Soil Nutrient Management for Irish Organic Agriculture

1. Introduction

This booklet gives an overview of soil nitrogen (N) phosphorus (P) potassium (K) and pH management in Irish organic agriculture and horticulture. As for many other aspects of organic agriculture, it is not 'a recipe' of how to grow organic crops, but more of a guide on 'how to farm'. It must therefore be combined with other sources of production information as well as farmers own experience to create a nutrient management strategy that is tailored to the climate, soils and production system of an individual farm or holding.

This booklet presents information for all farm types, e.g., pure livestock, mixed farming and pure cropping. A considerable amount of the information is therefore general in nature and more detailed advice may only be applicable to some farm types. The information is also applicable to all forms of farming and growing, non-organic as well as organic. With 2007 and 2008 seeing considerable increases of fertiliser prices, particularly N (which is made from and with 'oil' / natural gas), agricultural techniques, such as recycling manures and using clover for N fixation, which were once the preserve of organic farmers are now finding increasing favour in mainstream agriculture as well.

With organic agriculture only having been a small proportion of total agriculture to date, and with its role as a counterpoint to mainstream farming, the volume of scientific research into organic agricultural techniques is disproportionally small. Therefore, much of the information in this booklet can only be of a more general nature, as the detailed research that is required to make firm recommendations does not yet exist.

This booklet does not state what low, optimum and excess nutrients levels are in terms a quantitative amounts of unit of nutrient per unit of soil (e.g., milligrams nutrient / litre soil) because soil analysis tests vary among the different providers and are updated in light of new research. Instead it describes soil nutrient levels as:

- **low or deficient**, where there would a clear crop response from nutrient application;
- **optimum**, where there is sufficient soil nutrients for strong healthy crops with good yields and adding nutrients is unlikely to improve crop performance;
- **excess or surplus**, where there are more nutrients than needed to produce good crop growth. Adding nutrients will not improve crop performance, it may even diminish it, and may cause environmental pollution, e.g., eutrophication.

Many soil analysis laboratories use a similar approach, often referred to as an index, which simplifies the quantitative laboratory results into more straightforward recommendations whether nutrients should or should not be applied. To gain the most from this booklet it should therefore be used in conjunction with soil test results.

Teagasc also produce a book called “Major & Micro Nutrient Advice for Productive Agricultural Crops” more informally, but better known, as the 'Green Book'. The third edition was published in 2008, and it is highly recommended as a complementary source of information to this booklet. This booklet formed the basis for Chapter 15. 'Nutrient Management in Organic Agriculture' of the 'Green Book'. While, this booklet contains considerably more, and detailed, information on nutrient management for organic agriculture than the 'Green Book', the book contains more information on the plant nutrients, optimum nutrient levels, their management, soil testing and a range of other information. To obtain a copy of the 'Green Book' contact your local Teagasc adviser, local Teagasc office or the Teagasc Head Office in Oak Park, Carlow.

1.1 Healthy soil - the foundation of organic agriculture

Optimising soil health is a key foundation of organic agriculture. Particular emphasis is placed on maintaining good levels of soil biological activity and organic matter coupled with balanced / optimum nutrient levels. Organic agriculture aims to 'feed the soil to feed the plant' by maintaining soil biology and nutrients at optimum levels throughout the rotation rather than the non-organic approach of applying nutrients to feed the current crop to maximise yield. Organics therefore takes 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. As for non-organic farming, the results and fertiliser recommendations of soil tests are tailored to a fields cropping history and soil type to give specific recommendations for each field.

1.2 The organic nutrient dichotomy

Organic agricultural practices contain something of a dichotomy regarding nutrient management. One view is the ‘law of return’ where it is considered essential that any nutrients removed in crops or livestock must be returned to maintain fertility i.e., a balanced nutrient budget. The other view considers the farm to be a ‘closed system’ for nutrients and that they should be carefully (re)cycled within the farm and the need to ‘import’ nutrients is considered a system failure. However, the latter approach does not consider the removal of nutrients in crops and livestock or losses from leaching or to the atmosphere. The scientific evidence is now conclusive, that both must be combined: efficient cycling of nutrients around the farm must be coupled with the law of return (balanced budgets). This means that it is absolutely essential that all nutrients removed from the land in crops and livestock sold ‘through the farm gate’ must be replaced. In addition, while livestock can be highly valuable in assisting the cycling and movement of nutrients around the farm, they do not replenish nutrients. Rather, exactly the same as crops, they cause the depletion of soil nutrients when they are taken off the farm and sold. So, while N can be replaced from atmospheric N (gaseous) via bacterial fixation, P, K, Mg and all the other nutrients, which only exist in non-gaseous i.e., solid or liquid, forms, can therefore only be replaced in solid or liquid forms (e.g., manure and slurry), either as biological matter or permitted mineral fertilisers. There are emphatically no other means of replenishing these nutrients at sub-geological timescales. Failure to replace these nutrients will, within a few years, inescapability lead to soil nutrient deficiency resulting in declining yields and plant and animal health, which is contrary to organic principles.

However, many english language standards are based on the ‘closed system’ concept which has resulted in some standards setting high barriers for importing solid nutrients such as phosphorous and potassium, even though ‘importation’ of the gaseous nutrient nitrogen via legumes is considered indispensable. Despite this dichotomy in certification standards, modern organic agriculture must take a similar high-level position to non-organic agriculture in that all nutrients removed or lost from the farm system must be replaced by appropriate means.

1.1 Feed the soil to feed the plant

With the aim of fertilisation in organic farming being to ‘feed the soil to feed the plant’. The use of soluble fertilisers is restricted as the nutrients they contain can be directly absorbed by plants, which can result in excessive uptake with resulting problems, e.g., lodging, reduced dry matter content, lower nutritional quality and increased susceptibility to pests and diseases. Some soluble fertilisers are more prone to leaching from the soil, leading to eutrophication of water bodies and atmospheric N compound pollution. The unprocessed (raw / rock) forms of mined mineral fertilisers (P and K) also contain small amounts of some micro and trace elements which are removed during processing into the more ‘pure’ soluble forms. This means that micro and trace elements often have to be applied separately when using processed fertilisers while they are supplied as part and parcel of unprocessed mineral fertilisers.

