or, particularly if there is a risk of high rainfall after application, a portion of the total N to be applied (typically <20%) can be retained and applied as a third application at GS 31.

Table 16-4: Available N[1] for barley (kg/ha) where proof of higher yields is available

Soil N Index[2]	Winter barley[3]		
	8.5 t/ha	9.5 t/ha	10.5 t/ha
1	180	200	220
2	155	175	195
3	120	140	160
4	80	100	120
	Spring barley[3,4,5]		
	6.5 t/ha	7.5 t/ha	8.5 t/ha
1	135	155	175
2	100	120	140
3	75	95	115
4	40	60	80

1. N rates shown above refer to application rates of available fertilizer. Chemical fertilizer rates should be calculated by deducting the available N contained in organic fertilizer applications from the rates shown in the above table.
2. See Tables 6-2 and 6-3 for Soil N Index.
3. Rates shown above are equal to the maximum allowed rates in the NAP regulations. The higher yields shall be based on the best yield achieved in any of the three previous harvests, at 20% moisture content.
4. To reduce the risk of poor establishment in spring cereals, not more than 75 kg/ha N should be combined drilled.
5. Where malting barley is grown under a contract to a purchaser of malting barley an extra 20 kg/ha N may be applied where it is shown on the basis of agronomic advice that additional N is required to address a proven low protein content in the grain.

Oats

Table 16-5 shows available N fertilizer rates for oats having moderate yields, as defined in the NAP regulations.

Table 16-5: Available N[1] for oats (kg/ha) for moderate yields[2] or where proof of higher yields is not available

Soil N Index[3]	Winter Oats[4]	Spring Oats[4,5]
1	145	110
2	120	90
3	85	60
4	45	30

1. N rates shown above refer to application rates of available fertilizer. Chemical fertilizer rates should be calculated by deducting the available N contained in organic fertilizer applications from the rates shown in the above table.
2. 7.5 t/ha winter oats, 6.5 t/ha spring oats.
3. See Tables 6-2 and 6-3 for Soil N Index.
4. Where proof of higher yields is available, an additional 20 kg/ha N may be applied for every 1 tonne above reference yield see Table 16-6.
5. To reduce the risk of poor establishment in spring cereals not more than 75 kg/ha N should be combined drilled.

Table 16-6 shows available N fertilizer rates for oats where proof of higher yields (as per the NAP regulations) is available.

Table 16-6: Available N[1] for oats (kg/ha) where proof of higher yields is available

Soil N Index[2]	Winter Oats[3]		
	7.5 t/ha	8.5 t/ha	9.5 t/ha
1	145	165	185
2	120	140	160
3	85	105	125
4	45	65	85
	Spring Oats[3,4]		
	6.5 t/ha	7.5 t/ha	8.5 t/ha
1	110	130	150
2	90	110	130
3	60	80	100
4	30	50	70

1. N rates shown above refer to application rates of available fertilizer. Chemical fertilizer rates should be calculated by deducting the available N contained in organic fertilizer applications from the rates shown in the above table.
2. See Tables 6-2 and 6-3 for Soil N Index.
3. Rates shown above are equal to the maximum allowed rates in the NAP. The higher yields shall be based on the best yield achieved in any of the three previous harvests, at 20% moisture content.
4. To reduce the risk of poor establishment in spring cereals not more than 75 kg/ha N should be combined drilled.

Timing of application

Nitrogen should not be applied to winter oats at sowing time (Tables 16-5, 16-6). For winter oats, where two applications are being used, the first application will be made around GS 30 and the second at GS 31-32. In general, a third application will not be required. The application of high N rates (>145 kg/ha) to winter varieties with poor lodging resistance may result in lodging in certain years even when a good growth regulator programme has been used.

For March sown oats a proportion, usually not more than half, can be applied at or before sowing and the reminder applied before GS 30. For later sown oats a greater proportion of the N will be applied at or before sowing.

16.2 Phosphorus and Potassium for Cereals

Advice for P and K is based on maintaining the soil test levels of these elements at the agronomic optimum level of Index 3. This is achieved by applying enough of the nutrient to replace the anticipated crop off-take, based on the expected yield of the crop to be fertilized. Where the Soil Index is below Index 3, build-up levels are required in addition to anticipated crop off-take in order to raise the Soil Index to Index 3. Regular soil tests should be carried out to ensure that soils are maintained within the agronomic optimum soil Index.

P and K offtakes in cereal crops

Table 16-7 shows offtakes per tonne of grain yield of P and K by cereal crops. While grain yield is used to calculate offtakes provision is made in the values for offtake in the straw where applicable. Note that higher K offtakes are likely in straw that is less mature (i.e. slightly green).

Table 16-7: P and K offtakes in cereal crops (kg/ha) per tonne of grain yield

Crop	Straw Removed		Straw not removed	
	P	K	P	K
Winter Wheat / Barley	3.8	9.8	3.4	4.7
Spring Wheat / Barley	3.8	11.4	3.4	4.7
Oats	3.8	14.4	3.4	4.7

Source: (DEFRA, 2006)

Table 16-8 shows total P and K offtakes in high-yielding crops.

Table 16-8: Typical P and K offtakes in cereal crops (kg/ha)

Crop	Yield (t/ha)	Straw Removed		Straw not removed	
		P	K	P	K
Winter Wheat[1]	11.0	42	108	37	52
Spring Wheat[2]	8.5	32	97	29	40
Winter Barley[1]	10.0	38	98	34	47
Spring Barley[2]	7.5	29	86	26	35
Winter Oats[3]	9.0	34	130	31	42
Spring Oats[3]	7.5	29	108	25	35

1. For winter wheat and winter barley crops where straw is also removed: increase or decrease P by 3.8 kg/ha and K by 9.8 kg/ha for every 1 tonne grain yield increase or decrease respectively from the yield indicated.
2. For spring wheat and spring barley crops where straw is also removed: increase or decrease P by 3.8 kg/ha and K by 11.4 kg/ha for every 1 tonne grain yield increase or decrease respectively from the yield indicated.
3. For oat crops where straw is also removed: increase or decrease P by 3.8 kg/ha and K by 14.4 kg/ha for every 1 tonne grain yield increase or decrease respectively from the yield indicated.

Source: (DEFRA, 2006)

Phosphorus advice

Yields from soils at Index 3 will normally be higher than from similar soils at Index 1 or 2, irrespective of the amount of P applied to the lower index soils. Therefore, advice for P fertilization of crops is based on maintaining soil test P levels at Index 3 by replacing anticipated offtakes and where necessary (i.e. where the soil is at Index 1 or 2 for P) applying P in addition to anticipated offtake so as to achieve Index 3. Maximum rates of P allowed by law are specified in the NAP regulations, and shown in table 16-9. Phosphorus can be supplied to cereal crops either as fertilizer or as organic manure.

Table 16-9: Annual maximum fertilization rates of P on cereal crops (kg/ha), as specified in the NAP regulations

Soil P Index	Available P (kg/ha)[1,2,3]
1	45
2	35
3	25
4	0[4]

1. The fertilization rates for soils which have more than 20% organic matter shall not exceed the amounts permitted for Index 3 soils.
2. P rates shown above refer to recommended application rates of available fertilizer. Chemical fertilizer rates should be calculated by deducting the P contained in organic fertilizer applications from the rates shown in the above table.
3. Where proof of higher yields is available, an additional 3.8 kg P/ha may be applied on soils at phosphorus indices 1, 2, or 3 for each additional tonne above a yield of 6.5 tonnes/ha (refer to Table 16-10) The higher yields shall be based on the best yield achieved in any of the three previous harvests, at 20% moisture content.
4. Where pH is greater than or equal to 7, 20 kg P/ha may be applied on soils at phosphorus Index 4.

Table 16-10: Available phosphorus advice for cereals based on crop yield (kg/ha)

Soil P Index[1]	Grain yield (t/ha)[2]					
	6.5	7.5[2]	8.5[2]	9.5[2]	10.5[2]	11.5[2]
1	45	49	52	56	60	64
2	35	39	42	46	50	54
3	25	29	32	36	40	44
4	0[3]	0[3]	0[3]	0[3]	0[3]	0[3]

1. The table above shows the levels of P for cereal crops based on soil P index and crop yield.
2. Additional P can be applied on the basis of proof of higher grain achieved yields in anyone of the previous 3 years at 20% MC. An additional 3.8 kg P/ha for each extra one tonne above the base yield of 6.5t/ha can be applied.
3. Where pH is greater than or equal to 7, 20 kg P/ha may be applied on soils at phosphorus index 4.

Timing of application

Where P is being applied as organic manure is should be incorporated into the soil before sowing where possible.

For spring sown cereals on low P soils (P Index 1 and 2) it is advisable that fertilizer P be incorporated at or before sowing. Research has shown a consistent benefit of placing P with the seed (combine drilling) for spring crops at Index 1 and 2 (Wall *et al.,* 2013) soils. While benefits to placing P with the seed can be obtained at Index 3 the benefits are likely to be smaller and less consistent than at lower soil P indices. For early sown spring cereals placement of P fertilizers may be more critical where soil and weather conditions are less than optimal.

For winter wheat crops research has indicated no consistent yield benefit, even where soil P levels are very low, of autumn applied P, compared to broadcast applications in the spring. While there is some evidence of increased seedling survival where P is placed with the seed at sowing time, this maybe more pertinent to winter barley crops grown on low P supply sites where yield formation is more dependent on tiller number development and survival compared to winter wheat. Since fertilizer P application after mid-September is prohibited, spring applications of P are normally advised for winter cereal crops and these applications should be made in February/early March before the onset of significant growth in the spring.

Restricted periods for fertilizer application as set out in the NAP regulations must be observed.

Potassium advice

Advice for K fertilization of high-yielding cereals crops are shown in tables 16-11 and 16-12.

Soils, with a similar soil Index, may vary in their capacity to supply K to a crop. This will largely depend on the mineralogy of the soil. Local knowledge of the ability of a soil to supply K to a crop should be taken into account when determining the fertilizer K requirements. In addition, a comparison of soil test results over time will give an indication of the soils ability to supply K.

On sandy or organic soils, K levels will not build up, and it is necessary to apply adequate levels of K each year. This is also true for K fixing soils, in which, for winter cereals, it may be worthwhile to apply some of the K to the seedbed and the remainder the following spring.

Table 16-11: Available K advice for cereals where straw is removed (kg/ha)

Soil K Index	CROP[1]				
	Winter Wheat[2]	Winter Barley[2] Spring Wheat[3]	Spring Barley[2]	Winter Oats[3]	Spring Oats[3]
1	140	130	115	160	140
2	125	115	100	145	125
3	110	100	85	130	110
4	0	0	0	0	0

1. Assumed crop yields:
   Winter wheat = 11 t/ha Spring wheat = 8.5 t/ha
   Winter Barley = 10 t/ha Spring Barley = 7.5 t/ha
   Winter oats = 9.0 t/ha Spring Oats = 7.5 t/ha
   Rates above assume no release of K from the soil.
2. For winter wheat and barley crops increase or decrease K rate by 9.8 kg/ha per tonne increase or decrease in grain yield.
3. For spring wheat and barley crops increase or decrease K rate by 11.4 kg/ha per tonne increase or decrease in grain yield.
4. For oat crops increase or decrease K rate by 14.4 kg/ha per tonne increase or decrease in grain yield.

At soil K Index 1 it is advisable that at least a portion of the total K be incorporated at or before sowing. At soil K Indices 2-3, K can be incorporated prior to sowing or surface applied after sowing. If compounds are used, restricted periods for P fertilizer application as set out in the NAP must be observed.

Table 16-12: Available K advice for cereals where straw is not removed (kg/ha)					
Soil K Index	CROP[1]				
	Winter Wheat[2] Winter Barley[2]	Spring Wheat[2]	Spring Barley[2]	Winter Oats[2]	Spring Oats[2]
1	80	70	65	75	65
2	65	55	50	60	50
3	50	40	35	45	35
4	0	0	0	0	0

1. Assumed crop yields:
   Winter wheat = 11 t/ha Spring wheat = 8.5 t/ha
   Winter Barley = 10 t/ha Spring Barley = 7.5 t/ha
   Winter oats = 9.0 t/ha Spring Oats = 7.5 t/ha
   Rates above assume no release of K from the soil.
2. For wheat, barley and oat crops: increase or decrease K rate by 4.7 kg/ha per tonne increase or decrease in grain yield.

16.3 Sulphur, Magnesium and Micronutrients for Cereals on Mineral Soils

The application of micronutrients should be based on a recent soil test report i.e. one taken in the last 3-5 years. Once crop symptoms appear, treatment with micronutrients may be too late to avoid crop yield losses for that year. Consult soil test results in advance of sowing and identify fields that require micronutrient supplementation during the growing season. Plant analysis may be used in conjunction with soil analysis to confirm trace element deficiencies see table 23-1.

Sulphur

Cereals can show a response to applied sulphur where the soil is unable to meet the crops requirements. Responses to S are most likely on sandy, free draining soils where S release from the soil can be low and S can be leached from the soil. Responses are less likely on heavier textured soils. Soils with low organic matter levels will also be more prone to sulphur deficiency. Plant analysis is a better guide than soil analysis as an indicator of S deficiency.

There are numerous S containing fertilizers on the market which when used to supply 15 kg/ha S will prevent the occurrence of S deficiency in cereals (Conry, 1993). Organic manures will also supply sulphur, but in many instances, much of the sulphur in the manures is not immediately available to a crop and will only become available at a slow rate (see table 9-7). Therefore, where a deficiency is anticipated a sulphur containing fertilizer should be used, in conjunction with animal manures, to prevent deficiency from occurring.

Sulphur applications should be completed before GS 32 in cereals. Typically sulphur will be applied with the first and/or second application of fertilizer N.

Magnesium

Responses of cereals to magnesium application are difficult to demonstrate and application of Mg is only advisable for cereals if soil Mg is less than about 50 mg/l (Index 1 & 2). On such soils, use magnesium limestone when liming is necessary. Where there is no lime requirement, Mg should be supplied with Mg-containing fertilizers once every 3 to 4 years as per table 16-13. If a crop deficiency appears, Mg chelate or other recommended inorganic formulation can be applied by spraying. Magnesium sulphate (epsom salts) is widely used to correct Mg deficiency in cereals because it is cheap and comes with the benefit of additional small quantity of S. Magnesium deficiency symptoms can be transitory in nature, often occurring early in the season when root growth is restricted but disappearing again as root growth resumes. Studies indicate that magnesium deficiency is more likely where there are poor soil structure conditions as this can limit Mg release.

Table 16-13: Available Mg for cereal crops (kg/ha)	
Soil Mg Index	Available Mg (kg/ha)[1,2]
1	60
2	30
3	0
4	0
	Source (DEFRA, 2010)

Copper

Copper deficiency is common in cereal crops. The availability of Cu is not greatly affected by soil pH. Soil analysis is a reliable measure of soil available copper levels. High organic matter e.g. in peats, can markedly reduce the availability of Cu. Copper deficiency occurs most frequently in coarse-textured or sandy soils. In heavy textured soils, Cu deficiency is not likely unless the soil Cu level falls below 1 mg/l (see Table 6-7) whereas on light textured soils, deficiency may occur in soils containing up to 2.5 mg/l Cu.

