Soil and nutrient management on organic farms

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What is this booklet about?

Management of soil fertility is one of THE major challenges facing the organic farmer. Soil fertility needs to consider soil nutrient status, soil physical condition and biological 'health' of the soil.

Organic farming aims to build up, or at least maintain, soil nutrient reserves whilst at the same time maximising nutrient recycling and reducing external inputs. Only skilful management can address this apparent conflict.

Efficient management of nutrients, soil structure and soil biology should ensure good yields of crops and healthy animals. Poor management can result in poor yields, poor animal health and increased environmental pollution.

This booklet provides:

- Information on the underlying scientific principles behind soil fertility in organic farming systems.
- Practical advice on managing soils in organic systems to maintain soil fertility.

This booklet draws on scientific research undertaken in the last 10 years, much of it in the UK, and most of it funded by Defra.

Contents

Summary

Management to optimise nutrient recycling and the maintenance of all aspects of soil fertility include:

The use of carefully planned rotations -

Develop crop rotations that take account of the nitrogen supply from legumes. Match 'fertility building' and 'fertility depleting' phases of rotations to ensure that enough N is available in the rotation to sustain the levels of yield that are anticipated. Crop sequencing in the rotation should aim to match N release and timing to crop uptake demands.

Think field AND farm

Nitrogen can be transferred around the farm, e.g. where forage is harvested from one field, fed to animals and the manure spread on another field. Use farm and field nutrient budgets to assess the sustainability of the system and avoid the depletion of N from one area of the farm and excess loadings in other areas.

Frequent return of organic matter to the soil (e.g. legumes, manure and crop residues)

Fresh organic matter provides nutrients (particularly N and P) and benefits soil physical condition and biological activity. Soil benefits from regular additions. Manures are a useful way of transferring nutrients (and fertility) around the farm.

Using supplementary nutrients only when absolutely necessary

A well designed and managed crop rotation, where losses to the environment are minimised, should not require too much support from supplementary nutrients. There will be exceptions, perhaps on light textured soils or soils that start with low inherent fertility.

Use of cover crops and catch crops wherever possible

Well-grown cover and catch crops can retain nitrogen that might otherwise be lost (by leaching). Hold on to valuable nutrients. They also provide a source of fresh organic matter.

Maintenance of soil drainage and soil pH

Looking after the soil has huge benefits. Inspect soil structure regularly. Look for tell-tale signs of problems: wet patches, areas of poor crop growth and find and correct the cause. Beware acid patches developing in fields. Lime as appropriate. Good soil drainage and pH benefit soil biological activity and nutrient cycling.

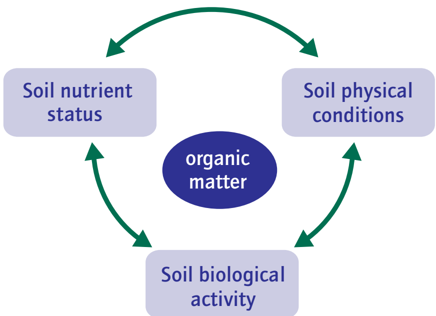
Adopting appropriate soil cultivation methods and timeliness to maintain soil structure (i.e. optimising for soil biological activity)

Many factors will determine when a soil is to be cultivated, and how it will be cultivated. Sometimes, the practicalities of needing to cultivate will override other factors; beware of the long-term damage that cultivating in wet conditions might cause and take steps to minimise occurrences.

What is 'soil fertility'?

- The interaction of biological, chemical and physical attributes: not just how much nutrient is in a soil.
- The key word is 'interaction': enhanced biological activity improves nutrient recycling and soil structure; good structure benefits biological activity.
- Organic matter is central to good soil fertility management.

'Soil fertility' can be considered to be a measure of the soil's ability to sustain satisfactory crop growth, both in the short- and longer-term. Organic farming recognises the soil as being central to a sustainable farming system. Soil fertility is determined by a set of interactions:



Organic matter is essential for soil fertility. It maintains good soil physical conditions (e.g. soil structure, aeration and water holding capacity). It also contains most of the soil reserve of nitrogen (N) and large proportions of other nutrients such as phosphorus (P) and sulphur (S).

Important: soil fertility is markedly affected by quantity and quality (type) of organic matter.

Organic rotations avoid inputs of water soluble ('readily plant available') nutrients. Organic farming therefore relies on:

- Release ('mineralisation') from organic residues or from native soil sources.
- Solubilisation of insoluble fertiliser sources (e.g. rock phosphate).

Here, soil organisms (e.g. bacteria, fungi, earthworms and a whole range of organisms - the soil microflora, macro- and micro-fauna) are an essential part of the system, helping to release and recycle nutrients.

Organic farming relies on sound crop rotations to include **fertility building** and **fertility depleting** stages, returns of **crop residues**, **nitrogen fixation** by legumes/Rhizobium, nutrient retention by **green manures** and effective use of **manures/composts**. Certain other materials, which are essentially slow release nutrient forms, are also permissible under various organic certification schemes. The emphasis is clearly on efficient nutrient cycling, especially as the import of manure on to organic farms is being looked upon less favourably.

Important: the changes that organic management should aim to bring about are:

- **An increase in soil nutrient reserves.**
- **A change in processes of soil nutrient supply.**
- **Changes to the soil physical attributes.**

How organic farms are 'different'

- Organic farming aims to create an economically, socially and environmentally sustainable agriculture.
- The emphasis is placed upon self-sustaining biological systems, rather than reliance on external inputs.
- Organic farming is much more than simply replacing synthetic inputs with natural ones, though it is often described as this.

The International Federation of Organic Agriculture Movements (IFOAM) defines organic agriculture as "*... a whole system approach based upon a set of processes resulting in a sustainable ecosystem, safe food, good nutrition, animal welfare and social justice. Organic production therefore is more than a system of production that includes or excludes certain inputs*".

Legal aspects

Organic farming is a legally defined production system within the EU (Council Regulation (EEC) 2092/91). Each Member State has to establish a competent authority to implement the regulation. The UK, authority is the Advisory Committee on Organic Standards (ACOS), which provides baseline organic standards for the UK. ACOS has approved10 private UK Certification Bodies (see Appendix I) to implement and police the regulation. These register organic producers and processors and monitor operations to their own organic approved standards (based on, and with, the ACOS basic standard as a minimum) through a routine and spot inspection system. In all cases, it is the system of production and produce from that system that is being certified.