The aim for organically approved fertilisers is to allow biological soil processes (microbial activity) to progressively release the nutrients contained in the fertiliser so plants get a more balanced and continuous supply. Many of these biological processes are temperature dependent, so more plant available nutrients are released during the growing season when the soil is warmer and when plants need them, while less are released in the cold of winter when there is a greater risk of nutrient leaching and many plants are barely growing. This also means that it is not normally possible to get a ‘quick response’ from organic fertilisers, so if a deficit occurs it will take some time to correct. This means that it is essential to have a long-term nutrient strategy, which is also a requirement under organic certification standards. In a nutshell, a nutrient strategy is based on regular, ongoing soil nutrient analysis, coupled with nutrient budgets, which are used to determine the need to apply manures, composts and permitted fertilisers.

1.2 Transformation of soil biology during conversion

The wider aim of soil management in organics is to create a healthy, biologically active soil flora and fauna by maintaining good levels of soil organic matter and minimising soil disturbance caused by tillage. Changing from a synthetic fertiliser regime to one based on legumes for N fixation, manures and mineral fertilisers can considerably increase soil biology, which results in many positive benefits. However, there is significant scientific evidence and farmer experience that this change takes several years and can result in an initial drop in crop yields in the first two to three years of conversion until the soil biological processes have increased sufficiently to support good yields again. This effect has also been documented when changing other production practices, for example from tillage to no-tillage. This effect is important to consider when deciding whether to continue cropping during conversion or to sow pasture. Maintaining cropping has the advantage of continuing income, but has the disadvantage of lower transitional produce prices while yields may be depressed. It is also likely that the soil will take longer to adjust to the new management system than under pasture. Growing a clover based pasture during conversion will help speed soil transformation, but unless there are stock on farm to graze the pasture, it is unlikely to generate any income so will be a financial burden in the short term. Farmer experience indicates that growing pasture during conversion has the greater longer-term advantage.

1.3 Soil analysis and nutrient budgets are the best guide

Whatever type of fertiliser is to be applied, e.g., mineral or manure, application rates must be determined by field-by-field soil analysis coupled with nutrient budgets. It is not appropriate to apply fertilisers and manures ad hoc, as this has the potential to waste valuable and sometimes expensive fertilisers, cause leaching and run off which pollutes waterways, and cause an imbalance of soil nutrients e.g., a high K with low P. Soil tests should be viewed as a long-term strategy and investment with each field being tested every three to five years depending on intensity of production. They should be taken at the same time of year, ideally at the same stage in the rotation. These should be cross-referenced with nutrient budgets for each field, which will give a useful double check if excessive, or insufficient amounts of nutrients are being applied. If the soil tests and nutrient budgets agree, e.g., more K is being applied than removed and K soil levels are increasing then the action required is clear (do not apply any more K until the level drops and budgets balance). If they are at odds, e.g., more P is applied than removed but the P level is decreasing, this indicates a loss from the system, which requires further investigation.

Soil testing is not however a totally precise science. There are a range of tests for the same soil nutrient, which can give differing results, and they vary in their suitability for different soil types. Therefore, swapping among soil tests or testing laboratories will result in unusable information. Consistency is the watchword: choose your soil-testing laboratory and nutrient advisers / consultants and stick with them. Only change if you are seriously dissatisfied.

There are also considerable differences in how well different soils provide nutrients to plants, what their optimal pH is, and how they respond to fertilisers and lime. There is also wide disparity across Ireland on micro and trace element availability with some soils being deficient while others are at potentially toxic levels. In all cases, it is essential to have the tests and advice tailored to your particular soils, which reputable testing services and advisers will do automatically. Where you have a number of different soil types on your farm, especially if some are mineral and others peat (organic) based, then individual soils types are likely to require quite different fertilisation and liming programmes and this must be taken into account when working out a soil sampling strategy.

Soil tests also need to be tailored to the production system. Lower intensity and livestock only farms have lower demands on their soils, and will be less affected by minor nutrient deficiencies. In comparison more intensive arable crops and very intensive horticultural crops can experience sizeable yield and quality reduction due to small deficiencies. On lower intensity farms, testing may only be required every five years with only the basic suite of tests, while three years is considered a minimum for intensive systems with the full range of tests required for horticultural holdings. Soil tests should also be viewed as an investment not a cost. While the tests may seem expensive, the information they provide can potentially increase product yield and quality dramatically which can improve profit many times that of the price of the tests. Soil tests can give some of the best return on investment of any farm expenditure.

1.4 ‘Advanced’ soil and plant analysis

Internationally, particularly in North America and Australasia, considerable emphasis is given by some organic famers, their advisers and scientists to micro / trace elements, cation exchange capacity and the ratios between specific nutrients. There are also specialist soil testing laboratories, which undertake highly detailed soil tests and give very comprehensive fertiliser advice, often for an equally comprehensive fee. While there is scientific consensus that exchange capacity, and the ratios of various nutrients plus pH, are real and important aspects of soil quality and performance, what the optimum exchange capacity, nutrient balances, etc. are, is contested among the various proponents. In addition, the importance of these effects compared with ‘just’ optimising NPK and pH is even more contentious. Furthermore, many of the soils and climates where the research has been undertaken are quite different to Irish conditions and are not directly transferable. Until such ideas are authenticated under Irish conditions it is recommended Irish organic farmers and growers continue to use the same nutrient advice as non-organic producers and focus on optimising major nutrient levels and pH while still ensuring that micronutrients are within prescribed ranges.

1.5 Organic, national and international compliance rules

With soil health being a key focus of organic systems, a significant portion of organic standards relate to soil management, particularly what materials can and cannot be used as fertilisers. Certification has three ‘categories’ that it puts farm inputs into, ‘permitted’, ‘restricted’ and ‘prohibited’. Permitted are allowed to be used without restriction. Restricted are allowed to be used but normally only after permission has been given by the certification agent, and prohibited are completely banned. When deciding which fertilisers to use, whether it is mineral or biological, make sure you are clear which categories each is in and ensure you have the necessary permissions to use them. In addition, Certification standards are constantly changing so the advice in this booklet must be read in conjunction with the latest standards to ensure compliance.

