Soil Association Organic Standard

Soil Association technical guides

Soil management on organic farms

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Contents

Good soil management is the key to plant and livestock nutrition in organic farming. At last the wider value of good quality soils and appropriate soil management to our environment is starting to receive greater recognition and attention. This technical guide provides advice on soil management in relation to both long-term land management and day to day decision making.

This guide is designed to highlight the importance of good soil management. It will give users an understanding of soil and how farming operations can affect soil properties. It also provides practical information on how to maintain and improve soil health and fertility. The information in this guide will help achieve efficient and sensitive land management on organic farms.

This guide is aimed at organic farmers, farmers in conversion and farmers interested in organic techniques. The guide will also be of value to those supporting the organic sector with advice and information, as well as policy makers.

1. Introduction

The soil beneath our feet is something most of us take for granted. Yet it is a precious resource that largely governs agricultural sustainability and environmental quality, both locally and globally.

Simpson (1983) sums up the soil as "the basis of agriculture. It is the main raw material from which food is produced. Unlike the raw materials of most industries it can, with some supplementation, be used again year after year, century after century."

Soil conditions govern crop production and crop quality and, in turn, influence both animal and human health. This was recognised by the founders of the modern organic movement in the mid-20th century. These pioneers recognised that in order to deliver health, farming systems need to build and conserve natural soil fertility through the development of humus. In order to achieve this, farming practice needs to observe and emulate biological cycles of growth and regeneration. It is these observations that underpin the principles and practices of organic farming today.

Soil health is at the heart of successful organic production. This guide is designed to highlight the importance of good soil management. It will give users an understanding of soil and provide practical information on how best to improve and maintain soil health.

It is certain that as we learn more about this complex and fascinating subject, so too, will we make developments in agricultural practice that best serve to protect and enhance the health of our soils. Indeed, the growth of the organic food and farming movement is being driven by an increasing understanding of the complex interactions between our farming methods and human health, our environment, and the welfare of animals and society.

1.1 Principles

Organic farming systems seek to achieve sustainability through the emulation of natural biological cycles. In natural ecosystems, the processes of death and decay are balanced. This is best observed in a forest soil, where a mixture of different species co-exists and artificial interference is avoided. Forest vegetation protects the soil from the direct impact of the elements, while the forest fertilises itself through the death and decay of numerous native animals and plants. The result is a large reserve of soil fertility derived from the conversion of decaying organic matter into humus by soil organisms. These forest systems share a number of characteristics (as outlined by Albert Howard in his 1940 book *An Agricultural Testament*):

- They are mixed, with a diversity of animals and vegetation
- Decaying animal and vegetable material is converted into humus
- Large reserves of fertility are maintained
- The soil is protected from the elements to prevent erosion
- Animals and plants are responsible for protecting themselves against disease
- Water is stored effectively.

Alteration of a natural ecosystem to one that produces food poses some problems for achieving these characteristics. However, a combination of good agricultural practices can be used to emulate natural systems and cycles very effectively. Sir Albert Howard stated that "the correct relation between the processes of growth and decay is the first principle of successful farming." This fundamental principle contrasts to the conventional approach that relies on targeted short-term solutions, such as application of a soluble fertiliser or herbicide.

Instead, organic farms sustain and build soil fertility by recycling nutrients to achieve crop and livestock health. This reduces the need for artificial intervention to tackle nutrient disorders or pest and disease invasion. This can only be achieved by paying particular attention to soil in its biological form alongside its physical and chemical properties.

Soil biology is the foundation for sustainable farming from which good soil structure and soil fertility is derived. In line with this, the organic standards state that soil management should aim to maintain or build up soil organic matter, structural stability and biological activity. This guide focuses on the practical measures that should be adopted to enable this to occur.

1.2 Policy

Soil is only just beginning to be recognised as a key priority in national and international policy. The recent recognition of soil as a key measure of environmental sustainability comes after fifty years of neglect, and some mismanagement. The consequence has been a raft of ecological disasters, including soil degradation (in the form of erosion), salinisation, acidification, and declining soil structure, fertility and carbon bank. These problems have affected the capacity of soils all over the world to sustain agricultural production.

The development of a global soil policy urgently needs to take into account the many essential functions of soil, together with supporting practices to ensure these functions can be achieved. A soil managed to achieve optimal health through recycling of organic matter and protection of soil biodiversity is important. By encouraging best practice in soil management, it is hoped to achieve:

- Maintenance of the basic resources for food production, clean water and a stable climate
- Maintenance of terrestrial and aquatic biodiversity
- Regulating the flow of water on the planet
- Reducing water clean up costs through reduction in pesticide and nutrient pollution
- Reducing the need for supplementary artificial irrigation for agriculture
- Improving crop, animal and human health through a reduction in pesticide residues.

At a global level, the UN Food and Agriculture Organisation (FAO) is pursuing an active programme on soil management and cultivation, including the welcome recognition of the importance of soil biodiversity. This is helping to shape policy at European and national level. In the UK, a consultation paper *The Draft Soil Strategy for England* was published in 2001. It sets out the following aims:

- To manage our soil resources in ways that ensure we can meet our present and future land use needs
- To manage diversity of soils, concentrating particularly on our most valued ones, so that the right balance of types is available to support our ecosystems, landscapes, agriculture and cultural functions
- To maintain and improve the quality of our soils in ways that ensure we can meet our current and future social, environmental and economic needs.

Following on from the consultation paper, the government in England is producing a 'Soil Action Plan', scheduled to be released in 2003. Similar policy initiatives are being undertaken in Wales, Northern Ireland and Scotland.

2. Organic standards

Organic standards identify protection of the soil as a fundamental principle of any organic system. This principle is underpinned, through a number of recommendations and requirements, within the *Soil Association Standards for Organic Farming & Production*.