Control of Cu deficiency in cereals can be achieved by soil application of 20 to 40kg/ha of copper sulphate. The benefits will last for 5 to 10 years depending on soil type. Foliar application of commercial Cu formulations (chelates / flowable / suspension concentrates) will correct a deficiency in the year of application. The application rate will depend on product Cu concentration. Frequently, more than one Cu spray is required because of the relative immobility of Cu within the plant. Typically for a spring barley crop once a deficiency is anticipated or identified, a foliar application should be applied at crop GS 14 – 15 and a follow up application where required at GS 30 – 31.

Manganese

Manganese deficiency is one of the most widespread deficiencies in cereals, especially at high pH or with recently limed soils. Yield responses to Mn are found with cereals growing in soils of pH 7 or more when the easily reducible Mn level in soil test falls below 50 mg/l (see table 6-9). Soil analysis (easily reducible manganese) is an indicator to soil Mn availability, however, this is not fully reliable for predicting the occurrence of Mn deficiency. However, leaf analysis is more reliable than soil analysis for diagnosis of possible Mn deficiencies.

Transitory Mn deficiency can also occur as a result of the conversion of Mn++, the plant available form that is found in the soil solution, to manganese oxides and hydroxides which are unavailable to plants, a process that occurs when it comes in contact with oxygen and is more likely during periods of drying weather conditions or low soil moisture levels. Conditions which increase the amount of air in the soil such as loose seedbeds or dry soils can induce manganese deficiency. Seedbed consolidation plays an important role in increasing Mn availability by increasing root to soil contact and reducing Mn oxidation. Manganese deficiency that occurs as a result of dry soils will often be corrected by rainfall. Manganese deficiency is controlled by the application of foliar sprays of Mn compounds with manganese sulphate (this requires high water volumes and check mix / product compatibility). Application should be repeated if the symptoms persist. Chelates and inorganic compounds of Mn are also effective and needs to be applied once a Mn deficiency is identified, as early detection will reduce crop yield loss. These have the added advantage of being applied in lower volumes of water, and compatible with certain fungicide and other pesticides. Manganese treated seed and manganese treated fertilizers are also available which can be effective in eliminating or reducing manganese deficiency. Applications of manganese sulphate to the soil are not effective in correcting deficiencies in the long term.

Zinc

Soil analysis is a reliable indicator of the availability of soil zinc as plant Zn deficiency can be quite difficult to diagnosis without plant analysis. An available Zn level of less than 1 mg/l (see Table 6-8) and a soil pH between 6.0 and 7.0 indicates that Zn deficiency is likely in cereals. High soil organic matter will reduce Zn availability and uptake. Good seedbed preparation will reduce the risk of Zn deficiency as it is often associated with loose, unconsolidated seedbeds and results in poor root to soil contact. High soil P and high soil pH reduce the availability of soil Zn. Zinc deficiency is also associated with continuous tillage soils with low soil organic matter levels. Where soils are known to be deficient, soil application of zinc sulphate applied at an application rate of 60 to 120 kg/ha Zn can be used to improve soil Zn levels and this treatment should have a residual effect for a number of years (HGCA, 2013). Zinc deficiency in cereals is usually controlled by good seedbed preparation and followed by the foliar application of zinc sulphate, chelates or inorganic formulations where required during the growing season.

17. Root Crops

17.1 Potatoes

Lime

Although potatoes can grow very well below pH 6.0 it is necessary to maintain the soil at a pH suitable for the other crops in the rotation. In a crop rotation with cereals on mineral soils target soil pH levels of 6.3 for oats and 6.5 for most cereals will be required. Lime can take years for full reaction with soil, and therefore needs to be applied in good time. Common scab is caused by the organism *Streptomyces scabies* which is endemic in soils, and infection can be exacerbated by fresh applications of lime. Therefore, lime should not be applied within the two years preceding a potato crop because of the increased risk of common scab. At least 4 years should intervene between liming and sowing a seed potato crop.

Nitrogen

Potato cultivars differ in their N requirement and there is no correct standard rate of N for all cultivars. Deep rooting varieties with very long haulm longevity such as Kerrs Pink and Markies are effective nitrogen scavengers and may require lower application rates in certain circumstances compared to those with medium or long haulm longevity. Varieties can be divided into four distinct groups according to the haulm longevity (Table 17-1).

Table 17-1: Classification of varieties according to haulm longevity[1] or maturity

Group			
1	2	3	4
Determinate varieties	Partially determinate varieties	Intermediate varieties	
Short haulm longevity[1]	**Medium haulm longevity[1]**	**Long haulm longevity[1]**	**Very long haulm longevity[1]**
Premiere	British Queen	Rooster	Markies
Home Guard	Lady Rosetta	Maris Piper	Kerr's Pink
	Lady Claire	Golden Wonder	Cara
	Nectar,	Record	
	Maris Peer	Electra	
	Charlotte		

1. Haulm longevity assessed from 50% emergence to haulm death.

The main effect of N is to increase canopy size and prolong its duration. Yield increases from higher nitrogen rates will only result if harvest is delayed to take advantage of the extended canopy duration and consequent solar interception. However, this is more likely up to September as yield increases are small from mid-September onwards due to reduced solar radiation intensity. Also harvesting prior to canopy maturity may result in reduced dry matter/specific gravity and after cooking blackening in some cultivars. Where sowing date is delayed, nitrogen rates should be reduced accordingly. Thus, where tuber quality is important it is essential not to use high amounts of N in the event of a restricted growing season. The recommended available N rates are shown in Table 17-2. For most crops apply the nitrogen to the seedbed prior to planting. However, where the risks of leaching are high (light or shallow soils) a top dressing of no more than one third of the total can be considered but should be applied well before canopy closure.

For early, second early and late maturing cultivars high N delays maturity therefore it is important to avoid over-use. The recommendations below take into account the length of growing period from planting to burn off. Where planting is delayed or early burn off is predicted to meet early market demands N use should be reduced accordingly.

Table 17-2: Available N advice for potatoes (kg/ha)[2]

Length of growing season	Variety determinacy group	Soil N Index[1]			
		Index 1	Index 2	Index 3	Index 4
		--------------------- Available N ---------------------			
< 60 days	1	100 -140	80 -120	60 -100	40 -60
	2	80 -120	60 -100	40 -70	0 - 40
	3	60 -100	50 - 80	30 - 60	0 - 30
	4	N/A	N/A	N/A	N/A
60-90 days Earlies	1	160 - 210	140 – 170	120 - 150	90 - 120
	2	100 – 160	70 – 130	50 - 110	40 - 80
	3	60 – 140	50 – 110	30 – 90	0 – 60
	4	40 – 80	30 – 50	10 – 40	0- 40
90-120 days Maincrop/Seed	1	220 - 270	200 – 230	180 – 210	150 – 180
	2	150 – 220	120 – 170	100 – 150	80 – 120
	3	110 – 180	90 – 110	70 – 90	40 – 60
	4	80 – 140	50 – 70	40 -50	0 - 40
>120 days Maincrop	1	N/A	N/A	N/A	N/A
	2	190 – 250	160 – 190	140 – 170	120- 140
	3	150 – 210	130 – 150	110 – 130	80 – 100
	4	100 – 180	70 – 90	50 – 70	20 – 40

1. See Tables 6-2 and 6-3 for soil N Index.
2. Note higher levels of available N than are currently allowable under the NAP regulations are recommended for potato crops when growing season length by variety determinacy group are considered.
3. Available N rate will need to be considered with crop factors such as soil type, field history, sowing date, and market requirements etc.

Examples of recommended N for potato crop types are as follows Table 17-3 and Table 17-5.

Table 17-3: Example 1. Main Crop Rooster planted into long term tillage land (Index 1)			
Length of growing season	Variety determinacy group	Index 1	Available N (kg/ha)
>120 days Main crop	3	1	170 kg/ha[1]
1. Recommended maximum N rate – for Rooster which has high soil N utilisation is not recommended to apply more than 170 kg/ha N.			

Table 17-4: Example 2. British Queen planted into long term tillage land (Index 1)			
Length of growing season	Variety determinacy group	Index 1	Available N (kg/ha)
90 -120 days Second early	2	1	150 kg/ha[1]
1. Recommended maximum N rate – for British Queen which has medium soil N utilisation is not recommended to apply more than 150 kg/ha N as a second early.			

Salad potatoes are grown at higher seed densities, for smaller tuber sizes and for a very short growing season and hence require less N. Most salad potato varieties fall into haulm longevity group 1 or 2.

Table 17-5: Available N advice for salad / baby potatoes (kg/ha)					
Length of growing season	Variety determinacy group	Soil N Index[1]			
		Index 1	Index 2	Index 3	Index 4
< 60 days Salads	1	60-100	50-90	40-80	30 -60
	2	50-90	40-80	30 -70	0 - 40
60-90 days Salads	1	80-120	60-100	40-80	30-70
	2	70-110	50-100	40-90	30-70
1. See Tables 6-2 and 6-3 for soil N Index.					

Phosphorus and Potassium

Potatoes are very responsive to P and K and it is necessary to apply these nutrients even at Index 4 (Table 17-6). All the P should be applied at sowing time but some of the K can be applied the previous autumn. Adequate supplies of available phosphorus are necessary to promote high tuber numbers per plant. Phosphorus will play an important part in the formation of tubers, especially for salad and seed crops where high tuber numbers are required to achieve economic marketable yield.

Potassium regulates the amount of water in the plant, where there is insufficient potassium, crops will not use water efficiently. Potassium will also help the crops to withstand stress caused by drought, heat, waterlogging, etc. The use of potassium sulphate is associated with higher dry matter crops. Lower dry matter when using potassium chloride can result due to higher plant water caused by increased chloride supply. Excessive chloride uptake can also reduce starch content of the tubers. However, these potential effects of potassium chloride can be mitigated by using lower application rates or applying 6-8 weeks ahead of planting.

The most efficient method of application of fertilizers to potatoes is by placing it in bands about 50 mm to the side and 50 mm below the level of the seed. Avoid high rates of placed potassium chloride as this can result in damage to the emerging sprouts. Apply the phosphorus and potassium to the seedbed and work into the soil prior to planting or placed at planting.

Table 17-6: P and K broadcast rates for potatoes[1] (kg/ha)

Soil P, K Index[2]	P	K
Maincrop		
1	125	305
2	100	245
3	75	185
4	50[3]	120
Earlies		
1	125	170
2	115	140
3	100	110
4	50[3]	80
Salad		
1	125	245
2	115	185
3	100	120
4	85[3]	65
Seed		
1	125	170
2	115	140
3	100	110
4	85[3]	80

1. Where all the fertilizer is band-placed, or broadcast on the open drills, the recommended rates can be reduced by 20%.
2. Table 6-4 for soil P Index, and Table 6-5 for soil K Index.
3. Where soil P test is above 15 mg/l, no fertilizer P is necessary.

Magnesium

Magnesium deficiency is occasionally encountered with potatoes, particularly in sandy soils. High K applications in conjunction with high soil K can reduce the availability of soil Mg. Apply 60 kg/ha of Mg for a soil Mg Index of 1 or 35 kg/ha at Index 2 (see Table 6-6 for Mg Index definitions).

Manganese

Potatoes are tolerant of relatively low soil pH values compared with other crops except in soils with high easily reducible Mn concentrations. In such soils, Mn toxicity can occur.

Sulphur

Sulphur is usually low in sandy soils with low organic matter content, however, except in extremely deficient soils, potatoes do not usually respond to S applications. Sulphur deficiency symptoms include a general yellowing of the younger leaves.

Boron and zinc

Most soils contain sufficient levels of micronutrients to meet crop demands; however, in some areas micronutrient shortages can limit yields. Increases in potato yields with B and Zn applications have been reported in the literature on potatoes grown in sandy soils. However, excess applications of B can be toxic.

Identify the risk of a trace element deficiency in potatoes using soil analysis, experience of previous crops, field history, and knowledge of soil properties such as pH, soil type and organic content. Where deficiencies are identified apply required nutrients early in the development of the growing crop for example early crop emergence.

Maximum chemical fertilizer N and P allowed for potatoes in compliance with the NAP regulations.

Maximum chemical fertilizer N and P rates allowed under the NAP regulations are shown in Table 17-7.

Table 17-7: Annual maximum fertilisation rates of available N and P for potatoes[1] (kg/ha) as specified in the NAP regulations

Soil N, P, K Index	N	P
	Main crop	
1	170	125
2	145	100
3	120	75
4	95	50[3]
	Early	
1	155	125
2	130	115
3	105	100
4	80	50[3]
	Seed	
1	155	125
2	130	115
3	105	100
4	80	85[3]

1. See Tables 6-2 and 6-3 for soil N Index and Table 6-4 for soil P Index.

17.2 Fodder Beet and Sugar Beet

Soil pH

The pH for beet should be at or above 6.8. Apply lime as recommended on the soil test report and incorporate into the seedbed before sowing the crop.

Nitrogen

N advice for fodder beet and sugar beet is shown in Table 17-8. Note that in higher summer rainfall areas, more N is required to achieve optimum yields. Nitrogen, phosphorus and potassium fertilizers should be applied during soil cultivations and worked in to the top 5 to 10cm of soil. Of the total N to be applied, it is recommended that 30 to 40 kg N/ha is applied at the 2 to 4 leaf stage of the beet crop.

Table 17-8: Available N for fodder beet and sugar beet subject to different rainfall amounts[1] (kg/ha)

Soil N Index[2]	Rainfall (mm) April-June		
	140	200	260
1	165	175	185
2	135	145	155
3	95	105	115
4	60	70	80

1. For late-sown crops, reduce N by 20% if sown after April.
2. See Tables 6-2 and 6-3 for Soil N index.

Phosphorus, Potassium, Sodium and Magnesium

The P, K and Mg nutrient and trace element advice for fodder beet are given in Table 1-9 and the accompanying footnotes. Although uptake of P by fodder beet and sugar beet is low compared with N and K, fertilizer P inputs are important because of high response by the beet crop.

Table 17-9 relates to non-K fixing soils of average clay content with adjustments for K-fixing and clayey soils. Beet has a high K requirement, in common with other carbohydrate-producing root crops. Although Na can substitute for K, it cannot completely replace the K requirement. There is no detrimental effect from using Na at levels found in beet compounds.

Take account of the nutrient (N, P & K) inputs from organic manures (refer to chapter 9 organic manures) and adjust fertilizer advice in table 17-8 and 17-9 accordingly.

Where the soil test for Mg is 50 mg/l or less (see Table 6-6), a response to Mg application is possible, although there is very little experimental evidence for such a response. Magnesium limestone should be used when lime is required on soils of Mg indices 1 or 2.