It is also vitally important to check that all planned fertilisation activities comply with national and European Union (EU) legislation and environmental protection schemes, e.g., the Rural Environment Protection Scheme (REPS). Many of these policies are now enacting the types of environmental protection that the organic movement has been advocating for many decades. With the rapid advancement of some of these policies compared with the comparative slowness in progressing EU organic standards, national and EU legislation can now have stronger environmental and societal protection than organic standards, i.e., meeting organic standards does not guarantee cross-compliance with legislation. In any situation, if you are unclear if an activity is allowable under organic or other regulatory systems, it is essential to consult with the appropriate authorities before undertaking the activity.

2. Nutrient sources

The sources of the major and micronutrients for organic farms depend on the nutrient that needs to be replenished. Most are applied as biological material such as manures and composts and/or approved types of ‘mineral’ fertiliser. Most of the mineral fertilisers are minimally processed, mined, fertiliser rock, for example, ground phosphate rock (GPR). Normally, chemical processing is not allowed, however, the rock is typically ground to a sufficiently fine size that biological soil processes can release all the nutrients over a few years.

3. Nitrogen (N)

3.1 Introduction

The primary source of N in organic farming is the fixation of elemental atmospheric N into ammonia by the bacterium *Rhizobium* that live in the root nodules of leguminous plants and also in the soil. Ammonia is rapidly converted into other mineral N forms, e.g., ammonium, nitrate and nitrite by other soil microbes (Figure 1). Nitrite is the primary form in which plants take up N although they can also take up nitrate and ammonium. The mineral forms of N are also converted into organic matter, by both microbes and plants, which is the form in which most N is ‘stored’ in soil. Therefore, growing legumes, in pasture, as green manures and as cash crops is essential for successful organic N management. For example, red clover has been measured as fixing up to 450 kg N/ha/year and white clover up to 420 kg N/ha/year (Table 2) although these figures are from international research and are probably not representative of Irish conditions. A balance therefore has to be struck between exploitative and restorative phases of the rotation to ensure that as N drops during the exploitative cropping phase it is replaced by restorative crops and pasture so maintaining N levels over the rotation as a whole.

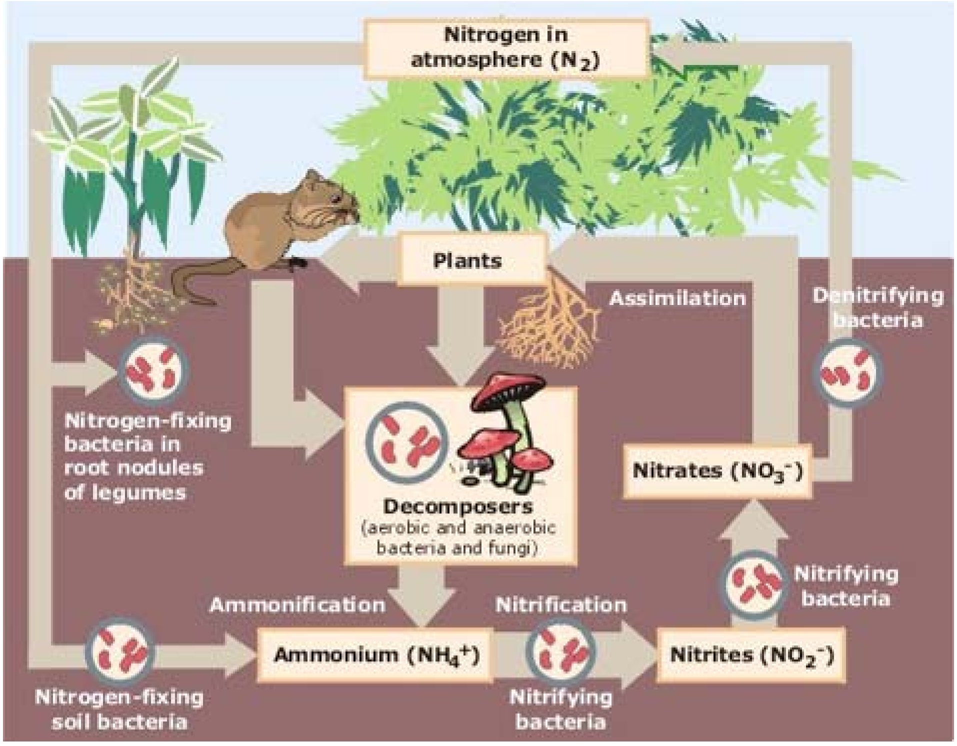

Figure 1. Simplified diagram of the nitrogen cycle (source United States Environmental Protection Agency).

There are legislative and other national and EU level restrictions on the total amount of N that can be applied to the soil as manure, compost and other biological and mineral forms. This is currently 170 kg of N per ha per year of agricultural area used, which includes both applied manures and that produced by livestock while grazing. Figures are provided by government agencies and in organic standards detailing the amount of manure and its nutrient content produced by different livestock types which when combined with stocking rates and amounts of manure applied give the total N application. These are likely to be updated so it is essential to use the most recent versions.

Organic certification also limits the amount of biological material brought onto holdings to replace N. Greater leeway is made for smaller dedicated horticultural units where the absence of livestock reduces the ability to move nutrients from the restorative phase to the exploitative phase via manure. However, horticultural units still face the same national and EU application limits as less intensive operations. There is also the possibility of using more soluble forms of N in intensive horticultural operations, for example, seaweed meals, where a need can be proven to the certification agency. However, such products are also often expensive, so their use is only economically viable on high value crops and in sowing and potting composts. The most economical long-term strategy is likely to have a restorative clover and pasture phase in the rotation.

In all cases, if you are uncertain if what you plan to apply is within the limits please consult a qualified agricultural adviser, your certification agency and/or government agency as appropriate.