2.1 Conversion

A soil management plan will be required as part of your application to enter land for conversion to organic management. This must demonstrate that adequate consideration has been given to how soil fertility and structure will be protected and enhanced over the course of a crop rotation. This requires close consideration of key practices, such as rotation design, fertilisation strategy, composting, cultivations and livestock management.

Each of these topics is considered in greater detail in this guide. It is also recommended that soil testing is routinely used to assess the existing status of the soil and to help plan management practices; for example, by carrying out tests each year at the same time and place, or at the same point in the rotation.

2.2 Rotation design

Rotations should be developed to balance the nutritional and structural demands on the soil, while providing an adequate break between crops to avoid specific pests and diseases.

Rotations should provide diversity both above and below ground. Where possible, crops with different root structures should be grown to help protect and improve soil structure. While the rotation will vary depending on the type of enterprise and market outlets, it is important that all farms balance exploitative cropping with fertility building.

Furthermore, every effort should be made to prevent the soil from laying bare for any prolonged period, particularly over winter. Cover crops could be used to prevent this, where necessary. Permission to use 'quick fix' inorganic inputs to address nutrient deficiencies is only likely to be permitted if preventive cultural practices have been adopted as a first line of defence. A nutrient budget (see section 6.3, 'Nutrient losses and gains') is a good tool to help make sure that there are adequate nutrients to cope with the rotation that has been developed.

2.3 Manures and plant wastes

Origin and treatments

The responsible and effective use of manures and plant wastes is a key practice to cycle nutrients effectively, and build soil fertility. It is recommended that all manure should be composted and that all slurry should be aerated. Composting results in a stabilised product, free of pests, pathogens and weed seeds, that is an excellent material for building soil organic matter and supporting soil microbial communities. For further information on production of compost see section 5.1, 'Compost'.

The organic standards require that permission must be granted for the use of any manure brought in from non-organic farms. Depending on the source of the manure, a treatment process will be required before application (see Table 1):

Table 1: Required treatment of manures to be applied to organic land

Source of manure	*Treatment*
Straw and farmyard manure (FYM) from acceptable non-organic sources	Stacked for six months OR properly composted for three months
Manures from non-organic straw based pig units and extensive non-organic poultry units	Stacked for 12 months OR properly composted for three months
Slurry from acceptable non-organic sources	Aerated

The Soil Association standards relating to manure, compost and supplementary nutrients are currently under review. Please refer to the Soil Association for latest developments.

The Soil Association standards make further recommendations for manures being applied to land used for the production of horticultural crops. These are designed to ensure that any risk of pathogen transfer from manures to 'ready to eat crops' is minimised. Table 2 (overleaf) details recommended treatments and time periods between application and harvest.

Timing and volume of application

The organic standards encompass a number of

Table 2: Recommended treatment of manures that are applied to organic land in horticultural use

	Non-organic origin		Organic origin	
Material	*Treatment*	*Harvest interval*	*Treatment*	*Harvest interval*
Slurry	Aerated	One year	Aerated	One year
Fresh manure	——	Prohibited	——	Six months
Stacked manure	Six months (cattle) or 12 months (pig/poultry)	Three months	Three months	Three months
Composted manure	Three months (cattle) or six months (pig/poultry)	Three months	Two months	Two months

Note: The Food Standards Agency (FSA) are likely to develop new regulations regarding the treatment of manure and its application to ready to eat crops.

measures to ensure responsible use of manures to prevent environmental contamination. Measures include:

- The total amount of manure applied must not exceed 170 kg of nitrogen per hectare per year on average across the holding or linked holdings. In addition, the Soil Association standards prohibit the application of more than 250 kg nitrogen per hectare per year on any one area of land. This equates to approximately 28 tonnes and 40 tonnes of cattle manure per hectare per year, respectively. These limits are based on the *DEFRA Code of Good Agricultural Practice for the Protection of Water*. Where land is in a Nitrate Vulnerable Zone, local limitations may also apply
- The spreading of slurry on to frozen ground is prohibited, as is the spreading of manure less than 50 metres from waterways or 100 metres from bore holes
- The storage and composting of manures indoors, under breathable sheeting, or on hard standing where leaching can be prevented (or intercepted) is recommended. It is also recommended that applications of manures and slurry should take place onto fertility building crops, grassland and cropped land in spring and summer when plant physiological demand and nutrient uptake is highest
- Standards also require that over winter storage capacity is adequate.

Composts from non-agricultural origin

Composts from green waste composting sites, which shred and compost plant waste from parks and gardens, are becoming more widely available. This is classified as 'municipal waste'. These are acceptable under organic standards and are compatible with basic principles of recycling organic matter. Suppliers may need to provide a heavy metal analysis of the end product, as well as being able to declare that no genetically modified ingredients have been used.

2.4 Supplementary fertilisers

Plant wastes and manures should form the basis of the farm's strategy for building and maintaining soil fertility, in combination with a sound rotation. Other materials permitted for use within the organic standards, such as rock potash and rock phosphate, should be regarded as supplements to sound system design.

It is likely that permission will need to be granted by your certification authority prior to any application of supplementary fertilisers, and a soil or foliar analysis will be required to justify usage. Recourse to such products may be required to address imbalances early in the farm's conversion to organic management. Problems can also occur on sandy soils which are very deficient in potash or trace elements. For further information on supplementary fertiliser products refer to the Soil Association fact sheet 'Fertilisers for use in Organic Production'.

3. Understanding soil

3.1 Soil health

Soil health is central to organic farming, but its potential has not been fully explored. At its heart is the idea of the soil as a living, dynamic entity that functions in a holistic way depending on its condition or state. It also allows comparisons with our own health. Phrases such as 'soil sickness' and 'feeding the soil' take on a real meaning when soil is managed and treated as a vital living system.

Soil health relates to the capacity of the soil to function as a living system, sustaining other organisms and the surrounding environment. A healthy soil will support crops and livestock without recourse to inputs of artificial pesticides or fertilisers. Although it must also be recognised that many soils are naturally deficient in some trace elements, such as selenium or copper, and that some elements may require replacement as a result of the sale of crops off the farm.