Table 17-9: P, K, Na and Mg advice for fodder beet and sugar beet for non-K fixing soils[1] of average clay content[2] (kg/ha)			
Soil P, K, Mg Index[3]	P	K	Mg
1	70	320	100
2	55	240	50
3	40	160	0
4	20[4]	80	0

1. Add 70kg/ha K for K fixing Athy soil series.
2. Subtract 50 kg /ha K for micaceous, clayey east Cork soils.
3. See Table 6-4 for soil P Index, Table 6-5 for soil K Index, and Table 6-6 for soil Mg Index.
4. Where soil P test is above 15 mg/l, no fertilizer P is necessary.

Sulphur

A response to S has been observed on sandy loam. This element is included in beet compounds. If not included it should be supplied at 20 kg/ha on S responsive soils.

Magnesium

A magnesium deficiency maybe observed on light sandy soils during dry / cold periods. Mg is advisable if soil Mg is less than about 50 mg/l (Index 1 & 2). On such soils, use magnesium limestone when liming is necessary. Where there is no lime requirement, Mg should be supplied with Mg-containing fertilizers once every 3 to 4 years as per table 17-9. If a crop deficiency appears, Mg chelate or other recommended inorganic formulation can be applied by spraying. Magnesium sulphate (epsom salts) is widely used to correct Mg deficiency and comes with the benefit of additional small quantity of S. Magnesium deficiency symptoms can be transitory in nature, often occurring early in the season when root growth is restricted but disappearing again as root growth resumes.

Boron

Boron leaches readily from all soils. This effect is severe in light sandy soils and less so in heavy soils but B application is generally necessary for all beet crops and especially for sugar beet. Boron uptake is severely restricted during periods of drought in all soil types. Thus, even when soil concentrations are above the critical level, B deficiency can still occur in sensitive crops. Where deficiency is likely to occur, a source of B may be included in the fertilizer to supply 3.0 kg/ha of B, preferably applied to the seedbed. Where the soil test results (hot water extractable B) are less than 1 mg/l B, it may be worthwhile to supplement the soil application with one or more foliar sprays. Foliar applications of boron should be made according to the product manufacturer's recommendations which will normally be once there is sufficient ground cover for absorption, typically the 4-6 leaf stage. Repeat applications may be required where deficiency is severe.

Manganese

Manganese deficiency (speckled yellows) can occur in beet when the pH is above 7.0 but is more likely at pH above 7.5. However, it has been recorded at pH 6.5 or lower in peats and dark soils with high organic matter content.

Manganese deficiency is controlled effectively by the application of foliar sprays of Mn compounds, e.g. manganese sulphate, Mn-chelate or inorganic formulations. The incorporation of manganese oxide in the seed pellet has proved very successful in preventing early deficiency. It works best when supplemented by a foliar spray at the 4-leaf stage.

17.3 Swedes / Turnips

Soil pH

The pH for swedes should be above 6.5. Apply lime as recommended on the soil test report and incorporate into the seedbed before sowing the crop.

Nitrogen, Phosphorus and Potassium

In general, the N, P and K fertilizer applications for Swedes and turnips (Table 17-10) should be broadcast after the land has been cultivated and just before ridging, thus ensuring that it is concentrated in the centre of the ridge and near to the developing roots.

Table 17-10: N, P and K for swedes and turnips (kg/ha)

Soil N, P, K Index[1]	N[3]	P	K
1	90	70	250
2	70	60	200
3	40	40	170
4	20	40[2]	125

1. See Tables 6-2 and 6-3 for soil N Index, Table 6-4 for soil P Index, and Table 6-5 for soil K Index.
2. If soil P value is above 15 mg/l, no fertilizer P is necessary.
3. Top-dressings are not usually required, however, following wet seasons where crops are backward, top dress with up to 30 kg/ha N.

Take account of the nutrient (N, P & K) inputs from organic manures (refer to chapter 9 organic manures and adjust fertiliser advice in table 17-10 accordingly).

Sulphur

Swedes and turnips respond to the application of S on sandy soils. A dressing of 25 kg/ha S should be adequate.

Boron

Swedes / turnips have a similar requirement for B as sugar beet (see Boron for Sugar Beet remarks). Boronated compounds should be used.

18. Other Crops

18.1 Oil Seed Rape

Soil pH

The soil pH for oil seed rape should be above 6.5.

Nitrogen management for winter oilseed rape

- For backward crops or crops grazed extensively by pigeons a light dressing (30kg N/ha) should be applied at the onset of spring growth (late Feb to early March), a third of the remainder should be applied 10 days later and the final dressing in early April.
- On moderate crops, one third of the N should be applied in mid -March with the rest applied in early April.
- On large crops with lots of leaf area post winter, early N will encourage excessive vegetative growth and applications should be delayed with the first third of the total applied in late March/early April and the remainder applied as late as possible whilst still allowing a uniform spread pattern between the tramlines (before the crop gets too tall).

This approach can be further refined by assessing the extent of green or leaf area development post winter using image analysis (mobile phone apps). A green area index (GAI) of 0.5 or less can be considered 'backward' or grazed. 0.5 to 1.5 would be normal, while anything in excess of 1.5 at the end of February would be considered large.

Nitrogen management for spring oilseed rape

For spring oilseed rape some nitrogen will normally be applied to the seedbed, but no more than 50 kg/ha N should be applied to reduce the risk of poor establishment. The remainder of the nitrogen will be applied between the two true leaf stage and the early stem extension stage.

Nitrogen, P and K advice for oil seed rape is shown in Table 18-1

Table 18-1: Available N, P and K (kg/ha) for oil seed rape yielding 5t/ha

Soil N, P, K Index[1]	N[2]	P	K
1	225	55	105
2	180	45	90
3	160	35	75
4	140	0	0

1. See Tables 6-2 and 6-3 for soil N Index, Table 6-4 for soil P Index, and Table 6-5 for soil K Index.
2. Crop N fertilizer requirements may be limited by the NAP regulations, where available N is calculated based on crop Green Area Index (GAI) system for backward / intensively grazed crops.

Sulphur

Oil seed rape responds to the application of S on most soils but particularly on those that are not frequently receiving organic manures are light or low in organic matter. Application of 20 to 30 kg/ha S will normally be adequate, with the higher rates being applied on lighter soils. The timing is not critical and Sulphur should be applied with the nitrogen.

Magnesium

If the soil Mg is Index 1 (see Table 6-6), apply a source of Mg. Use magnesium limestone if the pH is low. Where there is no lime requirement, Mg should be supplied with Mg-containing fertilizers once every 3 to 4 years as per table below. If a crop deficiency appears, Mg chelate or other recommended inorganic formulation can be applied by spraying. Magnesium sulphate (epsom salts) is widely used to correct Mg deficiency and comes with the benefit of additional small quantity of S.

Table 18-2: Available Mg for oilseed rape crops (kg/ha)

Soil Mg Index	Available Mg (kg/ha)
1	60
2	30
3	0
4	0

Source (DEFRA, 2010)

Boron

Boron should be routinely applied to oil seed rape especially when the soil test is below 1 mg/l. Severe B deficiency causes stunting and brittle petioles, but relatively mild deficiency results in poor seed set and a reduction in seed numbers per pod and seed weight. These conditions can also be induced by severe summer drought.

Normally B should be applied to winter oilseed rape at the onset of spring growth either in a compound fertilizer or more commonly as a foliar application. In situations where there is a high risk of deficiency e.g. low soil B levels, high pH, sandy soil, an autumn application should be applied. For spring oilseed rape an application should be made soon after emergence when there is good crop cover or alternatively it may be applied as a component of a compound fertilizer before sowing. Boron applications should be completed before the onset of flowering.

18.2 Field Peas and Beans

pH

The optimum soil pH for field peas and beans is around 6.8.

Nitrogen

Nitrogen is not required for field peas or beans. Research at Oak Park has shown no benefit of nitrogen application at sowing.

Phosphorus and Potassium

Phosphorus and K advice for field peas and beans is given in Table 18-3. On low P soils (Index 1 and 2) combined drilling some P at sowing time with beans has shown to increase crop vigour, pod number and overall bean yield. If combine drilling P-K compounds care should be taken to keep K levels low (< 60 kg/ha) to avoid the risk of adversely affecting germination.

Table 18-3: P and K for field peas and beans (kg/ha)

Soil P, K Index[1]	Peas		Beans	
	P	K	P	K
1	40	125	50[2]	125
2	25	60	40[2]	60
3	20	40	20[3]	40
4	None	None	None	None

1. See Table 6-4 for soil P Index and Table 6-5 for soil K Index.
2. For P Index 1 and 2 soils P should be placed at sowing time.
3. For Index 3 soils fertilizer should be broadcast after ploughing and cultivated deeply into the seedbed.

Magnesium

Field peas and beans may respond to the application of Mg at soil Index 1 (see Table 6-6).

Boron

Field peas and beans should not be drilled in soils that have been treated with B; i.e. they should not follow cases of crop failure that have been treated with B.

18.3 Maize

Nitrogen

Getting the N supply correct is a critical and difficult aspect of the maize fertilizer programme. Applying too much N will delay crop maturity and is often more damaging than applying too little. Thus, the grower or advisor should consider the nutrient programme and N application rates very carefully. Nitrogen is made available from three sources; soil N, organic manures and applied fertilizer nitrogen.

The soil N index (Tables 6-2 and 6-3) should be used to adjust fertilizer N inputs for variation in soil N supply. Livestock manures are frequently used to fertilize maize crops. Livestock manures have the potential to supply all the N requirements of the crop, particularly where crops are grown in a grass rotation. An application of 33 t/ha of cattle slurry will provide from 25 to 30 kg/ha of N depending on the quality of the slurry and the time and method of application. To achieve the maximum benefit from nitrogen in livestock slurries they should be applied in spring and incorporated into the soil immediately after application. Recommended rates of total available N (available N in manures + fertilizer N) at each soil index are given in Table 18-4. The amount of fertilizer nitrogen required will be dependent on the soil N index and the amount of available N applied in livestock manures (see Table 9-3 to 9-5) i.e. the available N applied in livestock manures must be subtracted from the recommended amount in Table 18-4 to determine fertilizer N requirement.

Nitrogen will normally be applied before sowing and incorporated into the soil. Placing a low amount of N near the seed (< 25 kg N/ha) at sowing can be beneficial. A portion of the fertilizer nitrogen can be retained and applied at the 5-7 leaf stage but leaf damage as a result of granule impact is likely which can adversely affect yield when high levels of leaf damage occur.

Phosphorus and potassium

Phosphorus and K advice for maize is also given in Table 18-4. An application of 33 t/ha of cattle slurry will provide 55 to 65% of the P and K needed at soil at Index 3 and above (i.e. soil levels at or above 6 mg/l P and 100 mg/l K). Apply the slurry in spring and plough in immediately to retain the N content.

Maize can experience P deficiency during the establishment phase particularly when soil temperatures are low. Placing 20 kg/ha P near the seed at sowing to provide a supply of easily soluble P at the very critical establishment phase is likely to be beneficial where adverse soil conditions occur during the establishment phase.

Maize has a relatively high requirement for potassium which should be applied prior to sowing and incorporated into the soil. Organic manures, particularly cattle slurry, can be used to supply a substantial proportion of K to the crop. It should be noted that offtakes of potassium by maize will also be high.

Table 18-4: Available N, P and K for maize (kg/ha), assuming a dry matter yield of 15 t/ha and not accounting for slurry application[1]			
Soil N, P, K Index[2]	N	P	K
1	180	70	250
2	140	50	225
3	110	40	190
4	75	20[3]	120[4]

1. N, P and K rates shown above refer to application rates of available fertilizer. Chemical fertilizer rates should be calculated by deducting the available N, P and K contained in organic fertilizer applications from the rates shown in the above table.
2. See Tables 6-2 and 6-3 for Soil N Index, Table 6-4 for soil P Index, and Table 6-5 for soil K Index.
3. Must be incorporated prior to or during sowing.
4. No fertilizer K is required when soil K is above 250 mg/l.

Magnesium

The Index system for Mg is given in Table 6-6. Magnesium deficiency can be a problem when the soil Mg is less than Index 2. Magnesium limestone is the most common form of Mg fertilizer. Where soil pH is already optimal, other fertilizers containing Mg such as Kieserite (magnesium sulphate) may be used once every 3 to 4 years as per table 18-5. Crops deficient in Mg should be treated with Mg chelate or a recommended inorganic formulation. During cold weather in April/May, most maize crops will show deficiency symptoms. These will often be evident even where Mg levels are adequate. Always check soil analysis results before applying nutrients.

Table 18-5: Available Mg for maize (kg/ha)	
Soil Mg Index	Available Mg (kg/ha)[1,2]
1	60
2	30
3	0
4	0
	Source (DEFRA, 2010)

Zinc

Maize is very sensitive to Zn deficiency during May and June. When deficiency is identified (see Table 6-8), spray with Zn Sulphate (5 kg/ha), Zn chelate or inorganic formulation as required. Foliar applications of zinc will normally be made after the 3-8 leaf stage. Repeat applications may be required if the deficiency is severe.

Manganese

Manganese deficiency often occurs in maize, especially at high pH for example if maize follows heavy lime applications in a rotation. Yield responses are expected in maize growing in soils of pH 7 or more when the easily reducible Mn level falls below 50 mg/l. However, leaf analysis is more reliable than soil analysis for diagnosis of possible Mn deficiencies.

Manganese is controlled by the application of foliar sprays of Mn compounds such as manganese sulphate. Application should be repeated if the symptoms persist. Chelates and inorganic compounds of Mn are also effective. These have the added advantage of being applied in lower volumes of water, and of being compatible with certain fungicide and pesticides. Applications of manganese sulphate to the soil are not effective in correcting deficiencies.

18.4 Kale

Advised N, P and K rates for kale are shown in Table 18-6.

Generally all fertilizer will be applied before sowing and incorporated into the soil.

Brassicas have a requirement for sulphur and an application of 15-20 kg S/ha should be made, particularly on light soils or soils with low organic matter where sulphur deficiency is more likely.

Brassicas can benefit from an application of boron particularly on light sandy soils where soil boron levels can be low.

Trace element applications should be made based on soil test results or where deficiencies have been experienced previously.

Table 18-6: Available N, P and K for kale[1,2] (kg/ha)

Soil Index[3]	N	P	K
1	150	60	220
2	130	50	210
3	100	30	170
4	70	0	0

1. For late-sown crops, reduce N by 20% if sown after April.
2. Advice assumes a yield of 40 tonnes/ha per cut, fresh weight. If yields are expected to be smaller, reduce the P and K application by 0.5 and 4 kg/ha for each tonne below 40.
3. See Tables 6-2 and 6-3 for soil N Index, Table 6-4 for soil P Index, and Table 6-5 for soil K Index.

18.5 Linseed

Advised N, P and K rates for kale are shown in Table 18-7.