3.2 Nitrogen sources

3.2.1 Mixed clover and grass pastures / leys

In mixed and livestock only farming systems, the main source of N is the mixed ley, which is typically based on grass and white clover due to its persistence under grazing. A mixed ley is far more effective at accumulating N and increasing soil organic matter, plus improving soil structure than any alternative, e.g., green manures. A two-year ley will produce more than double the benefit of a one-year ley as clover is slower to establish than annual crops and most of the benefits are gained in the second year. For silage production, red clover can be a better option as it produces more biomass, however, it does not perform so well when grazed as it is less persistent than white clover when regularly defoliated. Red clover also dislikes compaction. Teagasc has conducted considerable research into white clover management in pastures the results of which along with detailed practical guidelines can be found in the "Moorepark Dairy Research Update: A Guide to Management of White Clover in Grassland" most of which is directly applicable to organic farms. This advice is being continually expanded, ask your farm adviser for updates when available.

A key issue not addressed in the white clover guide is how to retain as much N as possible at the termination of the pasture before the start of cropping. A vigorous pasture can accumulate considerable amounts of N, e.g., up to 300 kg N/ha/year, in the form of organic matter, over its lifetime. Therefore, considerable care must be taken when terminating the pasture that large N losses do not occur due to mineralisation (decomposition) of organic matter. A typical scenario to cause this would be tillage using a mouldboard plough, followed by several secondary tillage passes in early autumn, when soils are still warm and biologically active but freely draining water, followed by over-winter fallow. Losses of 150 kg N/ha to the environment could be expected under this scenario, which is a very large financial loss and could cause major ecological harm. Better options include leaving the pasture overwinter, then shallow tillage in spring and planting a crop as soon as possible. If tillage at the end of the season is unavoidable, then the tillage should be minimal and a nutrient trap crop (cover crop), e.g., a winter cereal should be sown. There are national legislative restrictions on autumn ploughing, designed to reduce overwinter N leaching, that must be complied with.

3.2.2 Green manures / cover crops

Green manures are the next most importance N source after pasture. A green manure is a crop that is grown with the deliberate intension of returning it all to the soil. The name and technique is synonymous with 'cover crops', often with the same plant species being used for both. The names indicate the different intensions for the crops – for green manuring the main aim is to increase the N and organic matter in the soil, while for a cover crop, the main aim is to protect the soil and/or retain nutrients. In practice, both types of benefits accrue what ever the principle aim is.

A typical green manure consists of a cereal and a legume in about a 50:50 mix. This will produce the most biomass and can fix more N than a stand of pure legume. This is because the cereal takes up considerable quantities of soil N during growth, which temporally reduces soil available N which in-turn maximises N fixation by the legume. This is because when there is plenty of soil N, legumes minimise N fixation and use soil N instead, because fixation requires considerable amounts of energy and nutrients that could be used otherwise. Low soil N due to the cereal taking it up 'forces' legumes to get most of their N via fixation thereby maximising the total amount of fixed N compared with a pure legume stand that is free to avail of soil N. The two crop species also occupy different ecological niches, which make for better resource utilization, for example, cereals have a fibrous root system, which effectively explores the surface soil layers, while legumes have a tap root system that can penetrate deeper into the soil. Research on crop mixtures has consistently shown that the yield from two or more cultivars or species grown together is greater than the yield from the same plants grown separately and then combined.

Green manures can be planted at any time of year; however, in most cropping systems cash crops will occupy the fields during the summer so the main use of green manures is over the winter. Species and cultivar choice are therefore critical. The species chosen must be able to grow during the cold winter period and ideally fix N rather than just using what is in the soil. However, cold soil and weather are much less favourable to N fixation than warmer summer conditions, so N fixation levels are often low. Green manures can also be sown during the main growing season, especially if there are periods when land would be fallow for more than six weeks. Often very fast growing species are used, e.g., Phacelia (*Phacelia tanacetifolia*) or brassicas such as mustard (*Brassica juncea*). However these species do not fix N so they only have a catch crop effect, i.e., they prevent N loss rather than increase it. Such crops also have limited benefit on soil organic matter and levels, due to their low dry matter content and low C:N ratios. Also, if too much tillage is used in their establishment and destruction, e.g., ploughing, then this is more likely to reduce soil organic matter and N levels than to increase them, due to the loss of organic matter, and therefore N, caused by soil disturbance / tillage.

On mixed farming systems where there is a restorative pasture phase followed by an exploitative cropping phase, green manures can help extend the cropping phase, but in most cases they will add considerably less N to the system than the pasture phase. They are therefore valuable additions to the system but are unlikely to be essential to its success. Therefore, less expensive, but potentially less productive green manure options can be used. For systems without a pasture phase, e.g., stockless arable or horticulture, green manures and crop residues will be a key source of soil N and therefore should be primarily selected on performance and looked after as well as any cash crop, to ensure that the best results are obtained. Even so, it is difficult for such systems to achieve a balanced N budget from green manures alone. Brought in N sources, typically manure or compost may be required, which are often expensive. The alternative is to take land out of production and into mixed pasture that is then managed (e.g., by mowing) to maximise pasture growth and nitrogen fixation. However, this approach is not without its problems, due to it removing land from production plus the cost of maintaining the pasture. Overseas, farmers who have attempted such stockless rotations have often found that they are better off re-introducing stock to their systems as it is more profitable in the long term.

3.2.2.1 Returning green manures to the soil: grazing vs. mechanical destruction

To be useful, green manures have to be killed and the nutrients within them returned to the soil in time for the following cash crop to take advantage of them. There are two main approaches, grazing or mechanical destruction, for which there are pros and cons for both.

Grazing has the advantage that it breaks down the above ground plant matter in the livestock's digestive tract far quicker than soil organisms could, so there is a quicker turn around between terminating the green manure and planting the following cash crop. This is even more critical with green manures that have a higher carbon:nitrogen ratio, i.e., they contain more woody / strawy material. This is because soil organisms need N to decompose the plants, which if there is insufficient within the plant tissues, they will have to use soil N. Soil organisms outcompete plants for soil N, which results in a temporary N shortage called 'nitrogen robbery'. Grazing reduces this problem as the decomposition takes place in the animals gut, a good deal of the carbon (C) component is lost from the animal as carbon dioxide (though breathing) while much the N is returned to the soil in dung and urine. The exact amounts will depend on the type of stock, with growing or milking stock removing considerably more nutrients than stock just maintaining weight. Other advantages of grazing off green manures are that it requires no machinery, saving fuel, labour costs as well as machinery wear and tear. The green manures can also be useful feed.