Organic conversion

To be legally registered as an organic producer, the land or processing unit used for production must be registered with one of the ACOS approved Certification Bodies. For land to be classed as 'organic' it must typically undergo a 24 month 'conversion' period during which no prohibited substances (fertilisers, herbicides, insecticides, etc) can be applied to the land. During the conversion, the land is farmed under organic principles and standards, but any produce from the land is not certified as organic and cannot be sold as organic, although it may be identified as 'in conversion'. It is the responsibility of the Certification Body to monitor and inspect the producer on a regular basis to ensure that the producer is complying with organic standards.

Main features of organic farms

- Concept of recycling, less reliance on external inputs
- Often lower levels of nutrients with the challenge of making nutrients available when the crop needs them
- Greater emphasis on the whole-farm system (rotations, matching crops to differing levels of fertility through the rotation)
- Often, but not necessarily, a wider range of enterprises and more mixed systems
- Evidence or otherwise of differences in biological activity/functioning
- Supported by legislation (the only system of production that is legally defined)

'Fertility building'

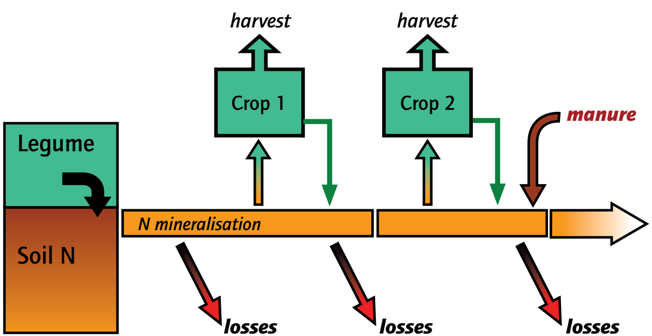
- Rotations rely on fertility building and depleting phases.
- Legumes are the main source of nitrogen.
- Manures/composts are valuable sources of nutrients.
- It is essential to minimise losses of nutrients to the wider environment.

Building soil fertility

Nutrients can be imported onto organic farms by several routes:

Nutrient sources	Nutrient losses
• Fixation of atmospheric N	• Nitrate leaching
• Purchased feed stuffs	• Ammonia volatilisation
• (Cover crops)	• N_2 and (NOx) emissions
• Imported manure/compost	• Crop/animal produce
• Rainfall	• Exported manures

However, the cornerstone of the organic philosophy is the use of alternating **fertility-building** and **fertility-depleting** phases:



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Important: it is especially important to minimise losses of nutrients from the soil to the wider environment. This helps to maintain the efficiency of the organic system.

Nitrogen

Organic farming aims to be self-sufficient in N through fixation of atmospheric nitrogen (N_2), recycling of crop residues and careful management and application of manures and composts. As well as legume-based leys, organic rotations often include an extra N boost by growing a legume (for example, field beans or peas) during the fertility depleting phase. However, it is the legume-based ley that is the most important element of fertility-building.

Fertility building crops

Typical crops under UK conditions include **red clover**, **white clover**, **vetch**, **lucerne**, **sanfoin**, sown as pure stands or **grass/clover leys** (white clover or red clover sown in combination with perennial ryegrass), **peas** and **beans**. **Lupins** and **soya** are also being used in southern Britain. Recent work in NE England has indicated that two new legumes may also be suitable: lentil (*Lens culinaris Medik.*) and pinto bean (*Phaseolus vulgaris*).

Nitrogen supply to the following crops relies on **mineralisation** of the residues that have been accumulated during the fertility-building phase. Captured N can also be returned to the soil as manure, either directly by grazing animals or indirectly in handled manure produced by animals that have been fed on leguminous forage or grains exported from the field. Other aspects of fertility-building crops also influence the design and performance of rotations, particularly the effect of pests, diseases and weed management during the fertility-building phase and implications for the following crops. These effects may be:

- detrimental - e.g. clover and lucerne could increase the risks of *Sclerotinia trifoliorum* for field beans.
- beneficial - e.g. green cover may reduce incidence of common scab of potatoes to the rotation or help to suppress and out-compete weeds.

Important: issues of likely pest, disease and weed population impacts on rotations also need to be incorporated into planning advice.

Organic matter

Additions of organic matter occur from the ley phase of rotations and from green manures, crop residues, animal manures and composts. The benefit of these additions depends on the amount and quality of organic material added. Grazed or mulched crops will add more organic matter to the soil than where crops have been harvested and much of the growth removed from the field.

Legumes will generally accumulate more organic matter than non-fixing crops, whose yields are limited by the small amounts of soil-N that are likely to be present at the start of the fertility-building phase. In pure clover and grass/clover leys with a high proportion of clover, most of the build-up of organic matter occurs in the first three years and there is relatively little additional benefit from extending the ley period much beyond this. Periodic inputs of crop residues and manures at other stages of the rotation, outside of the fertility-building phase, are also important as sources of fresh organic matter.

Phosphate and potash

Soil phosphorus supply relies both on microbial activity to convert ('mineralise') organic P sources and on chemical transformations within the soil. The fraction associated with soil organic matter accounts for 30 to 50% of the total P in most soils, with the remainder present as inorganic forms. Most P compounds in soil are either insoluble or poorly soluble.

The large reserves of P that have accumulated under conventionally managed fields may act as a source of P when farms are first converted to a less-intensive, organic management. However, the conversion of poorly soluble P compounds into crop available P is dependent on the maintenance of a neutral to slightly acidic pH (see later).

Changes in P availability arising from the activity of mycorrhiza will not be detected by the chemical extraction techniques commonly used for determining plant-available P in the soil. These analytical techniques only measure soluble P and some P obtained by plants may not be in a form that is being measured.

Very little **soil potassium** is associated with organic matter – most is present in inorganic forms. Careful management of nutrients to replace the large removals of K from cut grassland is particularly important in organic systems where there is great reliance on the N_2 fixed by clover.

Potassium is particularly important in organic systems as it is only possible to have vigorous clover growth if the K supply is adequate.

Managing nutrient supply

- Nutrient management is one of the main challenges facing the organic farmer.
- In the short-term, the problem is supplying sufficient nutrients to the crop at the correct point in its development to achieve economically viable yields.
- In the long-term, the challenge is to balance inputs and off takes of nutrients to avoid nutrient rundown or environmental pollution.
- Both of these goals must be achieved in the most part through the management of organic matter.

Within most organic systems, there are two main aspects to nutrient management:

- The fertility building ley, containing legumes to add N to the system.
- Manures used to redistribute nutrients around the farm.

Nutrients, other than N, are imported onto the farm mainly in bought-in feed and animal bedding, though other sources such as green waste compost and permitted fertilisers may be important in some systems.

Fertility Building Leys

The fertility building ley is the cornerstone of most organic rotations. A well-managed ley will provide N to cash crops, forage for animals and aid in the control of weeds, pests and diseases.