Table 18-7: N, P and K for linseed (kg/ha)

Soil P, K Index[1]	N	P	K
1	75	35	75
2	50	30	60
3	35	20	40
4	20	None	None

1. See Tables 6-2 and 6-3 for soil N Index, Table 6-4 for soil P Index, and Table 6-5 for soil K Index.

18.6 Forage Rape

Nitrogen, Phosphorus and Potassium

The N, P and K requirements for forage rape are shown in Tables 18-8. Normally all the N, P and K requirements should be applied before sowing and incorporated into the soil. Forage rape will normally be sown from mid-May to mid-August and fertilizer guidance in Table 18-8 relates to these crops.

Where forage rape is sown after harvest of a cereal crop, with the intention of providing livestock grazing, sowing can be delayed until after the optimum sowing window (e.g. when sown after a spring cereal crop) and yields will be considerably reduced. Research has indicated that yield of forage rape sown at the end of August is less than 30% of that sown at the beginning of August. Nutrient inputs, particularly nitrogen, should therefore be reduced.

Brassicas have a requirement for sulphur and an application of 15-20 kg S/ha should be made, particularly on light soils or soils with low organic matter where sulphur deficiency is more likely.

Brassicas can benefit from an application of boron particularly on light sandy soils where soil boron levels can be low. Trace element applications should be made based on soil test results or where deficiencies have been experienced previously.

Table 18-8: Available N, P and K for forage rape (kg/ha)

Soil Index[1]	N	P	K
1	130	40	100
2	120	30	75
3	110	20	50
4	90	0	0

1. See Tables 6-2 and 6-3 for soil N Index, Table 6-4 for soil P Index, and Table 6-5 for soil K Index.

18.7 Cover crops, catch crops, green manures

Vegetation established in the fallow period between two cash crops is variously referred to as cover crops, catch crops or green manures, with the principle functions of reducing nutrient loss from the soil, reducing soil erosion and/or improving soil characteristics such as organic matter levels. Unlike crops being grown as fodder/forage crops these crops are generally not harvested and therefore don't have a direct economic value (i.e. no harvested product for sale). Therefore, while cover/catch crops may respond to fertilizer application in terms of biomass production, it is difficult economically to justify the application of fertilizer to these crops (crops being grown for forage/fodder e.g. fodder rape and kale, do have a direct economic value and therefore can give a direct economic return on fertilizer application). Applying fertilizer to a cover/catch crop with the aim of benefiting from that fertilizer addition in the subsequent cash crop is likely to significantly reduce economic benefit from fertilizer use compared to where fertilizer is applied directly to the cash crop.

19. Nutrient Management in Organic Farming

Introduction

Organic farming is an "overall system of farm management and food production that promotes soil health, a high level of biodiversity, the preservation of natural resources, and a production method in line with the preference of certain consumers for products produced using natural substances and processes".

Optimising soil 'health' is the foundation of organic farming with particular emphasis being placed on maintaining high levels of soil biological activity and organic matter, coupled with balanced / optimum nutrient levels throughout the rotation. Organic farming aims to 'feed the soil to feed the crop' by first, maximising the use of home produced nutrients re-cycled around the farm and then replacing any off-takes (primarily through produce sold off the farm), with natural permitted manures from outside the farm and natural mineral fertilizers. There are few "quick fix" solutions to address soil fertility. Organic farmers take a long term, whole farm systems approach to nutrient management based on regular soil tests and nutrient budgets to determine when soil nutrients must be replaced in the rotation. Just as for non-organic farming, the results and fertilizer recommendations of soil tests are tailored to a field's cropping history and soil type to give specific recommendations for each field.

19.1 The organic approach to nutrient management

The management of nutrients in organic farming systems presents a considerable challenge compared to non-organic farming, as the use of synthetic fertilizers is not permitted as an option to address soil fertility. The aim for organically approved manures and fertilizers is to allow biological soil processes to progressively release the nutrients within the fertilizer in order to maintain a balanced and continuous nutrient supply in line with crop requirements. Therefore organic farmers must plan longer term with the aim of using a range of soil, crop, rotation, manure and natural mineral fertilizer management options to enhance soil nutrient supply, reach target crop yields and minimise nutrient losses to the environment.

Organic farming first and foremost places great emphasis on maximising the use of home produced manures and re-cycling these around the farm to enhance the biological life in the soil and to in turn maximise soil fertility. However, similar to non-organic farming, it is acknowledged that all nutrients removed or lost from the farm system must be replaced. Therefore, where required, the importation of certain inputs to address any soil nutrient deficiencies is permitted in organic standards.

The use of leguminous plants to fix gaseous N from the atmosphere is considered a necessary driver of production on organic farms. It is equally essential to replace P, K and other nutrients, using approved substances such as permitted organic manures and natural mineral fertilizers. On livestock farms, animal manures are vital for re-cycling nutrients around the farm, especially onto cropping ground, and should be handled carefully to minimise nutrient losses, e.g. target manures to fields with largest P and K demands based on soil analysis and apply manures in spring time to maximise N recovery. The nutrient content of manures varies widely, due to, animal type, diet and slurry dilution (see Table 9-1). Given the importance of organic manures to organic farmers, and to ensure nutrient budgets are accurate, the nutrient concentration in organic manures should be tested rather than relying on guideline nutrient values in published literature.

Unfortunately there is insufficient research to determine what the optimum soil nutrient levels for P and K are under organic systems as opposed to non-organic systems. There is some research showing that with the higher levels of biological, and especially mycorrhizal activity in organic soils, healthy crops can be successfully grown at lower nutrient indices than in non-organic soil. However, until further information emerges, the recommendations for non-organic farming should be followed.

Organic certification standards are constantly changing so advice must be taken in conjunction with the latest standards of the farmer's or grower's organic certification body. In all cases, before importing nutrients onto a certified organic farm, the most up to date organic standards should be consulted.

19.2 Approved N, P and K sources – organic farming options

A range of animal manure types may be imported onto organic holdings subject to normal government regulations in relation to farm to farm movement of animal manures. Importantly, organic farmers must adhere to an on-farm limit of 170kg/ha N (including livestock and imported organic manures) which means that higher stocked organic farms i.e. 1.6 to 1.9 L.U. /ha, must be careful not to exceed this limit if importing manures.

Some common examples of imported organic manures/materials permitted according to organic standards include the following:

- Cattle slurry from both organic and non-organic farms including non-organic derogation farmers (>170 kg N/ha) with a normal grass based outdoor system
- Free range and organic poultry manure,
- Dairy processing sludge from certain dairy processors (consult with an Organic Certification Body for a list of certified processors),
- Horse manure from organic or non-organic farms,
- Straw (conventional is permitted), sawdust (untreated) and wood chips (untreated) for bedding of animals or supplement to existing manures.

A number of caveats exist regarding the importation of such manures onto organic farms:

- Manures imported onto an organic holding must come from a system of extensive husbandry and manures from factory farming origin are not permitted; *vis a vis* imported organic manures from zero-grazing of bovines, ovines, caprines, equines; all poultry systems with the exception of organic and free range and commercial piggeries where pigs are permanently housed,
- A composting period of 3 months is generally required for organic manures that originate from non-organic sources,

- Chicken manure is a key ingredient in spent mushroom compost (SMC). For spent mushroom compost to be eligible there must be confirmation that the chicken manure used in the manufacture of the compost comes from a free-range or an organic poultry farm.

Purchased concentrate feed (which must be organic) contains high nutrient levels by its nature. Most of this will be excreted by the stock as manure and can contribute a significant proportion of the nutrient replacement needs of a livestock enterprise. Therefore, all biological sources of nutrients, whether they are manures, compost, bedding, feed or other materials, must be included in a nutrient budget plan.

19.3 Nutrient management for organic farming

Lime and Soil pH

The maintenance of optimum soil pH is as, if not more, important in organic farming than non-organic. The correct pH is essential for optimal soil biological activity, especially the mineralisation (decomposition) of organic material into plant available nutrients, which is the main source of N in organically managed soils. High pH also limits the rate of rock phosphate dissolution, so pH in organic system should tend towards the acidic rather than alkaline, within the range of pH 6.2 to 7.0.

Most sources of lime are permitted in organic farming, but it is important that the particular product to be used is either certified or the certification body confirms that the source is permitted. In general, lime is relatively insoluble in pure water, however, the finer particles (i.e. <0.15 mm) will react with acidity in the soil water relatively quickly (within 6 months) releasing the calcium and magnesium constituents. The courser particles (i.e. between 0.15mm and 3.35mm) will breakdown and dissolve over time and help to neutralise soil acidity in the longer term i.e. years 1-3.

Determining when to apply lime to maintain an optimal pH is achieved by the use of regular soil testing and preparing a farm lime programme based on lime advice as per a soil test report. See chapter 8 for detailed lime advice.

Nitrogen

The overriding source of nitrogen (N) on productive organic farms is from leguminous (nitrogen fixing) plants. Many imported organic manures also contain N but as most imported manures have to be aerobically composted, this considerably decreases their N content. However, composting can have advantages as it stabilises nutrients giving the material nutrient release characteristics which are more in tune with the demand of crops throughout the rotation.

The use of high N commercial fertilizers, e.g., pelleted chicken manure, which do not have to be composted are also permitted in organic farming. However, their use should be carefully considered as these can be prohibitively expensive, except for high value organic horticulture crops.

There are two main approaches to using legumes, either as a two or more year mixed pasture or as short term green manure crops. A multi-year pasture containing white or more especially red clover can fix large amounts of N and will always consistently and considerably out-perform shorter term green manures. The N is stored in biological material which is released by mineralisation. This N release is a temperature dependent process, which means that more N is released in the warmer summer months than cooler winter months. This pattern of N release reasonably corresponds with crop requirements, the exception being in early spring.

Leguminous crops can fix considerable amounts of N. While the majority of the fixed N is likely to be removed in the crop, a considerable quantity of N can also be returned to the soil which can potentially benefit the following crop in the rotation (Table 19-1).

Table 19-1. Typical amount of N fixed in one year by different crops, and of the amount remaining after harvest.

Crop	Amount of N fixed kg/yr[1]	Amount of N remaining after harvest kg/yr[1]
Red clover silage	160 to 450	50 to 150
White clover & grass silage	70 to 420	20 to 180
White clover & grass grazed	60-250	50 to 210
Forage peas (summer crop)	80 to 290	40 to 110
Field been grain crop (summer crop)	200-380	90-150

1. These figures were obtained from international sources and may not be fully representative of Irish agriculture.

For permanent grazing pastures, white clover is the best option as it survives regular defoliation by grazing. White clover is quite versatile as it is suited to both silage (1 cut) and grazing systems and it can persist for a reasonably long period (5 -10 years). For shorter term silage only and stockless systems, red clover is preferred as this will fix more atmospheric N and produce a higher yield and protein crop although it is less persistent than white clover. To maximise productivity from newly sowed white and red clover-grass pastures, white clover should comprise 15-20% of the seed weight for the former, while red clover should comprise 30-50% of the seed weight for the latter. Clover populations are also self-regulating: as soil N builds up they become less competitive with grass and so populations reduce, while in low N soils they will dominate. This is known as the ‘clover cycle’.

Due to the large amounts of N fixed under pasture, great care must be taken when terminating leys to avoid large N losses. Practices that minimise N loss are minimum-tillage and cultivating either when the soil is dry as this prevents leaching, and/or during cold periods as this minimises mineralisation. Practices that will cause large N losses are ploughing and other deep loosening cultivations and tilling the soil when it is both warm and when water is draining from the soil, i.e., during typical autumn conditions. Losses of over 120 kg N/ha from inappropriate termination of leys have been recorded which represents a large financial loss to the farmer and significant loss to the environment.

Green manures are typically planted during the winter. Generally a mixture of a legume and a grass is used as this maximises nutrient scavenging, N fixation, and biomass production, as well as enhancing weed, pest and disease suppression. Due to their short duration and cold winter temperatures N fixation is relatively small compared with multi-year pasture.

Stocking rates and meeting crop N demand

For good quality land with optimum nutrient levels, and good management, stocking rates of 1.3 to 1.6 LU/ha are generally achievable based on white clover and grass swards. This requires that all pastures on the farm have high levels of clover in them (10% dry-matter content in late spring to 35% dry matter content in late summer), not just the best fields. If red clover is used in place of white clover for silage, then stocking rates can potentially be increased to between 1.5 to 1.9 LU/ha, again based on quality of soil type, nutrient levels and management.

With the grass-legume based ley being the main N source, it is essential to grow the highest N demanding crops in the first three years after pasture is terminated.

Phosphorus

Phosphorus (P) is the key nutrient for optimising N fixation by *Rhizobium* bacteria in legume root nodules, so it is essential that P levels are maintained above minimum levels to ensure sufficient N fixation.

The main mineral source of P is rock phosphate, which is ground to sufficient fineness to allow it to be biologically degraded into soluble forms and is called ground rock phosphate (GRP). It typically contains 11% P which is released over three years with a third released in each year, so it will provide only a small amount of P if applied to a crop at sowing. The rate of release is also governed by soil pH with efficacy being best below pH 6.5. In more alkaline situations organic standards permit calcined aluminium phosphate rock. Legumes acidify the soil around their roots which assists them in the absorption of P even if soil pH is at the higher end of the recommended level.

Ground rock phosphate can also contain other minerals which can aid soil fertility. It contains about 35% Ca which has a small liming effect on soils. This is in contrast with superphosphates (not permitted in organic farming), which have an acidifying effect that has to be counteracted by liming.

Straw brought onto the farm for bedding contains small but useful amounts of P, e.g. wheat straw 0.5 kg/t, barley 0.65 kg/t and oat 0.69 kg/t and their grains contain about 0.4 kg/t of P fresh-weight (HGCA 2009). These should be included in nutrient budgets.

Potassium

As for non-organic farming, root crops have a relatively high potassium (K) requirement, so it is better to apply K prior to such crops than to other parts of the rotation. Where soil tests show K levels are low, a small number of unprocessed or minimally processed potassium sources are permitted. Consult with the organic certification body for updates. Permitted products are:

1. Potassium sulphate (also known as SOP or sulphate of potash)
    - 42% K
    - 18% S
2. Potassium sulphate with magnesium and sulphur: (e.g., Patentkali®)
    - 26% K
    - 6% Mg
    - 17% S
3. Potassium sulphate with sodium and sulphur (e.g., Magnesia-Kainit®)
    - 9% K
    - 3% Mg
    - 20% Na
    - 4% S

Magnesia-Kainit® and Patentkali® have EU level organic approval while SOP may require case-by-case certification body approval, depending on the source. All three forms are also highly water-soluble so they will be rapidly taken up by any plants present before the K is absorbed into the soil matrix. The risk of K leaching is low unless it is applied under very unsuitable conditions, e.g., where there is active surface run-off.