The N in fresh dung and especially urine (i.e., urea) is more soluble, is produced in larger quantities so is therefore, more available to plants than the forms of N produced by soil organisms decomposing the same material. This means that N, and other nutrients, from grazed green manures are likely to be more rapidly available for the following crop, giving it an early boost that it is less likely to get from green manures decomposed by soil microbes. This can be particularly valuable in spring when N availability in soil is often quite limited due to low soil temperatures restraining the rate of N mineralisation. However, if conditions are wet or the land is unplanted after grazing then the N could be lost and end up in ground water via leaching or streams and rivers via run-off. This is clearly an undesirable loss of N from the farm and potential environmental pollution, so must be avoided.

The other key negative effect of grazing is that it will not boost soil organic matter or biological activity as much as mechanical destruction. The green manure crop contains not only nutrients but also energy that the plants have gained from sunlight. This energy content can be considerable, for example, in the old days, the heat from burning cereal stubble showed how much energy was stored in the straw. Soil organisms, like all organisms, need energy as well as nutrients to thrive. If the green manure is grazed off then much of the energy in it is used by the livestock, even if most of the nutrients are returned to the soil. This lost energy is then unavailable to the soil microbes so they cannot grow and multiply nearly as much as if they had 'dined' on the green manure directly. As noted above, much of the carbon content of the green manure will be excreted from the livestock as carbon dioxide, which means it will also be unavailable to soil organisms, which will further reduce soil organic matter because carbon is a major constituent of organic matter along with hydrogen. Therefore, the loss of energy and carbon due to grazing is likely to lead to a less biologically active soil than had green manures been directly returned to the soil. Grazing off green manures is therefore something of a ‘double edged sword’. It can be beneficial under the right conditions and harmful under the wrong conditions. Care and forethought must therefore be given to its use.

Mechanical destruction typically involves using a mower to cut down and/or pulverise the green manure foliage typically followed by some form of soil incorporation. Mowers that leave the green manure in a swathe, e.g., silage mowers, are not ideal as this results in an uneven distribution of the foliage across the field resulting in uneven soil nutrition, which can result in problems in the following crop such as uneven ripening. Also, green manures that are left mostly whole will take longer to decompose and release nutrients to the following crops. Flail mowers that pulverise and spread the green manure more evenly across the field surface will minimise the chance of uneven nutrient spread and speed decomposition due to the much greater number of sites that microbes can quickly attack the plant’s tissues. This is at the cost of greater fuel use and often more expensive machinery.

Traditionally the view was that plant material left on the soil surface was ‘wasted’, the name ‘trash’ indicates its perceived low value. It was thought that the soil microbes could not ‘get at’ the material to decompose it, and therefore it should be incorporated into the soil, traditionally by ploughing. Research over the last forty odd years into no-till and conservation agriculture, which is widely used in the Americas and Australasia, has demonstrated that incorporation of plant residues into the soil by tillage frequently results in a net reduction of soil organic matter and lower soil health. This is because tillage causes considerable decomposition of soil organic matter due to the introduction of large amounts of oxygen into the soil. This often releases N and C (organic matter) in larger quantities than is gained from the incorporated residues. Continuous no-till cropping can restore soil organic matter to levels equivalent to, or even higher than, permanent pasture, and dramatically improves soil health, particularly soil structure and earthworm populations. Therefore, to maximise the benefits of a green manure it should be left on the soil surface or tilled into the soil surface as shallow as possible, i.e., only use the minimum amount of tillage.

However, high levels of crop residue on the soil surface can cause problems for later operations, notably drilling and weeding, e.g., clogging of drill coulters and hoe blades. If the green manure is still sufficiently young and green, with a low C:N ratio, so that it will rapidly decompose, then destroying the green manure a few weeks in advance of needing to drill may give sufficient time to allow it to break down sufficiently that it will not effect later operations. For materials with a higher C:N ratio or where a faster turn around is required it may be necessary to ensure that the material is chopped as finely as possible when being mown off, and then worked into the soil surface with the minimum number of passes. Materials that have a C:N ratio higher than 20:1 are at risk of causing N robbery as soil organisms temporarily use up soil N to decompose the high C compounds, after which the N is made available again as the decomposers themselves die. Above 30:1, robbery is highly likely. Table 1 gives some examples of the C:N ration of a range of materials.

Table 1. Carbon:Nitrogen Ratios for a range of materials (Source Aggie-Horticulture Network of the Texas A&M University System)

Material	C:N
Food scraps	18:1
Lucerne hay	10:1
Grass clippings	12-25:1
Coffee grounds	20:1
Vegetable trimming	12-20:1
Cow manure	20:1
Horse manure	25:1
Horse manure with litter	60:1
Rotted manure	20:1
Poultry manure (fresh)	10:1
Poultry manure with litter	18:1
Leaves, varies	35-85:1
Peat moss	58:1
Straw	80:1
Farm manure	90:1
Newspaper	50-200:1
Sawdust, weathered 2 months	625:1

Where residue with high C:N ratios have to be tilled in (rather than grazed off) and planted soon afterwards then ploughing may be the only practical option.

3.2.3 Leguminous cash crops

While leguminous cash crops can fix substantial amounts of N, much of the fixed N is often removed in the harvest (many legume seeds are high in protein, which is itself high in N). Generally leguminous crops should therefore be treated as N neutral or contributing only moderate amounts of N, e.g., 50 kg/ha. Table 2 gives a few examples of the maximum and minimum amounts of N fixed by crops and pasture and the amount remaining after harvest. These are collated overseas figures so should not be taken as representative of Ireland. From the perspective of N management, it is better to grow legume cash crops towards the end of the rotation when soil N will be lower, as this will promote the plants to fix more N than if they were grown at the start of the rotation where soil N is higher.

Table 2. Examples of the amount of N fixed per hectare per year by mixed pasture and two crops and the amount remaining after harvest (overseas figures, not necessarily representative of Irish conditions).