The health of the soil is dependent on the biological, physical and chemical components and how these interact. While there are traditional tests for chemical content of the soil, soil compaction and fertility, there is very little reliable information on how to test soil biology. Regrettably it is therefore very difficult to measure soil health. Work has been carried out in the United States to develop field test kits considering biological, physical and chemical factors for specific geographical regions. Application of this technology would be of value if developed for UK farm and soil conditions.

3.2 Soil biology

While the chemical and physical properties of soils have been thoroughly investigated, the critical link – soil biology – has received less attention. One gram of healthy soil can contain over one billion organisms, with over 10,000 different species of bacteria. We know the function of a number of these species, but for most their roles are unknown.

Bacteria are the most dominant group, potentially making up 600 million organisms within one gram of soil. The function, shape and size of these bacteria vary enormously; from root nodule forming nitrogen fixers, through to large fungi-like bacteria (*actinomycetes*), responsible for the earthy smell of healthy soil via the release of a chemical called geosmin. Soil fungi have a number of important roles; from the physical breakdown of organic matter by fungal hyphae through to providing a nutrient bridge into plant roots. Protozoa, which mainly feed on bacteria, make up around 10,000 organisms in one gram of soil, with sizes of about 1/150mm.

The ratio of fungi to bacteria depends on the type of system. The predominance of fungi tends to increase in perennial plant situations where fungi are better suited to breaking down hard to digest organic material. For example, fungal-dominated soils are most noticeable in established deciduous woodland ecosystems where several hundred metres of fungal *hyphae* are likely in each gram of healthy soil.

Nematodes, although not nearly as numerous as the bacteria or fungi (with under 50 in one gram), have a number of important roles, including nutrient cycling and disease suppression. While some nematodes are agricultural pests, many others play an important role in soil transformations, including suppressing other pest species.

Of the more visible soil organisms, perhaps the most important are worms. The UK has 25 different species of earthworm, but ten are common. They play a critical role in mixing and aggregating surface leaf litter with soil, as well as improving soil structure and microbial decomposition of organic matter.

Soil arthropods, such as mites, springtails and beetles, are very important in breaking down organic matter. Many also feed on potential crop pests. On average up to 300 arthropods are present in one square metre of healthy agricultural soil. The critical management message is to ensure a constant food supply for these soil organisms in the form of 'fresh' soil organic matter for example from crop residues, green manures, composts, and FYM.

Soil biology is very important for farming and the environment because the activities of soil organisms affect the functioning of whole ecosystems.

At present the levels of biodiversity in the soil necessary to carry out essential roles are uncertain but undoubtedly they are very large. Aside from nutrient cycling, soil biology performs a number of other essential functions such as disease suppression or degradation of pollutants.

Disease suppression

The first step in effective disease suppression is to achieve healthy plant growth by supporting effective microbial nutrient cycling to deliver nutrients for optimum crop health. But the microbial components of the soil serve to protect against disease in other ways:

- The microbial soil community around the root zone makes use of available resources, leaving little for opportunistic soil-borne pathogens. They effectively 'out-compete' pathogens

- The complex and diverse microbial community, which exists around the root zone and on leaf surfaces, make it difficult for plant pathogens, such as *Pythium*, to penetrate
- Some soil organisms like the *Vampyrellid amoebae* attack fungi, such as *Gauemannomyces.graminis*, that cause take-all in cereals
- Organisms within the soil produce a wide diversity of chemicals, some of which are suspected of having toxic or antibiotic effects on pathogenic organisms
- As non-pathogenic organisms come in to contact with the plant root they can trigger an immune response, similar to the mechanism of vaccination in humans or livestock. This is logged in the memory of the plant which can then combat future attack by pathogens that are related to the non-pathogen.

Degradation of pollutants

Soil has often played the role of the 'universal dustbin'. All kinds of waste have been dumped into the soil, either intentionally or accidentally.

Remarkably, soil organisms have a great ability to decompose pollutants, ranging from nitrate fertilisers to organophosphorus pesticides. Much of this biochemical versatility is due to the capacity of bacteria and fungi to decompose a wide range of natural and synthetic chemicals. This can be particularly useful in the remediation of soils contaminated with materials such as fuel oil. However, there is a limit to their ability to cope with pollutants and in high concentrations, or when repeatedly applied, these chemicals can be toxic.

3.3 Soil fertility

Soil fertility is the condition which results from the operation of nature's round … there must always be a perfect balance between processes of growth and the processes of decay. The consequences of this condition are a living soil, abundant crops of good quality, and livestock which possess the bloom of health. The key to a fertile soil and a prosperous agriculture is humus.
Albert Howard, *An Agricultural Testament*, 1940

Organic farming must aim to build and conserve a bank of soil fertility. The balance of fertility will be dependent on what is removed from the soil and what is returned.

In simple terms, losses from the soil arise as a consequence of crop removal from the field, combined with leaching either through soil or across soil surfaces or through evaporation into the atmosphere. Organic matter, particularly in the form of compost, provides an ideal food source for soil microorganisms. It is the action of these organisms and the feeding of the soil with appropriate organic matter that generates sustainable soil fertility through the production of humus. In addition to humus, the soil's microorganisms also contain minerals and nutrients that are released and made available to plants through natural processes of regeneration.

What plants need and why

Plants require ten different macronutrients (calcium carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, chlorine, sulphur and magnesium) and another six micronutrients (iron, manganese, zinc, copper, boron and molybdenum) for growth. The main nutrient elements for plant growth are detailed in Table 3, facing page). However, many other trace elements are important for plant and animal health.

A fertility management programme based on returning organic matter to the soil delivers a broad range of essential nutrients for plant growth, rather than focussing on a selected few.