Despite the importance of the ley in fixing atmospheric N, there is a remarkable degree of ignorance within both the farming and research communities about how much N a ley will fix, and how this N is released after incorporation ('mineralisation'). Being able to predict these two aspects more accurately would prevent N losses due to excess N and crop failures due to too little N.

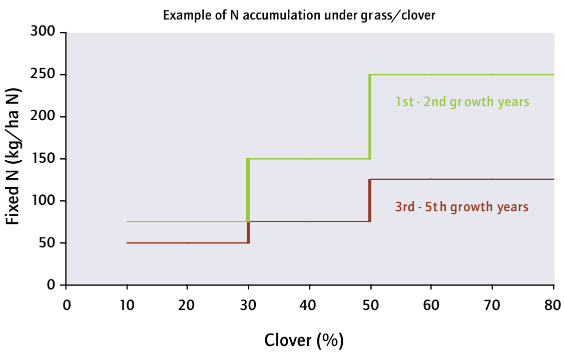
The challenge with trying to determine N fixation and mineralisation is that many factors are involved, such as legume species, soil type, climate, pests and disease. However, for a particular legume species, there is generally a close relationship between total N content and yield. Management can maximise the amount of this N that is fixed, as opposed to taken up from the soil, i.e. maximise the N input to the farm.

Important: legumes only fix significant amounts of N if they cannot obtain it from the soil. Thus, anything that adds N to the ley potentially reduces fixation, anything that removes N increases fixation.

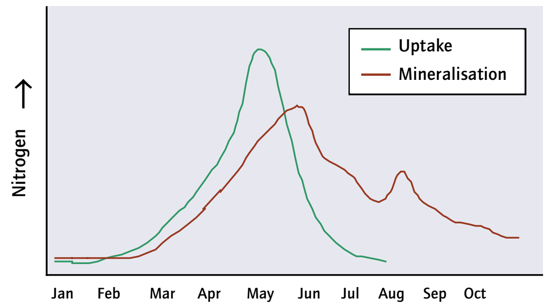
This is an important consideration when deciding how to manage the ley. For instance, it is common practice to add manure to the ley. Ground conditions make spreading easy and it provides P and K, especially important if the ley is cut for silage. However, the N in manure could reduce fixation and repeated applications could reduce the proportion of legume in the ley.

An **alternative strategy** is to add the manure to other parts of the rotation. The N will boost cash crop yield, while the P and K will still be available to the ley. The use of manure containing a high proportion of N in readily available form, such as slurry or poultry manure, is particularly detrimental to N fixation. The least detrimental is **composted FYM**, with a small proportion of N in an available form but retaining good P and K availability. Cutting and removing plant material (as silage, for instance) also promotes N fixation, when compared with grazing or cutting and mulching, as it removes N from the field. Though this means there is less N left for following cash crops, the N removed can be recycled back into the field in manure. Cutting leguminous plant and leaving the material in the field as mulch will add N rich material back to the soil and suppress the total amount of N fixed. However, this management strategy can be important for weed management.

Though good ley management can increase N fixation, soil N eventually builds up and the rate of fixation falls. For a grass/white clover ley, the optimum length is probably three years, after which there is little net fixation and incorporation is appropriate (see Figure).



Even more difficult than predicting fixation is **predicting mineralisation**. This microbial process is influenced by temperature, moisture and soil type, as well as the nature of the incorporated material. However, **it is possible to say that there will be a large peak in N availability soon after ley incorporation, with increasingly small amounts released in subsequent years** (see Figure).



The large peak in soil N is vulnerable to leaching. After ley incorporation is the greatest risk period for N loss. This can be minimised with spring incorporation and spring cropping, which also more closely matches release of N for the following crop. This may be impractical on many soils, in which case late autumn incorporation is preferred, when soil temperatures reduce microbial action and slow the rate of mineralisation of the incorporated residues.

If autumn cultivation is undertaken and crop establishment is delayed, or planned for the spring, sowing a rapidly developing green manure cover to protect the soil and prevent nutrient loss is recommended.

Manure management

The main route of entry for nutrients brought onto the farm is usually via animal feed and bedding. Animal manure provides an important method for redistributing nutrients around the farm, particularly N, P, K, S and Mg. Manure also supplies valuable organic matter.

Important: some nutrients in manure are all too easily lost, causing loss of a valuable resource and environmental pollution. Despite the obvious importance of manure to the organic farmer, there is plenty of scope for improved management on many organic farms.

Fresh manure, especially slurry and poultry manure, contains a considerable proportion of N in readily available (principally ammonium-N) forms, which can be easily and rapidly lost to the atmosphere. Similarly, nutrients (particularly N and K) can be washed out by rainwater. Both ammonia and nitrate losses can cause environmental pollution as well as representing a loss of N that could be used by the crop.

Effective manure management can minimise nutrient losses and maximise the benefits to the crop. There are two main treatment options available, **actively composting and stacking** for solid manure, and aerating slurries. For slurry, there is the additional option of **mechanical separation**, which can reduce the volume of material to be transported and enable irrigation of the separated liquid. Organic standards encourage the active composting of manure and aeration of slurry, however, on many farms this does not occur. Both approaches to dealing with manure have their merits and problems as far as nutrient management is concerned.

Composting

Effective composting of solid manures and aeration of slurry has a number of benefits:

- Reduced odours
- Weed seeds and pathogens killed
- Reduced volume of material
- Production of a more uniform product
- Nitrogen stabilised in an organic form (solid manure)

However, the turning process in composting solid manure can causes a large loss of N as ammonia, while the aeration of slurry can also increase N losses, particularly if the aeration is either too vigorous or not thorough. Carbon is also lost as carbon dioxide. The N in composted solid manures is also less available to the following crop in the short-term.

These problems can be overcome, to some degree, by a number of methods. Increasing the amount of organic carbon in manures can reduce N losses, so using more **straw per animal** will be beneficial. **Covers** are often recommended to reduce N losses or, better still, storing FYM under a roofed structure. Covering will reduce losses of N (and K) by stopping rainwater leaching through solid manure stacks, and can reduce gaseous losses by c. 60%. Undertaking composting in buildings after turnout is one method to avoid rainwater reducing the quality of the FYM and avoiding potential pollution. **Covering slurry stores** is also the most effective method of reducing losses of N from a liquid manure system.