Imported feed and particularly bedding straw can provide a significant proportion of the K requirements of organic farms. The K content of grain is similar to P at around 0.4 to 0.6%, however, the straw contains much higher amounts of between 0.8 to 1.5% K depending on species. It is essential that this is accounted for in nutrient budgets.

Trace elements

On well-established organic farms, good nutrient management practices should help minimise or render mineral supplementation unnecessary. The aim should be to reduce and eventually eliminate imported minerals by growing appropriate varieties of grasses, legumes and herbs where necessary.

Seaweed minerals, basic (steel work) slag and as discussed earlier lime, are commonly used by organic farmers to improve micro-nutrient levels. The organic certification body should be consulted to ensure that the relevant product is permitted under organic standards.

Where there is a known dietary deficiency in home grown feeds, or as a result of soil deficiencies, or there is other evidence (e.g. blood, or herbage) of a deficiency within livestock, restricted supplementation will be permitted with approval from the Organic Certification Body. Only minerals and vitamins from permitted sources may be fed.

19.4 Managing nutrient supply – the role of rotations

Rotations are the key management technique for managing nutrient supply on organic farms, particularly for mixed systems with cropping. The grass-clover ley is the most important fertility building phase, principally for N, but it is also an appropriate time to apply P and lime where required. Applying P to the start of the pasture phase means that it will help maximise N fixation. At the same time the higher levels of soil biological activity found under pasture plus the presence of clover will allow for the most effective breakdown of the mineral P and it's conversion into biological forms that will feed the following crops. For lime sensitive but nutrient demanding crops such as potatoes, putting lime on at pasture inception means they can be planted soon after pasture to make the most of the higher nutrient levels while minimising the possible risk of lime damage.

As the approved mineral forms of K are highly water soluble, putting them on at the start of the ley will result in them being rapidly taken up by the crops present before the K is absorbed and enters the less available K soil reserves. If K levels going into pasture are below optimum, then K should be applied to optimise pasture production. If K levels are within recommended levels, consideration should be given to reserving K application for crops with a higher K demand.

The cropping sequence following a ley, starts with the most N and other nutrient demanding crops, typically wheat and root crops. These are followed by less demanding crops, such as brassicas, and ending with crops that are efficient nutrient scavengers, e.g., oats, or N fixing legume crops. The addition of manure (FYM, slurry, compost) is generally reserved for the last half of the rotation. While this can be an effective way to 'top up' soil nutrients it is very unlikely to be able to build soil N up to the levels found after the ley. The same is true of green manures, as discussed previously.

Rotations are not pre-ordained and fixed, but highly flexible and may change on a yearly basis. Unless a very simple rotation is being followed, then crops should be matched to fields at the start of each year, based on each field's history, crop needs and market requirements. This has to include an evaluation of the field's nutrient levels and general soil conditions, plus presence of pests, disease and weeds. This is then matched to the crops nutrient and soil condition requirements, the length of rotational gap it needs in relation to pest and disease carry-over and how competitive it is with weeds.

Where insufficient soil nutrient replacement has occurred, and soil indices for any of the nutrients or pH are outside optimum levels, action to replace nutrients must be taken. The best option is almost always to establish a grass-clover ley rather than attempting to crop depleted land. This is because yields and the nutrient content of crops are likely to be poor. It will be much harder to rectify nutrient deficiencies under crops that are removing nutrients compared to pasture where off-takes are much lower and cycling of nutrients through livestock is much higher which aids the building of soil biology.

Conclusions

- In keeping with the key aim of organic farming of maintaining a productive and biologically-active & “healthy” soil, nutrient levels need to be maintained at optimum levels across the whole rotation. These levels are determined by regular soil tests and field-by-field nutrient budgets.
- Soil tests and budgets provide the information to establish the best fields on which to use farm produced manures (slurry, FYM and compost) and, when necessary, where to use imported manures and permitted mineral fertilizers to replace nutrients exported in crops and livestock or lost to water or the atmosphere.
- Correcting soil pH and lime deficiencies is a priority on organic farms to ensure the availability of soil major nutrients such as N, P & K,
- The use of crop rotations are a key technique for managing overall nutrient supply on organic farms, particularly for mixed and stockless systems. The grass-clover ley is the most important fertility-building phase, principally for N, but it is also an appropriate time to apply P, K and potentially lime,
- On well managed organic farms, routine trace element supplementation should not be necessary unless there is an underlying soil deficiency,
- There is a range of national and EU level legislation covering the storage and use of manures which are often modified and updated. Compliance with organic standards does not guarantee cross-compliance with legislation and advice from farm advisers or the appropriate Government agency should be obtained,
- When considering using an off-farm source of manure or mineral fertilizers, consult with the latest Organic Certification Body standards to ensure that it is permitted.

20. Nutrition of Vegetables

Introduction

As with tillage crops, fertilizer advice for vegetables is based on soil analysis results for P, K, Mg and micronutrients. Since there is no soil N test capable of predicting crop response, N advice is based on experience of the crops to be grown, previous cropping and manurial history of the field (*c.f.* Table 6-2, 6-3).

The nutrient advice for vegetables is, for the most part, derived from the results of field experiments on major and trace element nutrition in this country and abroad, as well as on the considerable amount of field experience gained in the use of fertilizers commercially on a wide variety of soil and climatic situations in vegetable crop production in Ireland. For each area, the advice may be varied on the basis of other factors such as soil type, previous cropping history and local experience. For example, on P fixing soils, such as the Clonroche soil series in parts of Wexford and Louth, heavier than the recommended dressings of P fertilizer are needed to ensure an adequate supply. Thus, optimum fertilizer application for vegetables may be developed from this tabulated advice by modifying it according to the local circumstances which apply in the area of the country in which the vegetables are to be grown.

It is convenient to distinguish two phases in the use of fertilizers, the response phase (build up) and the maintenance phase.

During the response phase, the soil fertility is low and crops will show large yield responses to fertilizers. The use of high rates of fertilizer is necessary to ensure the maximum economic return from the investment made in crop production. The use of high rates of fertilizer will also increase the fertility level of a soil. This is because a highly fertile soil is more productive than a low fertility soil even when high rates of fertilizer are used.

In the maintenance phase, the soil fertility is high and lower rates of fertilizer are advised. The aim is to ensure that the crop is supplied with sufficient nutrients and that the soil fertility is maintained at an optimum level. When fertilising crops care should also be taken to avoid soil nutrient build up to excessive levels.

20.1 Nutrients for vegetables

Nitrogen

Nitrogen advice for mineral soils is based on an arable/ley rotation. Under conditions of intensive tillage and depletion of soil organic matter, heavier rates than those recommended should be used. Likewise, if considerable quantities of FYM are used in spring or if the crop is grown after peas or following the ploughing down of a ley rich in clover, smaller dressings than those listed here should be used. Nitrogen fertilizer use should be restricted where rainfall is heavy and increased on light sandy soils low in organic matter.

Phosphorus

In general, P fertilizer dressings should be increased:

- On soil of low total P i.e. typically soils derived from shales, sandstones, boulder clays or outwash gravels
- On soils with high levels of aluminium and iron (Oxylate or Mehlich III extractable Al and Fe) or soils with high levels of calcium (high soil pH >7) as these will bind with P and render it unavailable for plant uptake
- On very acid soils and because P may be rendered unavailable under such conditions

Potassium

In general, K fertilizer dressings should be increased on:

- Soils low in total K i.e. newly reclaimed peat and limestone soils
- Limestone soils - in the Dublin, Meath, Kildare, Offaly and Carlow areas because K fixation is greater in these soils
- Poorly drained soils, where restricted rooting reduces uptake

Form of K compound

Potassium chloride has a higher salt Index than potassium sulphate. Consequently in soils where intensive cropping is practised and heavy amounts of inorganic fertilizers are applied, it is suggested that potassium sulphate should be used. Where vegetable crops are grown as part of a farm rotation, potassium chloride is satisfactory for most crops. However, research findings have shown that potassium sulphate should be used on carrots, and also on crops such as onions, leeks and French beans where extra heavy dressings of K are required.

Magnesium

Although Mg is a major plant nutrient, it behaves in many ways like a micronutrient or trace element. Deficiency can occur on acid, sandy or compacted soils and under conditions of either drought or high rainfall. If soil analysis indicates a deficiency of Mg in the soil, apply Kieserite (17.5% Mg) at 350 - 400 kg/ha. If lime is being applied use dolomitic limestone which will supply the Mg needed. Crops showing deficiency symptoms can be sprayed at 14 day intervals with Epsom salts (10% Mg) at 20 kg/ha in 1,000 litres of water.

Calcium

One of the commonest deficiency symptoms in vegetable crops, apart from N, is calcium. It's usually results from an induced deficiency rather that an actual shortage of calcium in the soil. Calcium is not a very mobile element within the plant and if the transpiration stream in the plant is interrupted, for example in drought conditions, a shortage of calcium can occur within the plant and deficiency symptoms appear in the weeks following. Calcium deficiency symptoms are called a number of different names depending on the crop: brassicas and lettuce (tipburn), celery (blackheart), tomato (blossom end rot), potato (internal rust spot). The most effective methods to mitigate calcium deficiency are through irrigation and by foliar application of calcium.

Organic Manures

The fertilizer advice given in Tables 20-1 to 20-40 is based on the assumption that livestock manure is not used. However, fertilizer application may be reduced where organic manures are available, with the extent of the reduction based on manure type and nutrient values - see chapter 9 - organic manures. However, the nutrients in different organic manures vary widely with dry matter content and season of application, thus it is suggested that fertilizer dressings be modified to take these factors into account. It is good practice to test organic manures in advance of application to determine their actual nutrient values. Although the use of livestock manures can be very beneficial for vegetable crops, it is essential under the NAP that the quantities of N and P nutrients they contain are accounted for in deciding on the nutrition of the crop.

20.2 Specific Advice for Vegetables

Asparagus

Available N, P and K recommendations for establishing and maintaining asparagus crops are shown in tables 20-1 and 20-2.

Table 20-1: Available N, P and K advice for establishing asparagus crops (kg/ha)

Soil Index	N	P	K
1	140	65	250
2	115	45	200
3	95	35	170
4	70	20[1]	125[2]

1. If soil P is greater than 15 mg/l, no fertilizer P is necessary.
2. If soil K is greater than 250 mg/l, no fertilizer K is necessary.

Nitrogen

Apply 70 – 140 kg/ha N as a base dressing for establishing asparagus crops.

Table 20-2: Available N, P and K advice for maintaining asparagus crops (kg/ha)

Soil Index	N	P	K
1	0	27	100
2	0	22	75
3	0	15	50
4	0	10[1]	50[2]

1. If soil P is greater than 15 mg/l, no fertilizer P is necessary.
2. If soil K is greater than 250 mg/l, no fertilizer K is necessary.

Nitrogen

For top dressing, apply 30 - 70 kg/ha N at the end of the cutting period.

Broad Beans

Available N, P and K recommendations for broad bean crops are shown in table 20-3.

Table 20-3: Available N, P and K advice for broad bean crops (kg/ha)

Soil Index	N	P	K
1	0	65	160
2	0	45	120
3	0	35	80
4	0	20[1]	40[2]

1. If soil P is greater than 15 mg/l, no fertilizer P is necessary.
2. If soil K is greater than 250 mg/l, no fertilizer K is necessary.

Nitrogen

No N required as broad beans are a nitrogen fixing crop.

French Beans

Available N, P and K recommendations for french bean crops are shown in table 20-4.

Table 20-4: Available N, P and K advice for French bean crops (kg/ha)

Soil Index	N	P	K
1	90	65	160
2	85	45	120
3	75	35	80
4	70	20[1]	40[2]

1. If soil P is greater than 15 mg/l, no fertilizer P is necessary.
2. If soil K is greater than 250 mg/l, no fertilizer K is necessary.

Boron

Beans are sensitive to high levels of boron so boronated compound fertilizers should not be used.

Beetroot

Available N, P and K recommendations for beetroot crops are shown in table 20-5.

Table 20-5: Available N, P and K advice for beetroot crops (kg/ha)

Soil Index	N	P	K
1	140	65	250
2	125	45	200
3	105	35	170
4	90	20[1]	125[2]

1. If soil P is greater than 15 mg/l, no fertilizer P is necessary.
2. If soil K is greater than 250 mg/l, no fertilizer K is necessary.

Nitrogen

Apply 90 – 140 kg/ha N as a base dressing.

Boron

Beet is subject to a disorder known as 'Canker' caused by boron deficiency. Boronated compound fertilizer should be used or 11 – 22 kg/ha Solubor DF (17.5% B) can be applied. Monitor crops and apply foliar B during the growing season if required.

Brussels Sprouts

Available N, P and K recommendations for brussels sprouts crops are shown in table 20-6.

Table 20-6: Available N, P and K advice for brussels sprouts crops (kg/ha)

Soil Index	N	P	K
1	120	65	250
2	115	45	200
3	105	35	170
4	100	20[1]	125[2]
Top Dress	180		

1. If soil P is greater than 15 mg/l, no fertilizer P is necessary.
2. If soil K is greater than 250 mg/l, no fertilizer K is necessary.

Nitrogen

Depending on soil fertility, apply a base dressing of 100 – 120 kg/ha N. Top dressings of N can be applied up to 180 kg/ha.

Boron

Use a boronated compound fertilizer or 11 – 22 kg/ha Solubor DF (17.5% B) can be applied. Monitor crops and apply foliar B during the growing season if required.

Broccoli

Available N, P and K recommendations for broccoli crops are shown in table 20-7.

Table 20-7: Available N, P and K advice for broccoli crops (kg/ha)

Soil Index	N	P	K
1	120	65	250
2	115	45	200
3	100	35	170
4	90	20[1]	125[2]
Top Dress	120		

1. If soil P is greater than 15 mg/l, no fertilizer P is necessary.
2. If soil K is greater than 250 mg/l, no fertilizer K is necessary.

Nitrogen

Depending on soil fertility, apply 90 – 120 kg/ha N as a base dressing. If top dressings are required apply up to 120 kg/ha.

Boron

Use a boronated compound fertilizer or 11 kg/ha Solubor DF (17.5% B) can be applied. Monitor crops and apply foliar B during the growing season if required.

Cabbage

Available N, P and K recommendations for spring cabbage and other cabbage crops are shown in table 20-8 and 20-9.

Table 20-8: Available N, P and K advice for spring cabbage crops (kg/ha)

Soil Index	N	P	K
1	50	65	250
2	35	45	200
3	15	35	170
4	0	20[1]	125[2]
Top Dress	250		

1. If soil P is greater than 15 mg/l, no fertilizer P is necessary.
2. If soil K is greater than 250 mg/l, no fertilizer K is necessary.

Nitrogen

Depending on soil fertility apply 0 to 50 kg/ha N as a base dressing. If the crop follows early potatoes little or no N base dressing will be required. Heavy top dressings are required in the January to March period. Apply up to 250 kg/ha N in 2 split applications.