Humus – the soils bank of fertility

Humus has been recognised as one of the most important factors on the farm. Yet despite 200 years of scientific investigation, the precise composition of humus remains unknown.

It is clear that humus is dynamic and variable, and is derived from the microbial break down of animal and plant organic matter. The simple products of microbial degradation are converted to stable humic acids, such as fulvic and humic acid. These long chain humic compounds bind to clay particles in the soil to form a clay-humus crumb or 'colloid'. These colloids are fundamental to achieving good soil structure, while providing the basic currency for the soil's fertility bank. Plant roots specifically exude carbohydrates and sugars to stimulate microbial activity. In return, microorganisms process clay-humus colloids to release nutrients in a plant-available form.

Some of the properties of humus include:

- Serves as a storehouse of nutrients
- Practically insoluble in water
- Dark brown in colour
- Modifies the physical properties of soil, such as water holding capacity
- Can adsorb and help regulate cations, such as Ca and Mg, as well as pesticides and heavy metals.

Soil organic matter (SOM) to humus – the role of soil biology

Managing SOM is extremely important in organic farming. SOM provides a substrate and vital food source for biological activity, as well as being a major source of nutrients and playing a vital role in soil structure.

SOM plays an important role in soil water retention and drainage, as well as soil aeration. It also has an important role in regulating the cation exchange capacity (CEC) of soils.

Table 3: Main nutrient elements and their characteristics

Nitrogen (N)

Role in plants	*Primary sources*	*Plant availability*	*Gains*	*Losses*
Vital part of proteins and chlorophyll; too little causes early maturity and reduced yield	None in soil minerals; fixed from atmosphere by microorganisms	Only soluble forms directly available to plants; these are released from organic matter by microorganisms	Fixation by legumes; organic fertilisers; atmospheric deposition	NO_3 easily leached from soils; Nitrate can also be converted to gaseous nitrogen or oxide in warm, wet conditions

Phosphorus (P)

Role in plants	*Primary sources*	*Plant availability*	*Gains*	*Losses*
Key role in energy transfer in cells, DNA, cell membranes; too little causes root and shoot stunting and delays maturity in cereals	Soil minerals; amount in soil determined by soil parent material	Soil minerals rapidly absorb phosphate ions, where they become fixed and unavailable to plants; soil solution concentration therefore very low	Organic and mineral fertilisers	Only leached at very high soil indices; soil erosion is main route; causes eutrophic pollution of watercourses; crop uptake

Potassium (K)

Role in plants	*Primary sources*	*Plant availability*	*Gains*	*Losses*
Main role is in controlling water and ion balance in cells; too little causes general stunting; may be partially substituted by sodium	Soil minerals; amount in soil determined by soil parent material	Rapidly released by available soil minerals and exchange sites; readily available in soils	Organic and mineral fertilisers	Leaching losses can be high but most soils can sustain this through weathering of minerals; lighter soils more likely to be deficient; readily leached from manures and composts; crop uptake

Calcium (Ca)

Role in plant	*Primary sources*	*Plant availability*	*Gains*	*Losses*
Vital for the growth of new cells especially in the root	Soil minerals; amount in soil determined by soil parent material	Rapidly released by available soil minerals and exchange sites; readily available in soils; in most neutral or slightly acid soils calcium dominates soil exchanges sites; most soils contain sufficient for crop growth	Organic and mineral fertilisers	Leaching losses from soils high in calcium can be considerable but these soils can sustain this through weathering of minerals

(continued overleaf)

Magnesium (Mg)

Role in plant	*Primary sources*	*Plant availability*	*Gains*	*Losses*
Constituent of chlorophyll; also important in many enzyme reactions and energy transfer in cells	Soil minerals	Rapidly released by available soil minerals and exchange sites; readily available in soils; however liming and high K applications can induce deficiency	Organic and mineral fertiliser	Leaching losses from soils high in magnesium can be high but these soils can sustain this through weathering of minerals

Sulphur (S)

Role in plant	*Primary sources*	*Plant availability*	*Gains*	*Losses*
Some proteins and enzymes; mustard oils in brassicas; too little has profound effect on growth similar to nitrogen	Primary minerals, especially in marine derived soils; atmospheric deposition	Main form available to plants is mineral from clays and oxides; organic forms require microbial activity to make it available	Organic and mineral fertiliser; atmospheric deposition no longer sufficient to sustain crop growth; deficiency increasing	Leaching; fertilisers have little long lasting effect

Micronutrients

Role in plant	*Primary sources*	*Plant availability*	*Gains*	*Losses*
Mostly constituents of enzymes, most commonly copper, manganese, selenium and cobalt	Primary soil minerals	More available in acid soils except molybdenum	Deposition in dust, particularly near industrial areas; as impurity in some fertilisers; parent material	Not readily leached

Clay soils and silty soils generally have more SOM than sandy soils. The degradation of organic matter is also slower in clay soils than in sandy soils. Improving the organic matter content of sandy soils will lead to a major improvement in crop yield. Poorly drained soils also tend to have higher organic matter content than well-drained ones. Very high organic matter soils have a high water holding capacity; for this reason they can be very slow to warm up in spring. Typically well managed soils should contain the following levels of SOM:

- Light soils > 2.5 per cent
- Medium soils > 3.0 per cent
- Heavy soils > 3.5 per cent.

Soil organisms are responsible for decomposing organic matter to produce humus and make nutrients available to plants. When crop residues or compost are deposited on the soil surface they begin a complex journey, eventually ending up as essential nutrients that can be used by crops. The journey starts with a process of physical breakdown: larger soil organisms, such as worms, mites and insect larvae, feed on dead plant material and break up relatively large pieces of organic matter. Earthworms also have an important role in dragging organic matter from the soil surface into the topsoil.