Crop	Amount fixed kg N/ha/yr	Amount remaining after harvest kg N/ha/yr
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	80 to 290	40 to 110
Field been grain crop	200-380	90-150

3.2.3.1 Legume disease management

There are a number of soil borne disease of legumes e.g., sclerotinia rot (*Sclerotinia trifoliorum*), *Fusarium* and *Pythium*. General recommendations are that where the diseases are present, rotations of four to five years are required between susceptible crops. As there are a number of leguminous cash crops, this could potentially severely limit green manure, fodder and cash crop choices. However, most of the data on rotational break durations are anecdotal. Most experiments have been based on non-organic cropping systems where soil microbiology is often lower than organic soils and higher microbial activity is linked to increased disease suppression. While some pathogens attack a wide range of plant species other are restricted to a much smaller number, and there are increasing numbers of cultivars with good disease resistance characteristics. In short, there is simply too little research to make firm management recommendations. If there is a known problem on your farm, it will be best to get expert advice to correctly identify the pathogen(s) responsible, give you sound information on its lifecycle and hosts, so that a tailor-made solution for your farm system can be worked out. This is likely to involve some trial and error, however, there is evidence that even difficult diseases, such as sclerotinia, can be effectively managed by a good rotation.

3.2.4 Slurry, manure, compost: sources, application methods and dates

On-farm produced livestock manure and slurry can be valuable sources of N, especially for early season pasture growth. This is because white clovers need temperatures above 20°C to grow vigorously and fix significant amounts of N, so Irish spring soil temperatures are too mostly to cold for white clovers to meet grasses' high N demand in spring. Slurry and manures can therefore help meet this spring N requirement shortfall.

Slurry application should avoid spraying it into the air, e.g., using splash plates, as research shows that this increases the loss of more volatile N compounds, e.g., ammonia, to the air, especially in hot, dry and windy weather. Alternatives, such as the trailing hose and trailing shoe, are superior for maximising N retention. For example, research has shown a 20% improvement in grass yield between using the trailing shoe over a splash plate. Also by placing the manure on or in the soil, it reduces pasture contamination making it possible to graze sooner as the pasture is more acceptable to stock. However, care needs to be taken when applying solid manure to ensure it is thoroughly broken up and incorporated into the base of the pasture, e.g., by using a harrow, due to the risk of diseases such as salmonella. Hot composting such material at a sustained temperature above 60°C for at least seven days will kill most pathogens. This should be undertaken where fresh manure is to be spread onto fields that will be grazed in the following weeks.

Brought-in slurry, manure, composts, and other biological materials, e.g., food processing wastes, are also potential N sources. However, there are a number of restrictions on these materials outlined in the section on brought in biological materials below, the key one of which is that they must be aerobically (hot) composted which reduces their C and N content. Generally, the fresher the material the higher its N content will be, i.e., freshly dead plant material and slurry contain significantly higher N than after they have been composted. There is also growing evidence that fresh material, particularly undecomposed plant residues left on the soil surface, are better for soil health and earthworm populations than the same material after being composted. This is because much of the N carbon and energy in the original material is lost to the atmosphere in the form of ammonia, carbon dioxide and heat as part and parcel of the decomposition process. Therefore, the more complete the composting process, the less valuable an N and energy source it will be. Ammonia gas is also a significant environmental pollutant, although, fortunately it is not a greenhouse gas. Therefore, there is increasing evidence that the pros and cons of composting, compared to using material in a less decomposed state, need re-evaluation.

For example, one research project that has looked at some of these issues was a study of the comparative benefits of compost ('true' aerobically produced compost, not cold stacked material), FYM (farmyard manure) and slurry on pasture growth under Irish organic management. The results showed that slurry was best applied in spring (in agreement with current best non-organic slurry recommendations) as the N was rapidly taken up by the pasture and used for growth before clover was active enough to fix much N. Slurry applied in summer or autumn was less beneficial for pasture growth than FYM or compost. FYM could be applied in spring, summer and autumn getting a similar response at all three times but was less effective than spring applied slurry or autumn applied compost. Compost produced the best result when applied in autumn but underperformed spring applied slurry and spring and summer applied FYM. This indicates that different forms of manure should be used in different seasons to maximise pasture production.

4. Phosphorus (P)

Phosphorus is a key nutrient for the *Rhizobium* bacteria that fix atmospheric N into soil mineral N, so good P levels are critical for maximising N fixation.

The main sources of P on organic farms are on-farm produced manures, slurry and other biological materials. It is therefore important to utilize this resource where it exists and certification standards stipulate than the primary source of P should be from on-farm manures. However, the P content of manures varies considerably, for example 0.1% for watery slurries to 1.4% in turkey litter. Brought in feed and straw also contains P, for example, wheat straw can contain 0.15%, barley 0.25% and oat 0.22% P, and their grains contains around 0.4% P. The nutrient content of such materials should be included in nutrient budgets. Further details on manures and other biological materials are given below.

The main mineral source of P available in Ireland is natural rock phosphate called ground rock phosphate (GRP) that has a P content of around 13 to 40% depending on source. This should be generally available as it is used by the forestry industry, however, it may not be stocked by farm fertiliser merchants and may have to be ordered in. GRP is not suitable for soils above 7.5 pH as they are insufficiently acid to decompose GRP and release the phosphate. Organic standards recommend calcined aluminium phosphate rock for soils above pH 7.5, however, this is not currently available in Ireland and would have to be ordered from the United Kingdom. In this situation, specialist advice should be sought. However, clover is known to acidify the area around its roots which assist it absorb soil P, which means that GRP may decompose above pH 7.5 under clover rich pasture. Unfortunately, there is little research studying this effect, so no advice regarding it can be given.

GRP contains about 35% calcium (Ca) which helps balance the acidifying effect of the P compounds. This means that most GRPs have little effect on soil pH. This contrasts with super-phosphates, which have an acidifying effect. GRP also contains useful amounts of some trace nutrients.

GRP is a slow release fertiliser as the P and calcium are released by soil acids and biological activity. About a third of the P is released each year, which means that it takes about three years to decompose fully. This also means that it takes at least six months to a year for the fertilisation effect to be seen. This is in contrast with super phosphates, which are water soluble, rapidly plant available and give a quick crop response. This delayed fertilisation effect must therefore be planned for, with the GRP applied a year before the P is required. The slow release action can also help reduce P loss to the environment.