The decision to compost or not, or to aerate slurry or not, will depend on farming objectives. Effective **composting** can be a time consuming and expensive operation, which can result in enhanced N losses. It also reduces the amount of N available to crops immediately after spreading. The advantages are a reduced volume of material to spread and a more uniform sterile medium, which contributes to long-term soil fertility, plus the control of undesirable pathogens and the reduction of weed seed numbers. **Slurry aeration** is also expensive and difficult to achieve effectively. However, when done effectively, it reduces weed seed numbers, reduces odours (which can be a particular problem in liquid manure systems) and produces a more homogenous material. The best system for a particular farm will depend on the objectives that the farm is trying to achieve and what resources are available.

Important: retaining N prior to spreading is only half of the story. Manure still contains a significant amount of N in an available form, which can be lost by leaching or volatilisation after spreading.

To avoid nitrate leaching losses, manure should be **applied in spring**, after field drains have stopped running. This is also the period of maximum nutrient demand by crops. The worst time to apply is between September and November.

To prevent gaseous losses of ammonia, **rapid incorporation** is the most effective method. Avoiding spreading in hot and/or windy weather will also reduce gaseous losses. The Table below shows the effect of delaying the soil incorporation of manure on nitrogen losses.

Manure type	Proportion of available N retained	
	90%	50%
Slurry	Immediate	6 hours
FYM	1 hour	24 hours
Poultry	6 hours	48 hours

Where best to use manure in the rotation depends on the farm's objectives. Manure is often spread on to leys, but this can have a detrimental effect on N fixation. Use of manure on grazing land can cause nutrient imbalances in grass in spring, reduced herbage intake and disease problems, and is generally best avoided.

Nitrogen is the main factor limiting production in organic systems, so it makes more sense to use manure on cash crops. Top dressing cereals with slurry in spring is particularly effective at increasing crop yields and protein content, for instance. Though N loss by ammonia volatilisation can be large, it can be reduced using a band spreader or shallow injection.

Solid manure should be added before soil cultivations are carried out and, because of the danger of leaching of N during winter, it is best applied to spring crops or grass leys.

Green manures and cover crops

Green manures and cover crops form an important part of some organic systems, **but most farmers could probably use them more effectively**.

Research has shown that green manures and cover crops used regularly in the rotation for short periods of less than six months between cash crops can be as effective at maintaining soil N concentrations and yields as long-term (3 year) leys.

There are two principle types:

- Those that **capture N**, preventing it from being leached.
- Those that **fix N**, providing a boost to soil fertility.

They both also add fresh organic matter to the soil, which increases soil microbial activity, protect the soil from erosion and some can be used for forage. **Choice is dependant on purpose**.

Grazing rye, for instance, is good at capturing N, vetch is a good N fixer, and rape and stubble turnips provide good forage. Other factors to consider are the **time of year** involved (as some species are not frost tolerant), **soil type, climate, rate of development, persistence, potential as a subsequent volunteer weed and seed cost. There are also implications for disease.** Growing mustard in a rotation that includes a brassica crop can increase the risk of clubroot though, in contrast, members of the trefolium family can reduce the incidence of take-all in wheat.

Release of N is, again, an important consideration. The maturer the crop is, the slower will be the N release. Indeed, in some cases, there may be an initial period of N immobilisation. Some green manures, such as rye and vetch, have also been shown to have an **allelopathic effect**, inhibiting seed germination for several weeks after incorporation. The effect is much less of a problem for large seeded crops than for small seeded, and is less significant for transplants. With good planning this effect can even be put to use as it reduces weed seed germination.

Important: the boost to soil fertility that green manures and cover crops provide is relatively short-term and will occur several weeks after incorporation, depending on species, maturity at incorporation and temperature.

Crop residues

Crop residues can be an important source of nutrients and organic matter. Both the amounts produced and their nature varies between crop types. For example, cereal straw contains only around 35 kg N/ha and has a wide C:N ratio, compared with more than 150 kg N/ha for some vegetable residues, with a narrow C:N ratio. The narrow C:N ratio of green leafy residues means that N is released much more rapidly than from cereal straw. As a result, different types of residue will require different management if maximum benefit is to be obtained.

After incorporating green leafy residues, there is liable to be a rapid increase in soil N. Establishing the next crop quickly will enable this to be exploited. If that is not possible a cover crop could be used to retain the N. Incorporating a low N residue, such as cereal straw can have the opposite effect, immobilising N from the soil.

Supplementary nutrients

In time, all organic systems will require supplementary nutrients to replace those removed from the farm in crops and animal products or lost to the environment. In some cases, soil reserves may be able to supply nutrients for hundreds of years but, on some soils and in some systems, such as intensive vegetable production, supplementary nutrients will be required regularly to avoid nutrient run down.

Organic standards recognise this need and allow the use of a limited range of nutrient supplements, such as rock phosphate, potassium sulphate and green waste compost, some of which require a derogation and a requirement to 'demonstrate' need through the use of soil analysis and/or crop foliar analysis.

The most suitable supplement will depend on circumstances. Green waste compost is a good source of P, K and organic matter, but its availability is limited and cost can be high. Where a more specific need is identified, such as correcting low soil P status, it is probably best to go for a specific product, such as rock phosphate.

Important: most of these supplementary nutrient sources have relatively low availability and so should be regarded as part of long-term nutrient planning rather than a short-term yield boosting solution.

Soil pH

The most important soil parameter for guaranteeing nutrient supply to the crop is soil pH. Even when all plant nutrients are present in sufficient quantities in the soil, if the pH is not maintained at the right level (6.0-7.0) the crop will display nutrient deficiency symptoms and will not achieve its yield potential. This deficiency is partly due to the fact that in acidic conditions (low pH, below 5.5), soil biological activity is reduced, thereby slowing the release of nutrients. Also, at either end of the pH scale some major and minor nutrients become unavailable to the crop. Other effects of low pH or acidity include deteriorating soil structure, reduced crop quality, reduced fertiliser efficiency, increased nutrient losses, and deterioration of grass swards.

In soils that have a tendency to become acidic, it is very important to check pH levels every 3-4 years. Susceptible soils include those that are sandy and organic/peaty, especially in high rainfall areas, or receiving regular inputs of slurry.

Some soils are naturally rich in lime (calcareous) and will

never need liming. In general, acidic soils should be limed to raise the pH to 6.0 for grassland and 6.5 for arable soils, but it is important not to add too much lime in any one year. **Over-liming can result in nutrient deficiency and lost yield due to antagonistic and imbalance effects**. As a guide, it is inadvisable to raise the pH by more than half a point in any one application.

How much lime?

The following Table gives a guide as to the quantities (t/ha) of ground limestone required to raise the pH to 6.5. Lighter textured soils need less lime than the heavy soils to raise the soil pH to the same degree.