Once in the topsoil microorganisms, such as fungi and bacteria, secrete enzymes which break down the complex molecules to their basic constituent parts. As enzymes only act on particular links in the organic matter molecules, a large number of individual organisms are required to ensure that these large molecules are broken into smaller units. It is the resulting simple molecules that form long chains, and which bind to clay particles to form the clay-humus crumb that is subsequently processed by other soil organisms to deliver plant nutrients.

In some plant species a symbiotic fungus called *arbuscular mycorrhiza* (AM fungi) can provide a link between plant and soil. In a healthy soil a large proportion of the plant root will be colonised by AM fungi, which aid the plant by improving nutrient and water uptake. Most crop species depend on or benefit greatly from mycorrhizal associations. AM fungi provides a living bridge between the soil and the plant root, transporting a steady supply of nutrients into the plant as needed. The fungal *hyphae* extend from inside the root, out into the soil expanding the plant's access to nutrients and water. Mycorrhizae also produce acids that convert phosphorus into plant-available forms before being transported back to the root and there is some evidence that this beneficial fungi helps protect plants from harmful fungal infection. In return for this, the fungi obtains energy and sugars from the plant, thus creating a symbiotic and mutually beneficial relationship.

So the journey is complete. A web of interacting organisms process organic matter originally deposited on the soil surface to produce humus. In turn, soil organisms interact with humus to deliver the range and quantity of nutrients needed for healthy plant growth.

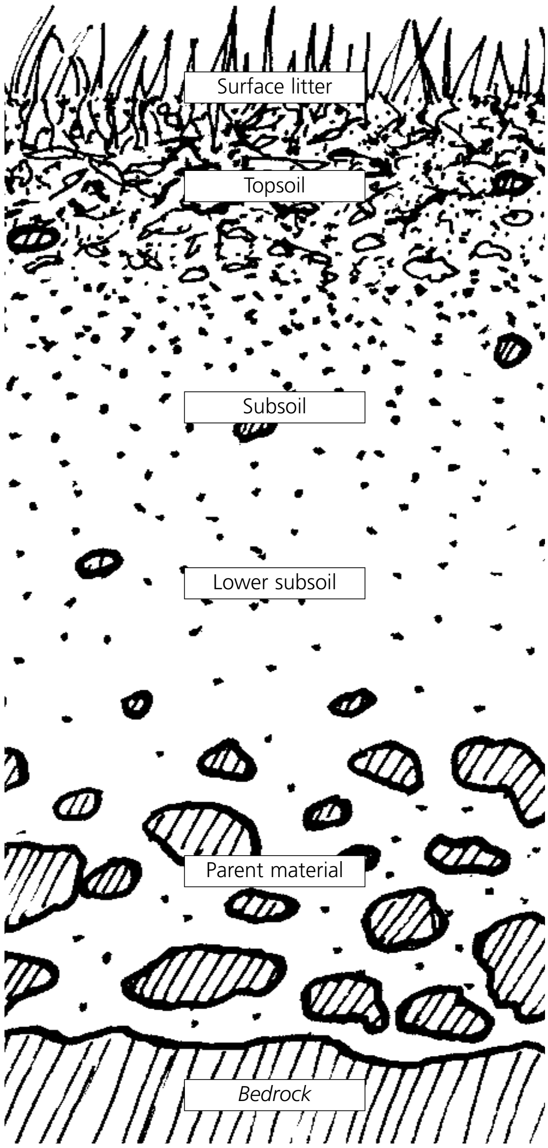
3.4 Soil types

Soils are formed over very long time periods and reflect past geology, climate, vegetation, landscape and human activity. In a soil pit successive soil horizons (distinctive weathered zones) are exposed, composing a soil profile (see Figure 1). These horizons vary in thickness and have irregular boundaries. Soil forming factors such as parent material (the geological precursors), climate and topography lead to different soil types. There are five main groups of soil types occurring in the UK.

- Brown earths. Fertile soils, characteristically pH range of 5.5–6.5, originally formed under broad-leaved woodlands
- Podzols. Acidic soils, leached of nutrients, formed under coniferous forest or heather moorland with distinct layers or horizons
- Gley Soils. Restricted drainage, formed under meadow, alluvium or estuarine conditions
- Peat. These soils are high in organic matter. Formed in cool climates and a product of anaerobic conditions. These soils are not necessarily acidic
- Calcareous. Characterised by high calcium content and a pH range of 6.5–8.0.

The pattern of soils can be very complex, often influenced by drift materials deposited above the parent rock material. Several different types of soil may occur on a single farm.

Figure 1: Soil profile



Source: Michael Hayter

3.5 Soil structure and texture

The physical properties of soil depend largely on the relative amounts of differently sized soil particles (soil texture) and their arrangement into aggregates (soil structure). Texture and structure together determine the amount and continuity of pore space for air and water movement, ease of tillage, root penetration and resistance to erosion and compaction.

Soil texture

The mineral fraction of soil is made up of sand, silt and clay. There are several systems of classification for particle sizes used worldwide, Table 4 shows the system used in the UK.

Table 4: Soil particle class size

Particle size class	*Diameter in mm*
Clay	<0.002
Silt	0.002–0.06
Fine sand	0.06–0.2
Medium sand	0.2-0.6
Coarse sand	0.6–2.0
Stones	>2.0

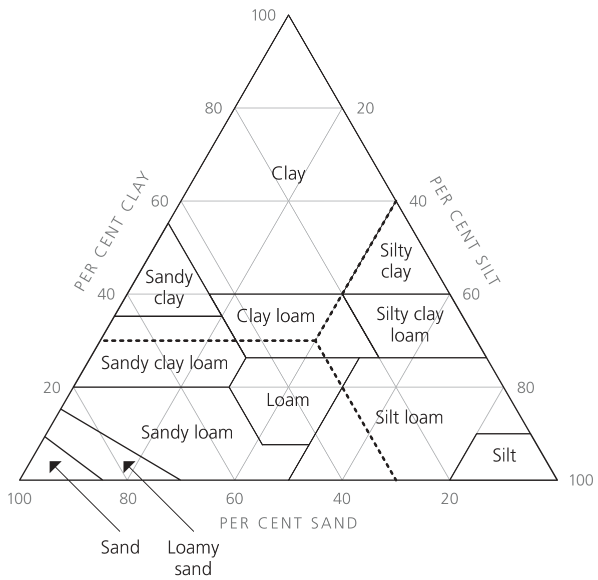
Source: Soil survey of England and Wales, British Standards and Mass Institute of Technology

The sand fraction is composed mainly of quartz particles and plays a more passive role in soil function. Silt particles are much smaller in size and originate from a mixture of different minerals, such as quartz or micas.