Phosphate rocks naturally contain heavy metals, particularly cadmium, in varying amounts. Certification standards require that lower cadmium content rock should be used and depending on quantities used, soil analysis may be required to ensure that cadmium levels in soil do not build up.

Basic slag is a restricted input for P, K and micro nutrient sources in organic agriculture. However, some forms / sources are prohibited and the P level content can be quite variable, to the point of containing only traces of P. Always consult your certifier before purchasing or applying basic slag and ask for a full nutrient analysis of the product.

5. Potassium (K)

As for P, the main source of K is on-farm produced manures, slurries and compost, which have K values ranging from 0.2% for cattle manure to 2% for poultry manure. Brought in materials, such as manure and compost as well as production inputs such as feed and straw can contain useful amounts of K, for example, grain contains 0.4 to 0.6%, with straw containing 8 to 15% K depending on species and K status of the soil they were grown on. As for all other nutrients brought in materials should not form the basis of an organic farm’s nutrient sources, rather effective internal cycling should be the main approach, supplemented with brought in materials to balance those lost from the system. For K this is principally in crops and livestock as K does not readily leach from soils. As for P, detailed records of all K sources and losses must be recorded to allow accurate nutrient budgets to be compiled.

Alternative sources to biological materials include wood ash, which has around 1 to 7% potash, and is permitted under certification rules. However, it must be mixed with compost or manures, the wood must be untreated and sources are limited. The increased interest in wood chip and other biomass boilers may see this situation change.

If K soil levels are lower than the desired value and on-farm sources are insufficient to meet needs, an application to the certification agent to use potassium sulphate (K_2SO_4), more commonly referred to as sulphate of potash (SOP), must be made. However, ongoing use of SOP may be restricted depending on circumstances. There are a limited number of SOP supplies in Ireland.

- Sulphate of potash K_2SO_4 (SOP) (a generic and widely available product)
  41% K (as 50% K_2O / potassium oxide)
  18% S (as 45% SO_3 / sulphur trioxide)
- Sulphate of potash with magnesium and sulphur: (e.g., Patentkali ®)
  25% K (as 30% K_2O / potassium oxide)
  6% Mg (as 10% MgO / magnesium oxide)
  17% S (as 42.5% SO_3 / sulphur trioxide)
- Sulphate of potash with sodium and sulphur (e.g., Magnesia-Kainit®)
  9% K (as 11% K_2O / potassium oxide)
  3% Mg (as 5% MgO / magnesium oxide)
  20% Na (as 29% Na2O / sodium oxide)
  4% S (as 10% SO_3 / sulphur trioxide)

The two propriety products, Patentkali ® and Magnesia-Kainit®, have EU level organic approval at the time of writing while SOP may require case-by-case certification agent approval depending on source. It is essential to check the current approval status before purchasing and/or using such materials.

All three forms are highly water-soluble so they will be rapidly taken up by any plants present before the K is absorbed into the soil. Potassium leaching is less of a problem than P and N, except if applied under very unsuitable conditions, e.g., where there is active surface run off.

6. Lime and pH

The maintenance of optimum pH is as, if not more, important in organic production 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 6.2 to 7.0. High organic matter levels also helps dissolve rock phosphate due to the presence of biological acids.

Most sources of lime are permitted in organic systems, but it is important that the particular product to be used is either organically certified or that your certifier confirms that the source is permitted. Similar to rock phosphate, lime is relatively insoluble and the calcium and other constituents have to be released by biological decomposition, which means it is released slowly, often over five years or more. The finer the lime is ground the quicker it will decompose and the quicker it will raise pH. However, finer material is more expensive and difficult to apply (it blows away), so that in most cases it will be more economic to apply larger amounts of courser material to rapidly rectify high pH than smaller amounts of finer material.

Determining when to apply lime to maintain an optimal pH is achieved by the use of regular soil testing, just as for soil nutrients. With lime taking several years to have its full effect on pH it needs to be used ‘pre-emptively’ before pH drops too low.

7. Optimal nutrient levels in organic vs. non-organic soils

There is increasing evidence, both scientific and on-farm experience, that organic soils can successfully produce quality crops at lower P and K levels than non-organic soils. However, the level of this effect and its causes are not well understood nor have they been sufficiently studied under Irish soil and climatic conditions. Both P and K exist in soils in three ‘forms’: ‘plant available’ which can be directly taken up by the plants, ‘medium availability’ which are not directly available to plants, but which can be altered to become plant available over a relatively short period of time and ‘slowly available’, which requires a long time (years to millennia) to become plant available. There is constant flux between these three different forms, for example if excessive amounts of P are applied to a soil, some of it will change into less available forms and visa versa, if the level of available K decreases, then the less available forms will change to the readily available form. It is possible that more biologically active organic soils mediate more rapid movement of K and P between the different forms and/or allow plants greater access to the less available forms of the nutrients, for example, organic soils have been found to have more mycorrhizal associations which are known to assist plants to take up more nutrients or make use of the less available forms of P and K in soils (mycorrhizal associations are where plant roots have a symbiotic (mutually beneficial) relationship with a fungus that lives inside or on the surface of the roots, the plant provides the fungus with carbohydrates and energy and the fungus provides the plant with water and soil nutrients that the plant cannot get for itself). It is therefore possible that fertiliser and nutrient advice for non-organic soils may not be optimum for organic soils. However, the detailed research required to give firm advice in this area is yet to be undertaken. In the interim, farmers should continue using the standard nutrient advice.

8. Brought in biological materials

8.1 Certification and legal requirements

Biological materials from certified organic sources and untreated wood products are permitted, with standards often requiring that material is composted or aerated. The use of the same type of materials from non-organic sources is more restricted. They must not form the basis of a manurial program, except in exceptional cases, e.g., intensive horticulture. However, they can be adjuncts (i.e., supplement) to internal nutrient cycling within a holding. Standards also prohibit biological material from intensive livestock systems (on welfare grounds) and animals fed transgenic ('genetically engineered') feed. Human sewage sludge is also banned due to contamination by industrial wastes, particularly heavy metals. Other non-certified materials may be permitted however, they will have to be aerobically ('hot') composted and/or treated as per certifier specifications. Compost produced from household waste that is not certified at source will have to be tested for heavy metal contamination. Considerable detail is given in organic standards about the different non-organic sources and treatments required, but essentially any material that would traditionally be considered as a useful biological source of nutrients is allowed (with the above exceptions) after notification to the certifier and completing the treatment they require.