Soil texture	Soil pH 6.3	6.1	5.9	5.7	5.5
Sands	2	4	5	6	7
Light	3	4	6	7	8
Medium + clay	3	5	6	8	10

*maximum amount of lime to apply in any one application, for given soil texture.

Liming materials

The effectiveness of a material depends on its 'neutralising value' (NV), its fineness, solubility and the hardness of the parent rock. The NV is a measure of a material's effectiveness relative to pure calcium oxide, expressed as a percentage. Thus, 1000 kg of ground limestone with a NV of 54 will have the same NV as 540 kg of pure calcium oxide. Most materials that contain calcium have some neutralising value. The monetary value of products can be compared using their cost per unit of NV, while taking into account any differences in fineness and hardness.

Not all liming materials are available to organic farmers. The fastest acting materials, slaked lime and quick lime are not permitted. Ground chalk, limestone and calcified seaweed are the main sources. The finer and softer the product, the higher the solubility and the more rapid the action. Thus, chalk ground to 1 mm diameter will have about the same solubility as hard limestone ground to a powder of 0.07 mm diameter.

Lime Application

The timing of applications will depend on which crops are in the rotation, but it is important to consider that it can take over a year for an effective rise in pH to occur, especially if coarser or harder liming materials are used.

A few of the crops to bare in mind are:-

- Brassica vegetables - liming can reduce the risk of club root by improving soil structure.
- Sugar beet (rarely grown in organic systems) and barley are sensitive to acidity. Any required lime should be applied well before these crops.
- Clover – the percentage cover of white clover is rapidly reduced at low pH levels, so it is especially important to maintain a neutral pH in organic systems.
- Potatoes – liming can increase levels of potato scab. Potatoes can tolerate acid soils, so any need for liming can wait until after the potato crop.
- Green manures – it may be a good idea to apply lime just before the establishment of lime tolerant green manures. By the time the following crop is drilled, the soil pH will have returned to the desired level.

Managing soil structure

- Structure is an important, though often neglected, characteristic of soil.
- Know your soil texture – this determines how the soil should be managed.
- Improve soil structure:
  - Timely cultivations
  - Organic matter additions
  - Avoid livestock poaching
- Regularly examine soils to assess structure, to identify problems and to decide on restorative action.

Soil structure affects the size and the distribution of soil pores, which are important for the movement of air and water and for root penetration.

Bad structure leads to poor root penetration, reduced access to nutrients, impeded drainage, poor microbial activity, soil erosion and ultimately crop failure. More power will also be required for cultivations and animal health may suffer in grassland systems.

Good soil structure

Bad soil structure

Soil structure, to some extent, is determined by **soil texture** (the proportions of sand silt and clay particles). These individual soil particles, along with organic matter, form clusters known as **aggregates**. It is the type and arrangement of these aggregates that determines soil structure.

Because soil texture has such a strong influence on structure, the type of soil may limit what is achievable:

- Weakly interacting sand grains cannot form aggregates
- Strongly interacting clay minerals can form stable aggregates, resistant to trampling by animals, cultivation, the weight of machinery, and rain impact.

Good biological activity is essential to maintain soil structure. Plant roots and fungal filaments enmesh aggregates while gums produced by bacteria feeding on organic matter help stick sand, silt and clay particles together.

Important: within the constrains of the soil texture it is possible to manage soil structure, using a combination of organic matter additions and careful cultivations, combined with a little understanding and some simple observation.

Soil examination

Recognising structural problems early on before they become difficult and expensive to correct is an important skill. Indications of structural problems include:

- Fields slow to dry and quick to become wet
- Poor seed germination and or emergence due to capping
- Patches of poor crop growth
- Increased pests, diseases and weeds
- Increased problems with producing a good seedbed

Assessing the structural condition of a soil is easily done in the field and should help spot problems before they begin to affect the crop.

Method

The best time to assess structure is when the soil is moist with a growing crop in place; assessment in dry soils is very difficult. Also, soil structure tends to deteriorate during the season, which should be taken into account when doing assessments. Repeat at points across the field - areas such as gateways and around feeding troughs are especially prone to poor structure and may provide an early warning of more general problems.

- Dig and remove a block of soil about 30 cm deep
- Bang the spit of soil on the ground to see how it breaks up
- Assess the soil visually and compare with Table opposite
- As well as assessing the plough layer, a further assessment should ideally be made at deeper levels with fewer pits to determine if deep compaction is occurring

Important: As well as being able to assess soil structure it is important to know how to avoid problems and deal with any that arise. Broadly speaking good management of soil structure involves a combination of avoiding operations that damage the soil, such as excessive trafficking and overstocking, and maximising operations that benefit structure, such as appropriate cultivations, and addition of organic matter.

Indicators of good structure	Indicators of bad structure (very bad structure in italics)	
	Medium to heavy soils	Light soils
• small to medium aggregates • easily broken when moist • loose friable overall • lots of pore spaces • good root penetration • plentiful earthworms	• mainly large clods • clods resist breaking • clods have smooth surfaces • poor root penetration persistent crop residues • few earthworms • compacted layers • *flattened clods* • *horizontal cracking* • *mottled orange grey colours sulphurous smell*	• lack of cohesion • surface capping • persistent crop residues • compacted layers • poor root penetration

Cultivations

Cultivation can have:

- Positive effects on structure - breaking up hard clods, or compacted layers.
- Negative effects on soil structure - breaking up aggregates and smearing and moulding the soil into clods, particularly if done when the soil is too wet.

If the soil is ploughed to the same depth every year, compacted plough pans can develop.

Important: deciding the most appropriate method and degree of cultivation will depend on a number of factors: the purpose of the cultivation, the soil type and the machinery available.

Considering soil type

- Light textured soils with a high proportion of sand do not form strong aggregates and are prone to compaction, therefore they should be ploughed.
- Clay soils can form strong, stable aggregates and so cultivations can be kept to a minimum, particularly if the soil contains free lime, which tends to result in a more robust structure.
- Keep secondary cultivations for seedbed preparation to a minimum to avoid pulverising aggregates, particularly on weaker soils.
- Excessive cultivation should be avoided. Reduced tillage has become increasingly common because of the many benefits though, in organic systems, the need for cultivation to control weeds means that there is often limited scope for this.
- Do not cultivate when the soil is too wet (including harvesting operations), particularly on heavier soils. Damage can take considerable time and effort to remedy. Any short-term benefits of working in wet conditions must be weighed against the long-term costs of yield reduction, and time and effort to remedy the damage.

Organic matter (again!)

Organic matter stimulates soil bacteria and fungi, which help to bind soil aggregates together. There is also a smaller but longer-term effect resulting from the **humus** produced by this microbial activity.