The smallest soil particles are clay formed from a mixture of minerals. Clay minerals are particularly important because they carry a negative charge, which attracts positively charged nutrient ions, such as calcium, potassium, ammonium and magnesium. Clay minerals therefore provide sites for minerals and nutrients derived from microbial break down of organic matter to stick to. This prevents these nutrients from being washed out of soil in drainage water (leached). Weathering of clay minerals and the action of microorganisms releases nutrients for plant uptake.

The relative proportion of sand, silt and clay results in texture classes. The percentage of sand, silt and clay can be determined through a soil analysis.

Figure 2: Textural triangle



Note: The three dotted lines indicate that a soil composed of 30 per cent clay, 30 per cent sand and 40 per cent silt has a clay-loam texture.

You may assess the soil texture using a simple in field test. Knead a small sample from the topsoil in your hands and knead it until all clumps have disaggregated. If the soil it's dry wet gradually. Enough moisture should be added to hold the soil together and show it's maximum stickiness. Follow the guidance in figure 3.

Figure 3: Method of hand texturing

Q1. Does the soil form a ball?
YES = go to Q2
NO = sand

Q2. Does the soil form a ribbon?
YES = go to Q3
NO = loamy sand

Q3. How long is the ribbon?

i. Less than 2.5cm long
smooth and slippery = silt loam
gritty = sandy loam
neither smooth not gritty = loam

ii. 2.5–5cm long
smooth and slippery = silty clay loam
gritty = sandy clay loam
neither smooth not gritty = clay loam

iii. More than 5cm long
smooth and slippery = silty clay
gritty = sandy clay
neither smooth not gritty = clay

Source: Dubbin W, 2001

Light textured soils (coarse sands, loamy sands through to sandy silt loams)

- Advantages: many cropping options, many cultivation opportunities to control weeds, tilth easily prepared, wide working window in spring and autumn
- Disadvantages: usually weakly structured therefore requires regular loosening, requires consolidation after deep loosening, low water holding capacity (unless irrigated), low nutrient holding capacity (need to work hard to maintain this), risk of wind erosion when crop small (leave surface rough or mulched).

Medium textured soils (sandy loams through to clay loams and silt loams)

- Advantages: generally quite readily form good seedbed, generally widely acceptable to a range of cropping and cultivation techniques, seedbeds retain moisture for rapid establishment, easily consolidated following deep cultivation
- Disadvantages: heavier end of medium may require weathering to form seedbed, optimum conditions for soil working more restricted than for light soils, structure easily damaged when handled wet.

Heavy textured soils (sandy clay to clay)

- Advantages: structure can be very stable once established, good water holding capacity provided drainage not impeded, self structuring clays lend themselves to non-inversion tillage
- Disadvantages: difficult to create seedbed unless weather dry and settled, very limited periods when soil workable, large power requirement for plough based cultivations, structure easily damaged if handled wet (smear, plastic), grass weeds can become difficult to control in rotations favoured on these soils.

Peat soils

Peat soils are often easy to work and fertile. They are generally well structured, they can be soft to travel on and, with inherently low density, require consolidation to ensure good root/soil contact. Many cultivated peat soils have shrunk and are partially oxidised and become mixed with mineral soils underneath. These generally take on characteristics closer to the mineral soil type depending on the relative proportions of each.

Soil structure

Soil structure is, to a large extent, determined by soil texture and can be defined as the arrangement of individual soil particles into clusters known as aggregates. Aggregates are formed when individual soil particles are brought together by physical and biological forces. Size and stability are two of the most important properties of aggregates. Stability is the ability of the aggregates to remain intact against trampling by animals, cultivation, weight of machinery, and water. Weak sand grains cannot form aggregates, while strongly interacting clay minerals can form stable aggregates. Aggregate stability is also influenced by factors other than soil texture. Micro-aggregates (<0.25mm) are held together by the interaction of clay, humus and sesquioxides (iron and aluminium oxides) which carry electrical charges that bind them together, and calcium carbonate which has a cementing effect. Larger macro-aggregates (>0.25 mm) are much more dependent on the biological activity of the soil to maintain stability.

Sandy soils have very poor structural stability and can often slump and compact in thin layers, especially above rock or chalk layers. Clay soils swell as they become wet. The soil cracks as it drys out which can help to improve soil structure. However, this relies on good soil drainage and good levels of soil organic matter to achieve this. Some assistance is often needed in the form of drainage and soil subsoiling to remove compaction by heavy machinery.

Small aggregates stick together into larger aggregates, resulting in a range of sizes with 'soil voids' or space between the aggregates. It is the pore space between aggregates that allows the movement of water, air, roots, and soil organism. If there are insufficient pore spaces, either because of compaction or because they are filled with water, then oxygen is depleted and carbon dioxide accumulates. This causes the soil to become anaerobic (oxygen deficient) and beneficial microorganisms cannot function resulting in poor plant growth. Instead, anaerobic organisms operate which produce reduced forms of manganese, iron and sulphur that are toxic to plants. These conditions are often characterised by an orange/ yellow colour in the soil and by a 'rotten egg' smell associated with anaerobic conditions.