Table 20-9: Available N, P and K advice for other cabbage crops (kg/ha)

Soil Index	N	P	K
1	150	65	250
2	135	45	200
3	115	35	170
4	100	20[1]	125[2]
Top Dress	100		

1. If soil P is greater than 15 mg/l, no fertilizer P is necessary.
2. If soil K is greater than 250 mg/l, no fertilizer K is necessary.

Nitrogen

Depending on soil fertility apply 100 to 150 kg/ha N as a base dressing. Top dressings can be applied up to 100 kg/ha.

Cauliflower

Available N, P and K recommendations for winter and spring cauliflower crops are shown in table 20-10.

Table 20-10: Available N, P and K advice for winter and spring cauliflower crops (kg/ha)

Soil Index	N	P	K
1	75	65	250
2	50	45	200
3	25	35	170
4	0	20[1]	125[2]
Top Dress	150		

1. If soil P is greater than 15 mg/l, no fertilizer P is necessary.
2. If soil K is greater than 250 mg/l, no fertilizer K is necessary.

Nitrogen

Depending on soil fertility apply 0 – 75 kg/ha N as a base dressing. Top dressings can be applied up to 150 kg/ha.

Available N, P and K recommendations for summer and autumn cauliflower crops are shown in table 20-11.

Table 20-11: Available N, P and K advice for summer and autumn cauliflower crops (kg/ha)

Soil Index	N	P	K
1	120	65	250
2	85	45	200
3	65	35	170
4	40	20[1]	125[2]
Top Dress	120		

1. If soil P is greater than 15 mg/l, no fertilizer P is necessary.
2. If soil K is greater than 250 mg/l, no fertilizer K is necessary.

Nitrogen

Depending on soil fertility apply 0 – 120 kg/ha N as a base dressing. If top dressings are required apply up to 120 kg/ha.

Carrots

Available N, P and K recommendations for carrot crops are shown in table 20-12.

Table 20-12-: Available N, P and K advice for carrot crops (kg/ha)

Soil Index	N	P	K
1	90	65	250
2	70	45	200
3	40	35	150
4	0	20[1]	110

1. If soil P is greater than 15 mg/l, no fertilizer P is necessary.
2. If soil K is greater than 250 mg/l, no fertilizer K is necessary.

Nitrogen

Depending on soil fertility, apply 0 – 90 kg/ha N as a base dressing. Top dressings are usually not required.

Potassium

Sulphate of potash is the preferred form of K for carrots.

Boron

The disorder known as '5 o'clock shadow' is caused by a deficiency of B, so the use of a boronated compound is recommended. Alternatively, 11 - 22 kg/ha Solubor DF (17.5% B) can be applied. Monitor crops and apply foliar B during the growing season if required.

Celery

Available N, P and K recommendations for celery crops are shown in table 20-13.

Table 20-13: Available N, P and K advice for celery crops (kg/ha)

Soil Index	N	P	K
1	120	88	375
2	85	65	300
3	65	55	250
4	50	28[1]	200[2]
Top Dress	180		

1. If soil P is greater than 15 mg/l, no fertilizer P is necessary.
2. If soil K is greater than 250 mg/l, no fertilizer K is necessary.

Nitrogen

Depending on soil fertility, apply 50 – 120 kg/ha N as a base dressing. Celery has a high N requirement and a top dressing of up to 180 kg/ha N as required depending on the N status of the soil.

Potassium

Celery has a high demand for K, so care should be taken to ensure that adequate levels are applied to the crop.

Boron

Celery is sensitive to B deficiency which causes the disorder known as 'Cat's Claw'. Use a boronated compound fertilizer or 11 kg/ha Solubor DF (17.5% B) can be applied. Monitor crops and apply foliar B during the growing season if required.

Blackheart (Calcium deficiency)

Use calcium nitrate as a N top dressing material and ensure that the crop is irrigated whenever necessary. Additional foliar applications with calcium nitrate at 3-4 kg/ha could also be considered.

Courgettes

Available N, P and K recommendations for courgette crops are shown in table 20-14.

Table 20-14: Available N, P and K advice for courgette crops (kg/ha)

Soil Index	N	P	K
1	140	65	250
2	125	45	200
3	105	35	150
4	90	20[1]	100[2]

1. If soil P is greater than 15 mg/l, no fertilizer P is necessary.
2. If soil K is greater than 250 mg/l, no fertilizer K is necessary.

Nitrogen

Depending on soil fertility 90 – 140 kg/ha should be applied as a base dressing.

Leeks

Available N, P and K recommendations for leek crops are shown in table 20-15.

Table 20-15: Available N, P and K advice for leek crops (kg/ha)

Soil Index	N	P	K
1	150	65	250
2	130	45	200
3	100	35	150
4	80	20[1]	100[2]
Top Dress	150		

1. If soil P is greater than 15 mg/l, no fertilizer P is necessary.
2. If soil K is greater than 250 mg/l, no fertilizer K is necessary.

Nitrogen

Hybrid varieties of leeks require more nitrogen than the older open pollinated varieties. Depending on soil fertility 80 - 150 kg/ha should be applied as a base dressing. Up to 150 kg/ha may be applied as a top dressing.

Lettuce

Available N, P and K recommendations for lettuce crops are shown in table 20-16.

Table 20-16: Available N, P and K advice for lettuce crops (kg/ha)

Soil Index	N	P	K
1	100	80	250
2	90	60	200
3	80	40	150
4	70	20[1]	100[2]
Top Dress	50		

1. If soil P is greater than 15 mg/l, no fertilizer P is necessary.
2. If soil K is greater than 250 mg/l, no fertilizer K is necessary.

Nitrogen

Depending on soil fertility 70 – 100 kg/ha N should be applied as a base dressing. Up to 50 kg/ha N may be applied as a top dressing.

Potassium

The preferred form of K for lettuce is sulphate of potash.

Onions

Available N, P and K recommendations for onion crops are shown in table 20-17.

Table 20-17: Available N, P and K advice for onion crops (kg/ha)

Soil Index	N	P	K
1	70	65	230
2	60	45	190
3	50	35	150
4	40	20[1]	110[2]
Top Dress	70		

1. If soil P is greater than 15 mg/l, no fertilizer P is necessary.
2. If soil K is greater than 250 mg/l, no fertilizer K is necessary.

Nitrogen

Depending on soil fertility, apply 40 – 70 kg/ha N as a base dressing. Top dressings can be applied up to 70 kg/ha but not later than mid-June.

Potassium

The preferred form of K for onions is sulphate of potash.

Scallions (Salad Onions)

Available N, P and K recommendations for scallion crops are shown in table 20-18.

Table 20-18: Available N, P and K advice for scallion crops (kg/ha)

Soil Index	N	P	K
1	90	65	230
2	80	45	190
3	70	35	150
4	60	20[1]	110[2]
Top Dress	60		

1. If soil P is greater than 15 mg/l, no fertilizer P is necessary.
2. If soil K is greater than 250 mg/l, no fertilizer K is necessary.

Nitrogen

Apply 60 – 90 kg/ha N as a base dressing and up to 60 kg/ha as a top dressing. If over-wintering use 30 kg/ha as a base dressing and up to 60 kg/ha as a top dressing.

Parsley

Available N, P and K recommendations for parsley crops are shown in table 20-19.

Table 20-19: Available N, P and K advice for parsley crops (kg/ha)

Soil Index	N	P	K
1	100	65	250
2	80	45	200
3	60	35	170
4	40	20[1]	125[2]
Top Dress	150		

1. If soil P is greater than 15 mg/l, no fertilizer P is necessary.
2. If soil K is greater than 250 mg/l, no fertilizer K is necessary.

Nitrogen

Apply 40 – 100 kg/ha as a base dressing and up to 50 kg/ha N after each cut but top dressings should not exceed 150 kg/ha in total.

Parsnips

Available N, P and K recommendations for parsnip crops are shown in table 20-20.

Table 20-20: Available N, P and K advice for parsnip crops (kg/ha)

Soil Index	N	P	K
1	100	65	250
2	85	45	200
3	70	35	170
4	50	20[1]	125[2]
Top Dress	70		

1. If soil P is greater than 15 mg/l, no fertilizer P is necessary.
2. If soil K is greater than 250 mg/l, no fertilizer K is necessary.

Nitrogen

Depending on soil fertility 50 – 100 kg/ha N should be applied as a base dressing and up to 70 kg/ha N may be applied as a top dressing.

Market Peas

Available N, P and K recommendations for market pea crops are shown in table 20-21.

Table 20-21: Available N, P and K advice for market pea crops (kg/ha)

Soil Index	N	P	K
1	0	65	160
2	0	45	120
3	0	35	80
4	0	20[1]	40[2]

1. If soil P is greater than 15 mg/l, no fertilizer P is necessary.
2. If soil K is greater than 250 mg/l, no fertilizer K is necessary.

Nitrogen

No N required as peas are a nitrogen fixing crop.

Rhubarb

Available N, P and K recommendations for rhubarb crops are shown in table 20-22.

Table -20-22: Available N, P and K advice for rhubarb crops (kg/ha)			
Soil Index	N	P	K
1	100	65	250
2	90	45	200
3	80	35	170
4	70	20[1]	125[2]
Top Dress	200		

1. If soil P is greater than 15 mg/l, no fertilizer P is necessary.
2. If soil K is greater than 250 mg/l, no fertilizer K is necessary.

Nitrogen

Depending on soil fertility apply 70 – 100 kg/ha N as a base dressing. Top dress with up to 100 kg/ha after pulling, to a maximum total N application of 200 kg/ha N.

Spinach

Available N, P and K recommendations for spinach crops are shown in table 20-23.

Table 20-23: Available N, P and K advice for spinach crops (kg/ha)			
Soil Index	N	P	K
1	140	65	250
2	125	45	200
3	105	35	170
4	90	20[1]	125[2]
Top Dress	100		

1. If soil P is greater than 15 mg/l, no fertilizer P is necessary.
2. If soil K is greater than 250 mg/l, no fertilizer K is necessary.

Nitrogen

Depending on soil fertility, apply 90 – 140 kg/ha as a base dressing. Up to 100 kg/ha may be used as a top dressing.

Boron

Spinach requires B which can be supplied in a boronated compound fertilizer.

Swedes

Available N, P and K recommendations for swede crops are shown in table 20-24.

Table20-24-: Available N, P and K advice for swede crops (kg/ha)			
Soil Index	N	P	K
1	70	70	250
2	45	60	200
3	25	45	170
4	20	35[1]	125[2]
Top Dress	30		

1. If soil P is greater than 15 mg/l, no fertilizer P is necessary.
2. If soil K is greater than 250 mg/l, no fertilizer K is necessary.

Nitrogen

Swedes are not a high nitrogen demanding crop. Depending on soil fertility, apply from 0 - 70 kg/ha N as a base dressing. Top-dressings of N are not usually required but where crops are backward, top dress with up to 30 kg/ha N.

Available N, P and K recommendations for early swede crops are shown in table 20-25.

Table 20-25: Available N, P and K advice for early swede crops (kg/ha)			
Soil Index	N	P	K
1	90	70	250
2	60	60	200
3	30	45	170
4	0	35[1]	125[2]

1. If soil P is greater than 15 mg/l, no fertilizer P is necessary.
2. If soil K is greater than 250 mg/l, no fertilizer K is necessary.

Nitrogen

Early swedes require more N than main crop. Depending on soil fertility, apply from 0 - 90 kg/ha N as a base dressing.

Boron

Boron is an issue with both early and main crop swedes. Boron deficiency can cause ‘Brown Heart’, a serious problem particularly on soils of high pH. Use of boronated compound fertilizer is advised or alternatively 11 – 22 kg/ha Solubor DF (17.5% B) can be applied. Monitor crops and apply foliar B during the growing season if required.

20.4 Micronutrients for Vegetables

Effect of soil pH

The pH of the soil affects the uptake of most mineral elements. There is a range of pH values within which the element is readily available and outside of which it becomes increasingly unavailable. The reactions are complex but to simplify: under very acid conditions, i.e. below pH 5.0, Mn and AI are released and taken up by the plant to produce toxicities of both elements. Aluminium toxicity reduces the uptake of P, and under these conditions both Ca and Mo are less available and are likely to be deficient. Under high pH conditions, i.e. above 7.5, Mn, Cu, Fe, Zn and B are all more likely to be deficient.

Boron

Swedes are very prone to boron deficiency and can also show up in other brassicas, celery, carrots and beet crops.

Solubility of B is pH dependent and B deficiency problems are more frequent on alkaline soils, with greatest severity at pH 7.0 and above. Boron deficiency is also common on light free-draining soils.

In mineral soils, a soil content of 1 mg/l B is satisfactory and less than 0.5 mg/l is potentially deficient. In peat soils, a content of 1-3 mg/l B is satisfactory and one with less than 1 mg /l B is potentially deficient.

Boron levels in soil can be maintained by applying 2-4 kg/ha of B as Solubor DF (17.5%) at 11-22 kg/ha. Boronated compounds containing 0.33% B applied at 625 kg/ha supplies the equivalent of 2.0 kg/ha of B.

Likely crop responses to boron are shown in Table 20-26.

Table 20-26: Vegetable crops and the likelihood of response to B on deficient soils

Response	Vegetable crop
High	Asparagus, beet, brassicas, carrot, celery
Medium	Lettuce, onion
Low to none	Beans, peas, potato

Copper

Copper deficiency in vegetables is usually only a problem in peat soils, especially in the early stages of reclamation of peat soils. On such soils all crops should receive 20-60 kg/ha Cu as a base dressing of copper sulphate (25% Cu). Maintenance dressings of copper sulphate should be applied during the rotation of crops susceptible to copper deficiency.

Crops response to copper on peat soils are shown on Table 20-27.

Table 20-27: Vegetable crops and the likelihood of response to Cu on peat soils

Response	Vegetable Crop
High	Beet, carrot, lettuce, onion, spinach
Medium	Cabbage, cauliflower, celery, pea, turnip
Low to None	Beans, potato

Manganese

Deficiency of Mn occurs where soil pH and soil organic matter are high and where soils are excessively drained. Manganese deficiency can be expected in peaty soils where pH is greater than 6.0. On mineral soils it is most severe in sensitive crops at pH above 7.5. Manganese deficiency is controlled by foliar spray applications of 2 kg/ha manganese sulphate (24.6% Mn) in 1,000 litres of water.

Crop responses to Mn are shown in Table 20-28 for peat soils.

Table 20-28: Vegetable crops and the likelihood of response to Mn on peat soils

Response	Vegetable crop
High	Bean, lettuce, onion, pea, potato, spinach
Medium	Beet, brassicas, carrot, celery
Low to none	Asparagus, parsnip

Molybdenum

Molybdenum in acid soils tends to be unavailable to plants. Of the brassica crops cauliflower is the most sensitive to molybdenum deficiency (‘whiptail’) especially on low pH ground. Lettuce is also susceptible to molybdenum deficiency. Other types of brassica are not normally affected. It can be prevented by normal liming practices. If required apply sodium molybdate (39% molybdenum) as a soil application at 0.3 kg/ha or as a foliar spray at 3g in 10 litres of water applied as a high volume spray – 1000 l/ha. Do not tank mix with other products.