The main influence of adding organic matter is relatively short lived. After ploughing a grass/clover ley, soil structure is generally very good as fungi and bacteria multiply as they break down the organic matter. However, there is a measurable decline in soil structure over the next 3-4 years, as the organic matter is used up and the activity of fungi and bacteria declines. This means that more care must be taken with cultivations and trafficking later in the rotation.

If a new ley is established by undersowing a cereal, care must be taken during harvesting operations to avoid trafficking over the field more than necessary. Very poor soil structure has been recorded in leys established by undersowing, which will impact on their productivity. Other types of organic matter, such as FYM and crop residues will also help improve soil structure, though stabilised organic matter such as compost will have a smaller (though more long-term) effect.

Important: management of soil structure is crucial to maintain good crop growth, particularly in organic systems where fertilisers and biocides cannot be used to compensate for effects of bad structure. Careful cultivations, along with regular additions of fresh organic matter, should ensure that good structure is maintained. Particular care should be taken later in the rotation, when the effects of the ley have declined and soils are more vulnerable to damage.

Managing soil biology

- Good biological activity is central to organic farming (and benefits all farming systems).
- This ranges from earthworms down to bacteria – micro-organisms play vital roles in nutrient cycling, soil structural development and pest and disease control.
- Encourage biological diversity/activity in soils by:
  - Providing good soil structure.
  - Providing fresh organic matter.
- 'Specialised' micro-organisms such as N fixing bacteria and mycchorizal fungi provide large benefits to organic systems – plan rotations and management to encourage them.

The living organisms in the soil are at the heart of organic farming. Though **earthworms** are the most visible soil organisms and perform an important role in organic matter breakdown, it is the microscopic organisms that are the key players.

In agricultural soils, the largest group of these, both in terms of numbers and biomass, are the **bacteria**, followed by **fungi**, followed by **protozoa** and **nematodes**. On a typical grassland, their total biomass exceeds that of the animals grazing on it several times over!

The practical difficulty in studying microscopic organisms in the soil means that there are large gaps in our knowledge about soil micro-organisms. What we do know is that, as well as huge numbers, there is huge diversity within all the different groups. The result is that there is a highly complex '**food web**' within the soil, with different organisms feeding on soil organic matter and other soil organisms.

Important: most of the activities of soil organisms are beneficial and it should be one of the central aims of the organic farmer to stimulate soil biological activity.

Improving biological activity

The options available to stimulate the activity of soil micro-organisms, which will in turn enhance the benefits they provide, are simple:

- Provide comfortable living conditions – good soil structure.
- Provide a food (energy) source – fresh organic matter.
- Avoid the application of materials that are antagonistic to biological activity.

The principal option is the addition of organic matter in the form of FYM, crop residues, green manures, compost, etc. Organic matter supplies carbon, which is the food source for the soil micro-organisms.

Fresh organic matter, such as crop residues, provides carbon in a form more easily processed by micro-organisms than composted organic matter, and so results in a larger though short-term stimulatory effect. As the carbon is used as a food source, nutrient elements such as N are excreted, just as with larger animals. These nutrients are then available to plants for uptake.

A large addition of organic matter can result in a large flush of nutrients, such as that which occurs after ploughing in a ley. In the absence of fresh organic matter, soil micro-organisms break down native soil organic matter at a very slow rate, such that a large proportion of the humus in soils is many hundreds or even thousands of years old. As well as providing a flush of nutrients, the addition of organic matter also stimulates many of the other services provided by soil micro-organisms, such as pest and disease control.

More generally, crops which return a large amount of high nutrient residue to the soil will cause a large (but short lived) rise in microbial activity, while those which produce low nutrient residues, such as cereal straw, will produce less of a rise in soil microbial activity.

The other main management practice that can influence soil biological activity is **cultivation**. In general, a small amount of cultivation is beneficial, as it breaks up soil clods exposing organic matter, and aerates the soil. More vigorous cultivation can have a negative impact. Deep ploughing in particular, kills earthworms and disrupts soil microbial activity by exposing organisms at the surface. Mycorrhizae are also disrupted by vigorous cultivations.

Important: there are specialised soil micro-organisms that perform specific roles, such as nitrogen fixing bacteria and mycorrhizal fungi. These require more specific consideration if they are to be encouraged.

Specialised micro-organisms

Adding organic matter high in available N can suppress N fixation, but adding P and K will stimulate N fixers.

In contrast, adding P will suppress mycorrhizal fungi (which form a symbiotic relationship with many crop species, helping them take up nutrients), while adding N can stimulate their activity. Specific amendments intended to stimulate more specialised groups of soil micro-organisms, such as compost teas are available, but as yet there has been little research done into their effectiveness.

Other factors to consider when addressing soil microbiology include **crop type** and **cultivations**. For instance, though many crops form a symbiotic relationship with mycorrhizal fungi, some, such as the brassicas and sugar beet, do not. Planting a non-mycorrhizal crop reduces the subsequent mycorrhizal infectivity of the soil, and can have a significant impact on the yield of highly dependant mycorrhizal crops.

Therefore, it is inadvisable to plant a crop that is highly dependant on mycorrhizae (such as maize) after a non-mycorrhizal crop, (such as a mustard cover crop). The Table shows temperate crops that are highly dependant on mycorrhizae and those which are non- mycorrhizal.

Non-mycorrhizal crops	High dependency crops
Brassicas	Maize
Sugar beet	Alliums
Leaf beets	Linseed
Lupins	Soybean
	Sunflower
	Cereals
	Pulses

Assessing soil fertility

- Because of the fertility-building and fertility-depleting stages of organic rotations, it is difficult to define the overall fertility of an organically farmed soil from measurements at a single stage of the rotation. It is also more important to include measurements of the reserves of less-readily available nutrients (e.g. organic P and non-exchangeable K) in assessing fertility than with non-organically farmed soils.
- Careful attention to nutrient movements on and off the farm and around the farm will allow maximum benefit from nutrients to be gained and avoid potential damage to the environment through pollution.
- Simple nutrient budgets combined with soil analysis can indicate weather the system is in balance or losing or gaining nutrients. This is best achieved by monitoring trends over time.