National and EU legislation and environmental protection schemes also have a number of requirements when it comes to handling and applying manures and other biological products that must be adhered to in addition to certification standards. If you are unclear over what is permitted and prohibited it is essential to clarify the situation with your certification agent and/or appropriate government department.

8.2 Sources of materials

Sources of biological materials are diverse, ranging from the traditional sources, e.g., farmyard manure (FYM), to non-traditional sources, such as composted household waste (kitchen and garden), and food processing wastes, e.g., the 'grounds' from instant coffee production or meal from oil extraction. Due to their bulk, transport costs can represent a considerable proportion of their total cost, so they are generally best sourced locally. It is therefore not possible to give detailed information on where to source them, but it can be worthwhile looking beyond traditional agricultural sources to other, particularly food processing, industries.

Commercial composts also vary considerably and research has shown that if incorrectly made they can even suppress crop growth rather than promote it. Ask the manufacturer what kind of quality control systems and guarantees they have and what compensation they offer if the compost fails to perform as stated. A good manufacturer should happily 'stand behind' their product. Organic certifiers are likely to require that commercial composts that are not certified at source be tested for pesticides, heavy metals and other contaminants. It is therefore critical to talk to your certification agent if you are considering using a new source of nutrients to see what compliance issues there will be.

The use of other biological sources of nutrients that are not manures or waste biological materials should also be considered. For example, animal bedding, e.g. straw, and feed can contain appreciable quantities of nutrients, as discussed above. When such materials are brought into a holding, their contribution to the nutrient budget must be taken into account.

The lists of permitted fertilisation materials in organic standards over the years have included a number of unusual materials e.g., kali vinasse and guano. Most of these lists originated in early standards and were designed to be exhaustive descriptions of allowed materials, i.e., anything not on the list was prohibited. However, despite their inclusion, many, if not most, have never been widely available, if at all. It is considered highly unlikely that any time or money spent trying to locate such materials will be rewarded.

8.3 Variable nutrient content

Biological sources also vary widely in their nutrient content both between sources and between different batches from the same source. It is therefore important to test the nutrient content of products where there are no general guidelines for their use or where there is likely to be considerable variation between batches. Many soil nutrient testing facilities can also analyse the nutrient content of biological materials. Nutrient content of farm produced manure, slurry and compost also vary considerably. To ensure the most accurate nutrient budgets, farm-produced manures should be tested every few years rather than relying on the averages given in official information.

8.4 Handling of manure, compost and biological materials

Animal manures, composts and brought in biological materials must be handled carefully to minimise nutrient losses. The primary cause of nutrient loss, mainly N and K, is due to rain exposure. Biological material must therefore be protected from the rain, for example, by being in a shed, under plastic sheeting or other suitable rainproof covering. However, tight fitting, air proof covers, such as plastic sheets, can impede airflow into and out of material that is undergoing rapid aerobic 'hot' composting. These are mostly best left uncovered until the composting process is finished unless there is so much rain that the compost cannot absorb it. Storing biological material in fields and/or on soil, is not recommended due to the potential for leaching and environmental pollution. Ideally, material should be stored on an impermeable base that allows the collection of any liquids produced. Silage pits and stock sheds are well suited for this, however, silage pits must be thoroughly cleaned before being used for silage.

There is a range of National and EU level legislation covering the storage and use of biological manures which are often 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.

9. The role of rotations in nutrient management

Rotations are a key technique for managing overall nutrient supply on organic farms, particularly for mixed and stockless systems. The clover-grass ley is the most important fertility-building phase, principally for nitrogen, but it is also an appropriate time to be applying P and potentially lime. 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 conversion into biological forms that will feed the following crops. Likewise, applying lime at the start of the pasture phase allows it to be incorporated into the soil by tillage and it allows time for it to be converted from mineral to biological forms while optimising soil pH under the ley, thereby maximising pasture productivity. 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 risk of lime damage. Putting lime on at pasture termination risks over-stimulating organic matter mineralisation in addition to that caused by tillage, which could result in substantial nitrogen losses.

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 converted to biological forms or entering 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, e.g., root crops.

The cropping sequence following a ley starts with the most N and other nutrient demanding crops, typically wheat, maize 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 manures (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 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 in the N section (above).

Unless a straightforward rotation is being followed, 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 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. Rotations are therefore not pre-ordained and fixed, but highly flexible and changed on a yearly basis.

Where insufficient soil nutrient replacement has taken place, and soil nutrient or pH levels have fallen too low, speedy action to replace the depleted nutrients must be taken. Probably the best option in such situations is to establish a grass clover pasture rather than attempting to crop depleted land. This is because yields and the nutrient content of crops are likely to be poor, the latter is clearly contrary to organic standards and the former means that profit will be reduced. It is also likely to be harder to rectify nutrient deficiencies under crops that are predominantly removing nutrients compared to pasture where removal will be lower and livestock assist with nutrient cycling through dung and urine. Other issues that make pasture the preferred crop when rectifying nutrient deficiencies are nitrogen fixation by clover, soil structure improvement by grass roots plus the absence of tillage, all of which will help build organic matter and biological activity resulting in most cases in faster improvement in soil health than under cropping. However, if soil nutrient deficiency is severe, great care must be taken to ensure stock do not also develop nutrient deficiency, e.g., by providing supplementary fodder and/or mineral licks, the latter must however be approved by your certifier.

10. Conclusion

In keeping with the key aim of organic agriculture of maintaining a productive and biologically active healthy soil, nutrient levels and pH are maintained at optimum levels across the whole rotation. These levels are determined by regular field-by-field soil tests and nutrient budgets. Soil tests and budgets provide the information to establish the best fields on which to use farm produced manures and, where necessary, where to use bought-in biological and mineral fertilizers to replace nutrients exported in crops and livestock or lost to water or the atmosphere. If this is not done, productivity and soil, plant and animal health will inevitably decline. Where nutrients are well managed, soil, plant and animal health and productivity will be at their best, in full accordance with organic aims and principles.