With a handful of soil, good structure is obvious as the soil crumbles in your hand. A spade full of soil will also tell you a lot about its structure. A loose, crumbly soil with lots of pore spaces, good root penetration and plenty of earthworms indicates good structure. Presence of mole heaps, earthworm channels and casts indicate earthworm activity.

Well structured soils have better water entry, airflow and water holding capacity than poorly structured soils. It is easier for roots and earthworms to move through well structured soils. They are also resistant to capping and erosion.

Fungal hyphae growing through the soil serve to hold soil particles together in soil aggregates. These hyphae also break up larger soil particles to give good crumb structure, allowing oxygen to penetrate pore spaces. Some bacteria are also important, producing sugary gums that help to bind soil particles together. Good crumb structure enables the soil to resist compaction, aids movement of roots, improves drainage by helping to avoid run-off, and protects against soil erosion.

Careful management can improve soil structure but soil texture is much more difficult to change. Good management of soil structure requires an understanding of the soil. Perhaps the most important skill is the ability to observe and recognise problems early on, before they become difficult and expensive to correct.

Moisture has some effect on structural stability. Up to a point known as the plastic limit, the greater the moisture content the higher the stability. Above this limit, strength is lost and working the soil can cause serious damage, due to clay particles dispersing and then drying to leave dense clods. It is this process that leads to the formation of plough pans. The plastic limit of the soil varies depending on the level of clay and organic matter.

Soil temperature is an important physical factor which affects crop growth. Low soil temperatures reduce root growth and reduce the activity of microorganisms, which in turn reduces the supply of nutrients. Soil temperature is strongly influenced by the amount of organic matter and, even more importantly, soil texture. A heavy clay soil holds a lot of water which takes longer to warm up than drier sandy soils.

3.6 Nitrogen cycle

Lack of nitrogen (N) is the most common reason for poor plant growth. N can control the growth rate and state of maturity of a crop. Plants deficient in nitrogen often look pale and yellow, as well as having stunted growth. Many of the biological processes that make up the nitrogen cycle, like nitrogen fixation and mineralisation, have been explained in the section on soil microbiology (see section 3.2, 'Soil biology').

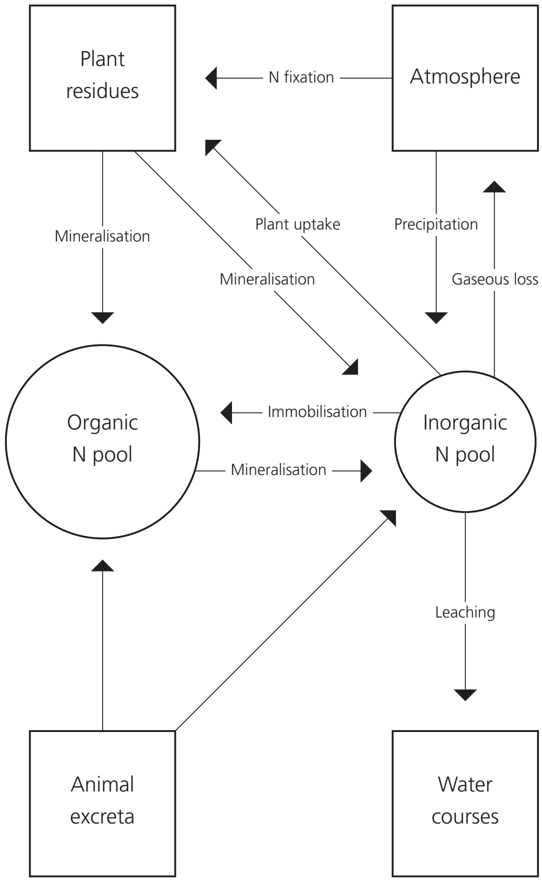
In organic farming systems, N is provided by the use of legumes in the rotation which fix N from the atmosphere, from recycling plant and crop residues, and from the addition of composts and animal manure.

Managing nitrogen so it is available when required by the crop is a huge challenge, mainly because the biological processes that influence nitrogen availability are heavily dependent on temperature and water availability. Figure 4 (right) also shows how manures and plant residues fit into the N cycle.

The inorganic N pool is made up of plant-available nitrate and ammonium, and it is also from this pool that there is a risk of environmental contamination.

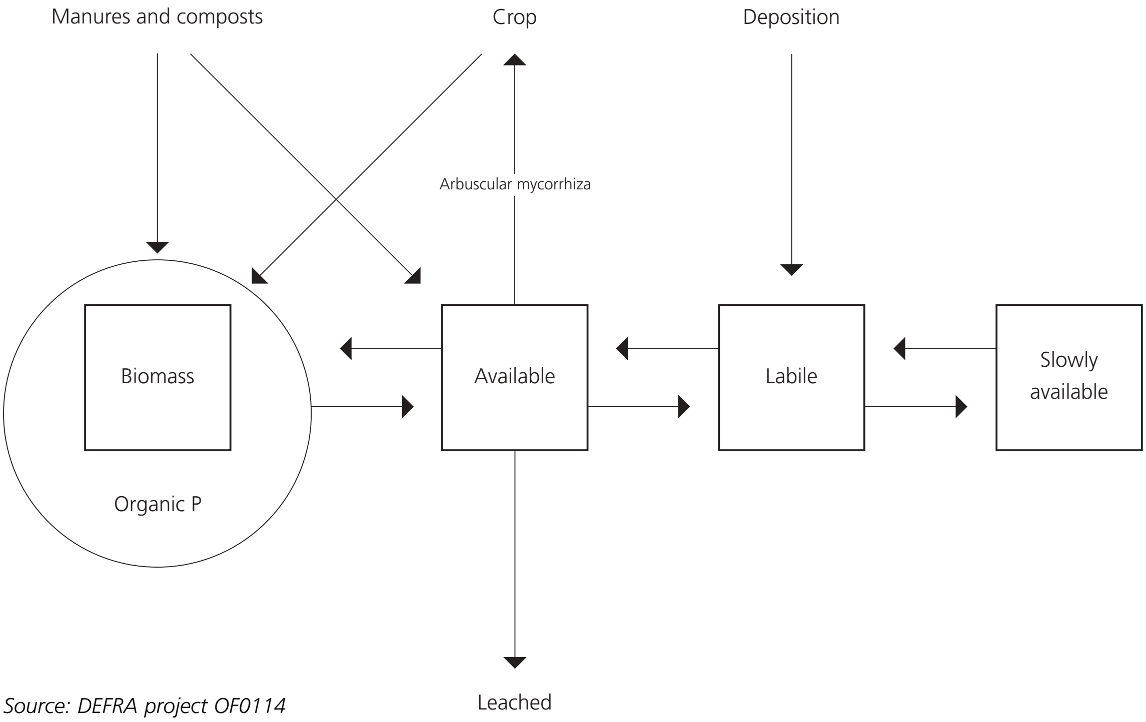
Nitrate leaching occurs when nitrate in the soil profile exceeds crop demand and the soil moisture content is high enough for drainage to occur. The point of major risk of nitrate leaching in the rotation is following the incorporation of leys. The challenge for organic farmers is to match the release of soil N to the demands of crops. Utilisation of different green manures in combination with cash crops or