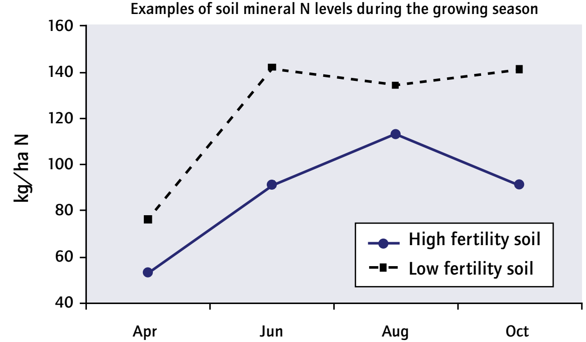
Testing the soil

Chemical extraction methods provide a **snapshot** of the nutrient content at a particular time. They are less suitable for determining plant-available N. Most soil N is in organic compounds, a small amount of which is gradually released as plant-available mineral N over the year (see Figure). The amount of mineral N present at any one time is a poor indicator of the amount that will be released during the rest of the season.

Many commercial laboratories offer services for determining the contents of P, K, Mg and trace elements in soils, and also soil pH. These simple **chemical extractants** cannot duplicate the processes operating around the plant root. The results are only an approximate guide to the amount of available soil nutrients. Not all laboratories use the same methods. Interpretation of the results must take account of the analytical method used. The most commonly used extractants in England and Wales are the **Olsen** reagent for plant-available P and **ammonium nitrate solution** for K and Mg. Nutrient contents can be expressed as availability indices ranging from 0 (deficient) to 9 (excessive). Different extractants are used in the SAC system in Scotland but, otherwise, the approach is similar.

There is interest in the **basic cation saturation ratio** (BCSR) and **soil audit system** introduced from the USA. This series of analyses differs from the other methods in providing recommendations that seek to achieve an 'ideal' ratio of cations (Ca, K, Mg and Na) in the soil. There is no evidence that this approach is superior to the more commonly used methods; nor has there been the extensive field testing to validate the concept under UK conditions. This soil audit also

Examples of soil mineral N levels during the growing season



provides measures of available P and N and of 'active humus'. The approach provides more information but at a higher cost. The most important aspect of soil analysis is the interpretation of the results in relation to soil type, historic and planned cropping and land use.

Important: whatever soil analyses are used, it is important that the correct procedure for collecting the soil samples is used.

Taking soil samples

- Sample soils with correct coring tools that take the same diameter core through the soil (see Figure). Do not bias the sample by using a trowel, for example.
- Samples should be representative of the field and taken from the correct depth for long-term grass or arable land as specified by the laboratory carrying out the analyses.
- Samples should be collected at the same time of year and should not be taken within 3 months of applying manure.
- Care should be taken to avoid contamination of the samples once they have been collected.
- It is generally unnecessary to sample fields more frequently than once every four years. For the examination of long-term trends, samples should be collected at the same stage of the rotation.
- The physical condition of the soil is best assessed by visual inspection of the soil in the field.

Nutrient budgeting

Nutrient budgets are important tools for organic farmers. Budgets:

- Assess how well nutrient inputs and outputs are balanced with current management.
- Examine the implication of alternative management strategies.
- Timing of nutrient imports and exports in different parts of the rotation.

If the input of nutrients to the farm is insufficient to replace the nutrients leaving in agricultural products, there will be a gradual depletion of the nutrient reserves. In contrast, where inputs exceed outputs, nutrients will either accumulate within the farm or be lost to the environment. Significant surpluses of N and P, though less likely on organic farms, are indicative of potentially damaging losses to the wider environment.

The simplest form of budget is the **farm gate budget**, which compares the nutrient input in purchased materials (feed, bedding, seed, manure, fertiliser) entering the farm with the quantities removed in products (crop, milk, livestock sales, etc.).

The necessary information can be readily obtained from farm records and from appropriate standard values for the nutrient content of the various materials entering and leaving the farm. Surpluses may indicate an excessive input of manures or livestock feed whereas a deficit, of K for example, may indicate a shortage that could be remedied by increasing the amount of straw bedding brought in to the farm.

Although adequate for P and K, these simple budgets are clearly unsuitable for N as they do not include the input of fixed N from the atmosphere. Nitrogen budgets require a separate estimate of the quantity of N fixed by individual legume crops on the farm and therefore involve greater uncertainties.

These simple budgets do not include any estimate of the quantities of nutrients lost by leaching or to the atmosphere. However, even when inputs and outputs are balanced, some loss is inevitable. Ideally, therefore, budgets should show a small surplus to balance these unavoidable losses. Typically, leaching losses from well-managed organic farms are likely to be less than 1 kg P/ha and 5 kg/ha per year. Losses of N are far more variable and often considerably larger. There is less information available for determining budgets for other nutrients.

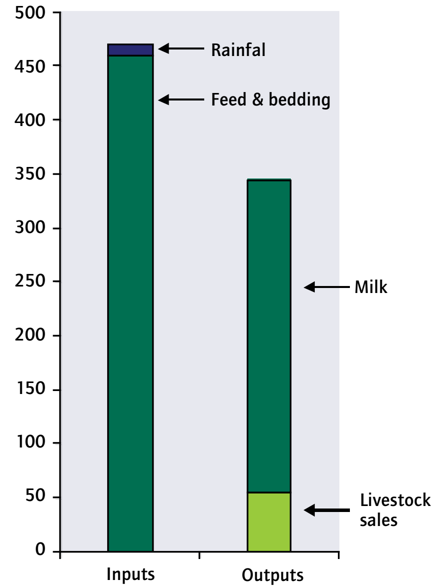
Field scale nutrient budgets

Although nutrients may be balanced at the farm scale, it is equally important to balance inputs and outputs for individual fields so that inputs are sufficient to replace the nutrients removed in harvested crops. Determining simple nutrient budgets through the rotation for **individual fields** can assist in developing an effective manure management plan and directing manures where they are most needed. For example, animal manures should be preferentially applied to those fields (e.g. silage fields) with the greatest nutrient offtakes. Further information about determining nutrient budgets is available from the various sector bodies.

Important: because of the uncertainties in the calculations and because they describe total quantities of nutrients rather than plant-available forms, budgets should be used with care as indicators of nutrient excess or shortage through the rotation.

Budgets may be particularly misleading where insoluble P fertilisers have been applied. Because of the high total content of P in the fertiliser, the budget may indicate a relatively large surplus. In reality, however, only a small proportion of the fertiliser P will be available to crops in any one year. Most will remain inactive in the soil so that its contribution to the budget should be spread across the full rotation.

Example of a P budget for an organic dairy farm



Important: budgets provide an indication of likely long-term changes in nutrient status but should be regarded as a supplement to soil analysis rather than as a substitute for direct measurement of the soil nutrient status.

Pitfalls and problems

- The practical management of organic systems requires the balancing of production and environmental objectives.
- There will sometimes be conflicts between 'best practice' and practicality.
- Do your bets to minimise these conflicts. If they are unavoidable, be aware of the consequences.