Zinc

With the exception of sweetcorn zinc deficiency in vegetable crops is rare. Deficiency of Zn can occur on alkaline soils, especially if heavy dressings of P fertilizer have been used. Peat soils are deficient in most micronutrients and peat-grown plants often develop Zn deficiency. Zinc deficiency can be controlled by 10-20 kg/ha of zinc sulphate (23% Zn) broadcast prior to sowing. Foliar application of 4 kg zinc sulphate per ha in 1,000 litres of water can be used, but for onions, soil applications are usually more effective.

Likely crop responses to zinc on deficient soils are shown in Table 20-29.

Table 20-29: Vegetable crops and the likelihood of response to Zn on deficient soils

Response	Vegetable crop
High	Beans, Sweetcorn
Medium	Onion, potato
Low to none	Asparagus, carrot, pea

An indication of the nutrients that are likely to affect the growth of different vegetable crops is presented in Table 20-30.

Table 20-30: Susceptibility of the major vegetable crops to deficiency of Ca, Mg and the main micronutrients

Susceptibility key +++ = very susceptible, ++ moderately susceptible, + = least susceptible							
Crop	Ca	Mg	B	Cu	Mn	Mo	Zn
Asparagus	-	+	+++	+	+	+	+
Beans	-	++	+	+	+++	++	+++
Beetroot	-	++	+++	+++	++	++	++
B. sprouts	+++	+	+++	++	++	+++	-
Cabbage	-	++	+++	++	++	+++	-
Calabrese	-	++	+++	++	++	+++	-
Cauliflower	-	+++	+++	++	++	+++	-
Carrots	-	+	+++	+++	++	+	+
Celery	+++	+	+++	++	++	+	
Courgettes	-	-	+	-	-	-	-
Leeks	-	+	++	-	+	-	-
Lettuce	+++	+++	++	+++	+++	++	-
Onions		++	++	+++	+++	++	+++
Parsnips					+	+	
Peas		++	+	++	+++	++	+
Potato (early)		++	+++	+	+++	+	++
Spinach		++	++	+++	+++	+++	
Swedes		+	+++	++	++	++	
Sweetcorn		+	+	++	++	+	+++

21. Nutrition of Fruit Crops

21.1 Nutrients for fruit crops

Soil acidity and liming

Most fruit crops are tolerant of slight acidity and grow best at around pH 6.0 to 6.5. Soil pH levels below about 5.5 can give rise to manganese toxicity, causing measly 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.

Any lime required should be applied and incorporated before planting. The whole plough layer should be limed to maintain a pH value of 6.5 in the early years of fruit growing. Because acidity at depth cannot be corrected by later lime incorporation, the quantity of lime (based on soil analysis) applied before planting should be calculated so that it will correct the pH of the top 400 mm of soil. If the total lime requirement is more than 7.5 t/ha, half should be deeply cultivated into the soil and ploughed down, and 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.

Nutrients

Where soil analysis shows soil acidity or a low soil P, K or Mg Index, the appropriate amounts of lime and fertilizers should be incorporated before planting. This applies particularly to P and to a lesser extent for K and Mg.

Only materials containing a large proportion of water soluble phosphate should be used for P applications. Potassium sulphate should preferably be used for raspberries, redcurrants and gooseberries where more than 100 kg/ha K is applied. To avoid induced magnesium deficiency, the soil K:Mg ratio should be no greater than 3:1 when calculated from the soil analysis values for K and Mg expressed in mg/l.

The N, P and K requirements for a range of fruit crops grown in soil are shown in Table 21-1 to 21-3, respectively.

Table 21-1: Available nitrogen applications for fruit crops (kg/ha)		
	Nature of Cultivated Area	
CROP	Grassed*	Cultivated
Apples (dessert)	125	40
Apples (culinary)	125	70
Pears	140	100
Cherries	140	100
Plums	140	100
Blackcurrants	-	110
Gooseberries	-	80
Raspberries	-	80
Strawberries	-	50
Redcurrants	-	80
Loganberries	-	80
Blackberries	-	80

* A hyphen in this column indicates that these crops should not be cultivated in grassed areas

Table 21-2: Available phosphorus applications for fruit crops (kg/ha)				
	P Index			
CROP	1	2	3	4
Apples (dessert)	25	16	12	8
Apples (culinary)	20	12	10	8
Pears	16	8	4	0
Cherries	16	8	4	0
Plums	16	8	4	0
Blackcurrants	20	16	12	8
Gooseberries	20	16	12	8
Raspberries	20	16	12	8
Strawberries	16	8	4	0
Redcurrants	20	16	12	8
Loganberries	20	16	12	8
Blackberries	20	16	12	8

Table 21-3: Available potassium applications for fruit crops (kg/ha)				
	K Index			
CROP	1	2	3	4
Apples (dessert)	110	70	50	30
Apples (culinary)	90	60	40	30
Pears	80	50	40	20
Cherries	80	50	40	20
Plums	80	50	40	20
Blackcurrants	90	60	45	30
Gooseberries	120	90	70	50
Raspberries	100	90	70	50
Strawberries	90	60	45	30
Redcurrants	120	70	60	50
Loganberries	90	60	45	30
Blackberries	90	60	45	30

Strawberries

Before planting strawberries a sample of soil from the site should be analysed for pH, P and K. Any deficiency of lime, P or K should be made up before planting.

Lime

Strawberries are tolerant of fairly acid soil conditions and unless the pH is below 6 the area need not be limed. When liming, the pH should be raised to a value of 6.5-7. Although not common in the important strawberry growing areas in Ireland, pH values over 7 can lead to iron and manganese deficiencies. Lime should not therefore be applied unless the soil analysis results indicate that it is necessary.

Nitrogen

Generally, sufficient N is available to strawberry plants from natural sources in the soil. Too much N causes excessive vigour, soft fruit and an increased risk of grey mould disease (*Botrytis*).

Phosphorus

Strawberries are not normally very responsive to P except where there is a severe deficiency. Usually a pre-planting application of P is adequate for the life of the plantation. Where a further application is considered prudent, a late summer application of a P & K compound fertilizer according to Tables 21-2 to 21-3 will normally be used.

Potassium

Potassium deficiency can seriously reduce the yield of strawberries. Pre-planting applications of farmyard manure supply useful quantities of this element. Potassium should be applied as indicated by soil analysis. Usually potassium sulphate applied pre-planting is adequate. This should be followed by a late summer K application of potassium sulphate or a P & K compound fertilizer at rates according to Tables 21-2 to 21-3.

Fertigation

Where strawberries or raspberries are grown under polythene mulch with sub-irrigation, nutrients can be applied in the irrigation system (fertigation). On soils which encourage vigorous growth, it may be beneficial to reduce nitrogen rates when applied by fertigation.

At P and K Index 2 or above, maintenance rates of P and K can be applied by fertigation. However, where the soil P, K or Mg Index is 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 irrigation nozzles.

Substrate strawberry production

When strawberries are grown in an inert substrate, a complete nutrient solution is required. Normally a conductivity of 1.6-1.8 mS/cm (mili-siemens per cm) is maintained at full crop growth and production for main crop 'June bearers' and the value should generally not exceed 2.0 mS/cm.

Deficiency of iron and manganese can occur at high (alkaline) pH levels in the substrate. Therefore 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 before planting with a feed solution for 2 – 3 days. 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 pH (5.6 – 6.0). Furthermore, feed recipes also depend on the chemical composition of the irrigation water which must be taken account of in the fertigation programme.

Table 21-4: Guidelines for nutrient solution for strawberry production using substrates

Nutrient	Nutrient solution optimum mg/l in dilute feed
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

Raspberries

Raspberries grow best in free draining soils capable of holding moisture in dry periods. The raspberry is largely surface rooting and will not grow well in badly drained or impeded soils. Cold, wet clays are to be avoided. Soils with high lime content are also unsuitable since growth may be limited by iron and manganese deficiencies, which affects the shoots and foliage.

Raspberries must be sheltered from strong winds by planting a shelter belt on the perimeter if required.

The soil should be brought to a pH of 6.5 preferably in the last year before it is intended to plant the crop. An application of magnesium limestone will help ensure adequate levels of magnesium. Where the pH is too high, micronutrient deficiencies such as iron and manganese can occur. Dressings of P and K fertilizer appropriate to the soil test result should be applied as a 30cm band along the rows after planting. The soil should be tested every 2-3 years to indicate the correct rates of P and K to apply. Nitrogen is also an important nutrient and the rate of application will depend on soil type and the age of the plantation. Generally the maximum N application permitted under the NAP regulations should be used to get the plantation established. The rate can then be reduced according to the vigour of the crop.

Gooseberries

Gooseberries may be grown in almost any situation and on a wide range of soils. Light gravelly soil and wet undrained soil are, however, unsuitable, the former on account of its liability to drought, the latter because of the likelihood of injury to the roots of the bushes by stagnant water. The most suitable soil is a strong loam and the best situation is a southerly aspect sheltered from strong winds.

Gooseberries can tolerate a fair degree of soil acidity and also do not suffer so much from chlorosis when on highly alkaline soils as do strawberries or raspberries.

The nutritional trouble most commonly met with in gooseberries is K deficiency. The symptoms are stunting of the growth and a scorching of the leaves especially around the edges. Gooseberries are particularly susceptible to chloride.

Blackcurrants

Blackcurrants are best grown on the medium to heavy clay loams, including those of a peaty character. Avoid light shingly types of soil.

Vigorous growth is essential for high yields and hence deep medium loams which encourage free rooting and retain ample soil moisture during the growing season, afford the most suitable conditions. Blackcurrants may tolerate some degree of impeded drainage, but waterlogged conditions are very harmful.

The crop can be grown well on even highly alkaline soils but is very susceptible to soil acidity. The pH should not be allowed to fall below 5.5 and should preferably be maintained above 6.0.

Routine dressings of N, P and K have been found in practice to be necessary for high yields. The amounts required will vary according to soil type and are best determined by soil analysis (see Tables 21-2 to 21-3).

Inorganic N is usually applied in March. Phosphorus may be applied in spring and K may be applied between late autumn and early spring. Potassium chloride (muriate of potash) is not advisable in early spring applications as there is some risk of chloride injury but it may be used safely in autumn or winter. Splitting the nitrogenous dressings into spring and summer or autumn applications is unnecessary; evidence suggests that a bigger response is obtained from a single spring dressing. Nitrate application should preferably in the form of CAN; if ammonium sulphate is used, the soil pH should be regularly checked. Apart from the intolerance of blackcurrants to even moderate acidity, P deficiency, accompanied by poor root action, may be induced if the pH is too low.

21.2 Micronutrients for Fruits Crops

Micronutrient deficiencies may occur in fruit crops in some areas, especially where the soil pH is over 7.0. These deficiencies can often be identified by visual diagnosis but should be checked by leaf analysis. Iron deficiency cannot reliably be confirmed by analysis.

Boron

Boron supplementation in all fruit crops is desirable, as it aids fruit set. Boron is normally applied as part of the orchard spray programme.

Copper

Copper deficiency in top fruit crops is not a problem in Ireland. If a deficiency ever did arise, it can be corrected by applying a foliar spray of copper.

Iron

Iron deficiency occurs commonly in top and soft fruit crops grown on shallow calcareous soils. It can be treated by either soil or foliar application of a suitable iron chelate.

Manganese

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

Zinc supplementation is credited as giving a positive effect for fruit bud formation. This deficiency can be corrected by foliar application of zinc at leaf fall or bud burst.

22. Nutrients for Energy Crops

22.1 Miscanthus

Miscanthus is a woody, perennial, rhizomatous grass which originated in South East Asia. It is not native to Europe and was first imported into Denmark in the 1930s. Interest in miscanthus as an energy crop developed in the 1980's as it was observed that certain genotypes exhibit very high biomass yields.

Following establishment a miscanthus crop can be expected to remain productive for up to 15 years. Genotypes of agricultural interest are sterile and need to be propagated from rhizomes (underground stems). It is recommended that miscanthus rhizomes are sown in the spring; shoots are produced from buds on the rhizomes. New shoots are produced each spring which grow rapidly during the summer to produce a tall crop (2-3m in height). The crop is left to dry during the winter during which the leaves fall off the stems to produce a layer of debris and organic matter at the soil surface. The bamboo-like canes are harvested in the spring before the commencement of the next season's growth. Miscanthus takes a number of years, typically 3-4, to reach full production potential. The crop concentrates on building its rhizome network during the first few years during which less emphasis is placed on shoot production.

Soil Type

Miscanthus can be grown successfully on a wide range of soil types and is tolerant of a wide range of soil pH levels, ideally aim to maintain soil pH 6.5. However, highest yields tend to be obtained on soils with high water holding capacity and high organic matter content. On clay rich soils lower annual soil temperatures tend to delay development during spring, while on sandy soils the crop can often suffer periodic water stress.

Nutrient requirements

Miscanthus is very efficient in the way it uses and cycles nutrients. There are a number of reasons for this high level of efficiency;

- Miscanthus is deep-rooted and can abstract nutrients from a large volume of soil,
- It has a higher nutrient efficiency compared to arable crops (wheat, barley) and native grasses (ryegrass). Fewer nutrients are needed for each unit mass (kg) of biomass produced by the crop,
- Excess nutrients are exported from the above ground parts to rhizome during the autumn as the leaves senesce (die). These nutrients are stored in the rhizome during the winter and are used to support early growth of young shoots during the following spring,
- Leaf fall from the miscanthus crop accumulates as a litter layer on the surface on the soil. This leaf litter layer decomposes over time and the nutrients are returned back into the soil where they can be once again absorbed by the miscanthus root system.

Nutrient off-takes are confined to the amount of nutrients in the harvested crop as the nutrients in leaves are returned to the soil. Final miscanthus harvest yields and consequent nutrient offtake depends on crop productivity which depends largely on rainfall and temperature in the case of miscanthus. Research from experiments conducted in Ireland (and throughout Europe) show that typical nutrient offtake from productive crops (10-15t DM/ha) are in the following ranges as shown in table 22-1.

Table 22-1:- Typical nutrient offtakes for miscanthus crops yielding between 10 to 15 t/ha dry matter

Nutrient	(kg ha)
N	65-100
P	10-15
K	85-130
Mg	8-12

Source Himken et al. 1997. Plant and Soil 189:117-126.

The offtake of potassium and nitrogen are broadly similar. A large number of N fertilizer response trials have been conducted for miscanthus, and many trials to date show no response to added N fertilizer. However, it must be pointed out that the trials conducted have been almost exclusively conducted during the establishment phase of the crop (years 1-5) with limited information being available on N responses of mature crops. No comprehensive fertilizer trials with phosphorus and potassium have yet been conducted and additional research is needed on the response of miscanthus to these elements.

Crop nutrient requirements ultimately depend on soil type, cropping history and nutrient offtake. Growers are advised to carry out regular soil tests to determine the levels of nutrients in the soil. The following preliminary nutrient advice has been developed for miscanthus. This advice may change as additional information on the crop becomes available. The philosophy is based on replacing nutrient removal by the crop.

It is not recommended to apply nitrogen fertilizer in the first two years of establishment as off takes are low and generally there are sufficient nutrients in the soil. Typically, fertilizer application during these years will only promote weed growth which will compete with the growth of the young miscanthus plants and incur additional expenditure on herbicides. Fertilizer requirements for subsequent years are summarised in the table 22-2.

Table 22-2:- Nitrogen guidance for miscanthus[1] based on crop removal of 13 t/ha dry matter

Soils N index	N	P	K[2]
1	100	33	120
2	80	23	75
3	50	13	40
4	30	0	0

1. Advice for miscanthus crops from 3 years post establishment onwards.
2. The use of Potassium (Potassium Chloride) should be avoided as the resultant high levels of chloride can lead to corrosion in heating boilers.

22.2 Short Rotation Coppice (SRC) Willow

Fertilizer should only be applied to any crop based on the result of a formal soil analysis and the consideration of other inputs in perennial crops such as internal recycling of nutrients in the leaf litter. In the case of short rotation coppice (SRC) willow and in the absence of any long-term direct information on fertilizer and yield, nutrient off take in the harvested crop should be used in calculating the fertilizer requirement. Research on moderate to fertile soils, particularly in the early rotations, shows that there is not necessarily a positive response to fertilizer applications. Sites with a naturally poorer nutrient status, however, may need early applications to maintain productivity.

It is reported that the use of inorganic fertilizers to meet nutrient requirements, particularly N and P are not economically sustainable for SRC willow. However utilising the nutrients in industrial or sewage organic manures provides not only the nutrients required to replace those removed by the crop but also a sustainable management option for these materials, provided legislative requirements and good practice in relation to land spreading are observed.

Nitrogen fertilizer application is not recommended in the first growing season. Weed control is likely to be most difficult in the establishment year and fertilizer application may well exacerbate the problem.

There is relatively little research on the nutrition of modern high yielding varieties of SRC willow. These willow varieties, grown in mixtures, will have productivity levels significantly higher (20-40%) than the traditional varieties used in much of the earlier trial work. Therefore, crop nutrient requirements will be higher than that of the traditionally willow varieties.

Based on this background, Teagasc has developed some preliminary nutrient guidance for willow. The guidance is based on nutrient removal by the crop, soil fertility levels and legislative limits on nutrient inputs. The underlying principles of these limits relate to balancing crop nutrient requirements and applications rates of N P and K based on the availability levels of these nutrients in the soil and in the manures being applied. SRC willow has a relatively high nutrient demand as shown in table 22-3. This nutrient demand by SRC willow can be supplied with biosolid or sewage sludge applications (refer to Table 9-11). It should be noted that the nutrient availability in biosolids or sludges can be altered depending on their pre-treatment. Refer to “Availability of phosphorus in biosolids when applied to agricultural land” (Fehily and Timoney, 2007).

Nitrogen (N) requirements

The risk of nitrogen leaching from SRC willow is relatively low compared with normal arable situations given the long term perennial nature of the crop and the absence of soil disturbance through cultivation. Typically willows have a low nitrogen requirement, however, research indicates crop N requirements from 150 to 400 kg/ha.

In the nutrient removal figures for the crop the efficiency of N use (in the region of 35%) should be considered. A significant proportion of nutrients will be used by the soil micro flora, lost to the atmosphere or bound up in the roots and leaves of the coppice although the latter will eventually be recycled in the leaf litter and the root turnover.

Research data shows that the N removal by a standard willow crop (12 ton DM/ha/year) under Irish conditions is approximately 100 kg/ha. However, as mentioned above this must be adjusted to take account of the soil N supply, which is on average 140 kg/ha for Irish grassland soils (Humphreys, 2007). Based on this information the recommended rates of N for SRC willow are shown in Table 22-3.

Table 22-3:- Guidance for willow[1] based on crop removal of 12 t/ha dry matter

Soils N index	N	P	K[2]
1	130	44	155
2	100	34	135
3	75	24	120
4	40	0	0

1. Adjust recommended rates of P by 2 kg/t or K by 10 kg/t based on crop yield potential.
2. The use of Potassium (Potassium Chloride) should be avoided as the resultant high levels of chloride can lead to corrosion in heating boilers.

It is important to note that these figures need to be adjusted to reflect crop yield. For example no N is required in the year following establishment.

Phosphorus (P)

Dawson (2007) indicated that one tonne of willow DM harvested removes approximately 2 kg of P. Therefore, the guidance P advice is 24 kg/ha where a standard annual DM removal is 12t/ha. This figure must be adjusted to take account of the soil P index. The P guidance figures for willow based on soil P Index are summarised in Table 22-3.

Test soils once every 5 years to determine soil P levels. With the relatively low levels of phosphorous removal in the harvested SRC the P status of the soil may well be the limiting factor in recycling organic waste in most circumstances. As with N, the P advice will require adjustments to crop yields in the establishment year and thereafter as crop yield potential will vary.

Potassium (K)

Potassium will vary greatly depending on the soil type. There is the potential to balance most of the potassium exported from the site at harvest by returning the ash to the site, after conversion of the woodchip to energy. Consult a recent soil analysis to determine the K application required.

Dawson (2007) indicates that one tonne of willow DM harvested removes approximately 10 kg of K. Therefore, the guidance K advice is 120 kg/ha where standard annual DM removal is 12 t/ha. This advice requires adjustment to take account of the soil K Index. The K guidance figures for willow based on soil K Index is summarised in Table 22-3.

22.3 Hemp

Cannabis saliva is an annual crop which has been grown widely across the world for millennia. The crop can be grown for both fibre and seed and varieties have been developed for both purposes. Hemp produces high yields of fibre which can be processed into a range of products including twine, rope rigging and nets. Use of the crop was largely discontinued during the 1930s. Renewed interest in hemp developed in the 1990s with the introduction of new varieties. Current uses for hemp for hemp fibre, include insulation, animal bedding, clothing and automotive parts, oil from hemp seed is valued because of its high nutritional value. Teagasc research in the late 1990s established that high biomass yields of hemp could be obtained at relatively low levels of inputs. These findings led to interest in hemp as a bioenergy feedstock.

Soils

Hemp can be grown on a wide range of soil types. However, well drained soils with good moisture and nutrient retention are preferred, as hemp is sensitive to water-logging as well as compaction. Soil pH greater than 6 is recommended.

Nutrient requirement

Teagasc research during the 1990s on a good soil in Co. Laois showed that respectable yields (>12 tonnes/ha) could be obtained with 120 kg N/ha. Nitrogen is generally applied to the seedbed before or during sowing. More recently Teagasc research showed that yield increases with nitrogen application rate up to 120 kg N/ha but that the application of N at times later than sowing or in splits had no effect on biomass yield compared to the practise of applying N at the time of sowing. Teagasc research on the effects of K fertilization on hemp yields showed that there was no significant relationship between hemp yield and either K fertilization rate or the level of soil K. No yield response can be expected on sites with moderate or high levels of soil K (>101 mg/L; Morgan's Test) and the optimum K fertilization strategy for hemp crops grown on these soils is to replace offtakes after harvest. Hemp crops grown on soils with lower levels of soil K (Index 1 or 2) may show a response to K and may require fertilization before sowing.

Table 22-4 Shows preliminary advice based on crop yield for crops grown for fibre and seed below.

Table 22-4: Nutrient guidelines for hemp[1] crops grown for fibre

Soils N index	N	P	K[2]
1	120	50	75
2	105	40	60
3	90	30	45
4	75	0	0

1. Nutrient guidelines based on a hemp crop yielding 12 t/ha dry matter.
2. The use of Potassium (Potassium Chloride) should be avoided as the resultant high levels of chloride can lead to corrosion in heating boilers.

23. Plant Tissue Analysis

While soil analysis is the main technique used in determining the nutrient capacity of a soil and hence fertilizer requirements, it does not always provide a measure of the soil's capacity to supply micronutrients to the plant. Plant tissue analysis measures the concentration of nutrients and this reflects the ability of a particular soil to supply nutrients to the plant. In many perennial crops such as top fruit mid-season leaf analysis is widely used in conjunction with soil analysis in determining optimum fertilizer use. In annual crops, plant tissue analysis has a more limited use in relation to crop nutrition but is a valuable aid in studies of nutrient disorders in plants.

Successful use of the plant analysis technique requires proper sampling, analysis and interpretation. In sampling, the correct part of the plant must be selected and usually these are fully developed leaves at the top of the plant. Plant tissue must be free from soil and chemical contamination. Proper sampling techniques have to be used to reduce sampling error. Interpretation of plant analysis results requires an extensive knowledge of a crop's nutrient requirements and distribution of nutrients within the plant. For instance, 20 g/kg K in lettuce could be sufficient while the same level in potatoes would indicate K deficiency. Aluminium and nickel for instance are not translocated to any extent and only accumulate to toxic levels in the roots. In general studies of nutrient disorders in plants plant tissue analysis can be useful. In these incidences, it is suggested that good and bad plant samples of similar physiological development and age should be analysed and interpretation based on the differences obtained.

Table 23-1 shows a range of nutrient concentrations likely to be associated with deficient, sufficient and toxic conditions on the plant. In view of the various complexities associated with plant analysis and its interpretation as indicated very briefly above, these values should only be taken as broadly indicative of possible deficient, sufficient and toxic conditions in the plant.

Table 23-1: Nutrient concentrations in plants				
Nutrient	Concentration in recently mature leaves			
	Deficient	Low	Sufficient	Toxic
Major Elements	**Units: g/kg in dry matter**			
Nitrogen	< 20	20 – 30	30 – 40	-
Phosphorus	< 1	1 – 3	3 – 4	-
Potassium	< 20	20 - 30	30 - 60	
Magnesium	< 1	1 - 3	3 - 6	-
Micronutrients	**Units: mg/kg in dry matter**			
Boron	< 15	15 - 30	30 -60	>200
Copper	< 4	5 - 10	10 - 20	>20
Manganese	< 20	20 - 30	30 - 100	>500
Molybdenum	< 0.1		0.5	-
Zinc	< 20	20 - 30	30 - 60	>400

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Appendix 1. Dimensions and Units

Table A1.1: Calculation of organic stocking rates based on annual nutrient excretion rates for livestock, as specified in the NAP regulations.

Livestock Type	Total Nitrogen (kg/year)
Dairy cow	85
Suckler cow	65
Cattle (0-1 year old)	24
Cattle (1-2 year old)	57
Cattle > 2 years	65
Mountain ewe & lambs	7
Lowland ewe & lambs	13
Mountain Hogget	4
Lowland Hogget	6
Goat	9
Horse (>3 years old)	50
Horse (2-3 years old)	44
Horse (1-2 years old)	36
Horse foal (< 1 year old)	25
Donkey / small pony	30
Deer (red) 6 months – 2 years	13
Deer (red) > 2 years	25
Deer (fallow) 6 months – 2 years	7
Deer (fallow) > 2 years	13
Deer (sika) 6 months – 2 years	6
Deer (sika) > 2 years	10
Breeding unit (per sow place)	35
Integrated unit (per sow place)	87
Finishing unit (per pig place)	9.2
Laying hen per bird place	0.56
Broiler per bird place	0.24
Turkey per bird place	1

Table A1.2: Conversion of metric to traditional/imperial units.

Usage	Metric	Imperial / Traditional
Rates	1 tonne/ha	0.398 tons/acre
	100 kg/ha	80.9 units/acre
	1 kg/tonne	2.03 units/ton
	1 m^3/ha or 1000 l/ha	89.0 gallons/acre
	1 kg/m^3	9.09 units/1000 gallons
	kg/tonne (w/w basis) to kg/m^3 (w/v basis)	Multiply by specific gravity
Length	1 kilometre	0.621 mile
	1 metre	1.09 yards
	1 metre	3.28 feet
	1 centimetre	0.394 inch
Area	1 square kilometre	0.386 square miles
	1 square kilometre	247 acres
	1 hectare	2.47 acres
	1 square metre	1.20 square yards
	1 square metre	10.8 square feet
	1 square centimetre	0.155 square inches
Volume	1 cubic metre	1.31 cubic yards
	1 cubic metre	220 gallons
	1 litre	0.220 gallons
	1 litre	0.880 quarts
	1 litre	1.76 pints
Weight	1 tonne	0.984 tons
	1 tonne	19.7 hundredweights
	1 kilogram	0.157 stones
	1 kilogram	2.20 pounds
	1 kilogram	32.3 ounces
	1 kilogram	2.00 units

Table A1.3: Conversion of traditional/imperial units to metric units

Usage	Imperial / Traditional	Metric
Rates	1 ton/acre	2.51 tonnes/ha
	100 units/acre	124 kg/ha
	1 unit/ton	0.492 kg/tonne
	1000 gallons/acre	11.2 m^3/ha or 11,200 l/ha
	1 unit/1000 gallons	0.110 kg/m^3
	Kg/m^3 (w/v basis) to kg/tonne (w/w basis)	Divide by specific gravity
Length	1 mile	1.61 kilometres
	1 yard	0.914 metres
	1 foot	0.305 metres
	1 inch	2.54 centimetres
Area	1 square mile	2.59 square kilometres
	1 acre	0.00405 square kilometres
	1 acre	0.405 hectares
	1 square yard	0.836 square metres
	1 square foot	0.0929 square metres
	1 square inch	6.45 square centimetres
Volume	1 cubic yard	0.765 cubic metres
	1 gallon	0.00455 cubic metres
	1 gallon	4.55 litres
	1 quart	1.18 litres
	1 pint	0.568 litres
Weight	1 ton	1.02 tonnes
	1 hundredweight	0.0580 tonnes
	1 stone	6.35 kilograms
	1 pound	0.454 kilograms
	1 ounce	0.0283 kilograms
	1 unit	0.500 kilograms

Table A1.4: 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

Table A1.5: 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

Appendix 2. Quick Guide to Texture Classes

Table A2 - 1 Assessing the texture of soils (Diamond, 2001)

Criteria	Texture Sand/gravel	Loamy	Clayey	Peat
General	Predominantly rough and gritty, porous	Crumbly, neither smooth nor rough	Smooth and silky or buttery	Dark brown to black colour. Obviously of exclusively organic origin. Very low bulk density when dry.
Ease of moulding wet soil	Difficult to roll into a ball	Moulds into a ball which does not polish or feel sticky	Moulds like plasticine, polishes, and feels sticky	
Mineral soil particles	Large, individual particles visible	Medium-sized	Small, individual particles invisible	Absent
Water absorption capacity	Low (prone to moisture deficit in dry conditions)	Medium	High	Very high
Workability	Good in all weather conditions	Good in all weather conditions	Poor in wet conditions	

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