Managing a farm to minimise environmental impacts requires a high level of skill. This booklet describes the approaches that can be adopted, but they need to be integrated into the farming system. Inevitably, there are occasions of conflict between what should be done and what can be done. There is no simple solution.

Holding on to nutrients in manure: Nitrogen is at risk of loss throughout the manure management cycle – production, storage and landspreading. Potassium can be leached from uncovered manure heaps. Care during storage (and composting) and spreading (time of application, method of application) will help, as described in this booklet.

Maximising N build-up from legumes: There is still much to be learnt about the management of legumes to maximise the nitrogen that they fix and the amount that is released to the following crops. During the legume phase, remember that fixation (i.e. 'new' nitrogen imported into the farm system) will decrease as the supply of N from the soil increases. Therefore, manage the legume with this in mind – as described in this booklet.

Maximising N use from legumes: Nitrogen lost by leaching cannot be used by crops in the rotation. Reduce leaching losses. Can leys be broken in the spring, or delayed until later in the autumn? Is this practical on your soil-type? Can the rotation be adapted to accommodate this? Also, match N release to crop requirements: use high N demanding crops at the start of the fertility depleting phase.

Green manures, good in theory? Well-grown cover crops and/or green manures can decrease leaching, can supply a welcome boost of fresh organic matter, and can assist with weed management. However, they are not always easy to accommodate in rotations, and can be especially difficult to manage on heavier soils where timeliness of cultivation is critical. The benefits that they can provide means that they are worth persevering with.

Pest and disease carry-over: Maintaining a green cover can sometimes increase the risk of pest and disease, and reduce the opportunity for weed control. Choice of species and careful planning of the rotation will minimise carry-over.

Fertility on light textured soils: Maintaining N for the rotation on light textured, less retentive soils will always be a challenge. Increasing organic matter levels and adopting practices to minimise nitrate loss will help. Cut it will always be a challenge.

Stockless systems: Managing systems that do not benefit from animals to increase and recycle soil fertility (feed import and manure production) provide special challenges. Good rotation planning and nutrient budgeting are essential.

Further information sources

Decision support tools

MANNER

MANNER is a decision support system that can be used to accurately predict the nitrogen value of organic manures on a field specific basis. MANNER has been developed using results from the latest research, funded by DEFRA, on organic manure utilisation on agricultural land. MANNER is available free on disk or CD-Rom from: ADAS Gleadthorpe Research Centre, Meden Vale, Mansfield, Notts, NG20 9PF. Tel: (01623) 844331; Fax: (01623) 844472

Or order from http://www.adas.co.uk/manner

Booklets/leaflets

1. A Guide to Better Soil Structure. National Soil Resources Institute, Cranfield University, Silsoe. To obtain a free copy Tel: 01525 863000 or www.cranfield.ac.uk/soil
2. Managing Livestock Manures: Booklet 1 – Making better use of livestock manures on arable land.
3. Managing Livestock Manures: Booklet 2 – Making better use of livestock manures on grassland.
4. Managing Livestock Manures: Booklet 3 – Spreading systems for slurries and solid manures.
5. Managing Livestock Manures: Booklet 4 - Managing manure on organic farms.

Manure booklets available from ADAS Gleadthorpe, Tel: 01623 844331.

Websites

Defra's organic farming pages:
www.defra.gov.uk/farm/organic/default.htm

Scottish Executive's organic farming pages:
www.scotland.gov.uk/Topics/Agriculture/Agricultural-Policy/15869/3748

Organic Centre for Wales:
www.organic.aber.ac.uk

Organic production information, Northern Ireland:
www.ruralni.gov.uk/bussys/organic/business_management/organic_food/

More information on organic soil fertility:
www.organicsoilfertility.co.uk

Research Centre websites:
ADAS: www.adas.co.uk
IGER: www.iger.ac.uk
HDRA: www.hdra.org.uk
Elm Farm: www.efrc.com
SAC: www.sac.ac.uk/consultancy/organic/
Newcastle University: www.ncl.ac.uk/tcoa/producers/

Environment Sensitive Farming:
www.environmentsensitivefarming.co.uk

Certifying bodies – contact addresses

Organic Farmers and Growers Ltd

The Elim Centre
Lancaster Road
Shrewsbury
Shropshire
SY1 3LE

Tel: 01743 440512
Fax: 01743 461441
Email: info@organicfarmers.org.uk
Website: www.organicfarmers.org.uk

Scottish Organic Producers Association

Scottish Organic Centre
10th Avenue
Royal Highland Centre
Ingliston
Edinburgh
EH28 8NF

Support & Development:
Tel: 0131 333 0940
Fax: 0131 333 2290
Certification:
Tel: 0131 335 6606
Fax: 0131 335 6607
Email: sopa@sfqc.co.uk
Website: www.sopa.org.uk

Organic Food Federation

31 Turbine Way
Eco Tech Business Park
Swaffham
Norfolk PE37 7XD

Tel: 01760 720444
Fax: 01760 720790
Email: info@orgfoodfed.com
Website: www.orgfoodfed.com

Soil Association Certification Ltd

Bristol House
40-56 Victoria Street
Bristol
BS1 6BY

Farmers and Growers:
Tel:0117 914 2406
Email: prod.cert@soilassociation.org
Processors: Tel: 0117 914 2407
Email: proc.cert@soilassociation.org
Website:www.soilassociation.org

Bio-Dynamic Agricultural Association

The Painswick Inn Project
Gloucester Street
Stroud
GL5 1QG

Tel: 01453 759501
Fax: 01453 759501
Email: bdaa@biodynamic.freeserve.co.uk

Irish Organic Farmers and Growers Association

Main Street
Newtownforbes
Co. Longford
Republic of Ireland

Tel: 00 353 506 32563
Fax: 00 353 506 32063
Email: iofga@eircom.ne

Organic Trust Limited

Vernon House
2 Vernon Avenue
Clontarf
Dublin 3
Republic of Ireland

Tel: 00 353 185 30271
Fax: 00 353 185 30271
Email: organic@iol.ie

CMi Certification

Long Hanborough, Oxford OX29 8LH
Tel: 01993 885651
Fax: 01993 885611
Email: enquiries@cmicertification.com

Quality Welsh Food Certification Ltd

Gorseland
North Road
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Ceredigion SY23 2WB
Tel: 01970 636688
Fax: 01970 624049
Email: mossj@wfsagri.net

Ascisco Ltd

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Farmers and growers: Tel: 0117 914 2406
Processors: Tel: 0117 914 2407
Email: DPeace@soilassociation.org

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