Figure 4: N cycle in soils



Based on: Brady N and Weil R, 1996

Figure 5: Soil P cycle



Source: DEFRA project OF0114

as covers between crops, such as over winter green manures, is important to regulate soil N retention and loss. Losing nitrogen from the farm system limits yield potential and causes environmental damage, such as the pollution of watercourses or the release of greenhouse gases. Substantial losses of nitrous oxides and ammonia can occur during storage and spreading of manures. For further detail see Shepherd *et al* (2001).

3.7 Phosphorous cycle

Phosphorus (P) behaves very differently in soils to nitrogen. At any one time, the amount of P in the available pool is small and P must be released from unstable pools and from readily mineralisable organic matter to become plant available. Arbuscular mycorrhizal fungi can access P which is not available to plant roots and can play an important part in plant P nutrition. The effects of non-mycorrhizal crops in the rotation are discussed in section 6.2, 'Crop rotations and crop diversity'. The soil P cycle is illustrated in Figure 5 (facing page).

For long-term sustainability, P added to soils should replace the P removed in crops. Continued application of composts and manures will increase soil P levels. In soils already high in P, addition of composts and manures carries with it a risk of P run-off. Relatively small losses of P can cause substantial environmental damage through eutrophication, where nutrient enrichment causes excessive growth of algae and plants in watercourses.

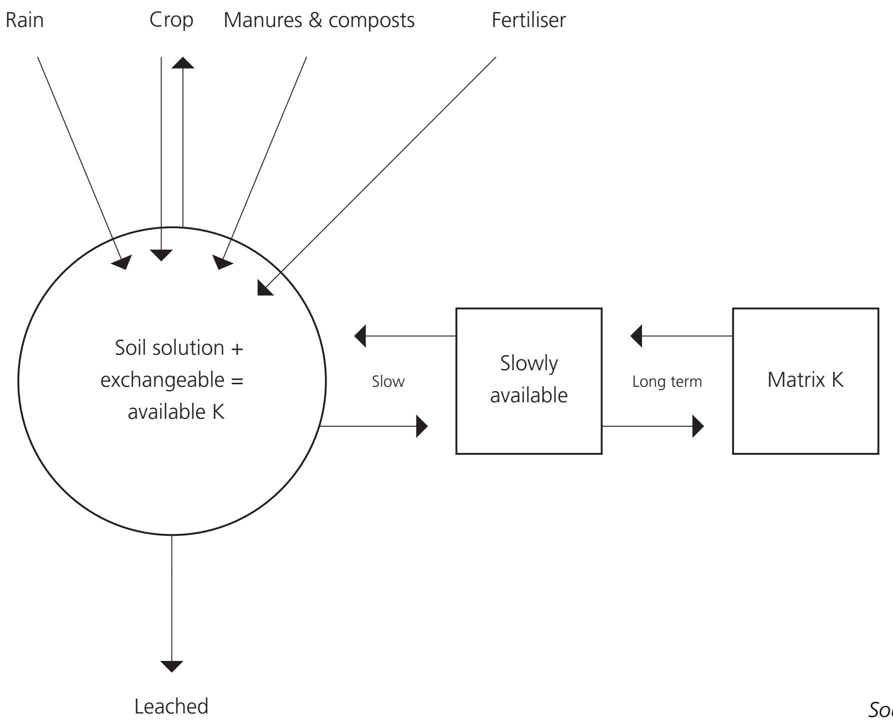
Phosphorus is mainly lost by surface run-off, in association either with soil particles or manure. In a review of phosphorus management of organic manures, Smith *et al* (1998) concluded that restricting topsoil extractable P levels to 70 mg/l (below index 5 using Olsen method – see section 4.3 'Interpreting results') should minimise the risks of unnecessary P enrichment and subsequent leaching. However, a much lower concentration of around 25 mg/l is adequate for crop growth.

3.8 Potassium cycle

Potassium (K) availability is much less dependent on biological processes than either nitrogen or phosphorus. The pool of plant available K is the K in soil solution combined with K which is readily exchangeable (see Figure 6, below).

Potassium can be leached from very sandy soils, and it can also be washed out of manure and compost heaps by rain. It is important to replace the K taken off by crops but the effect of crop removal on soil K differs according to soil type. On very sandy soils one forage crop can have a significant depletion effect, while on clay soils that contain high potassium reserves, deficiencies take much longer to appear.

Figure 6: Soil K cycle



Source: DEFRA project OF0114

4. Soil analysis

Soil analysis is the key tool for managing nutrient supply, crop nutrition and soil fertility on organic farms. However, its interpretation can be difficult and experienced consultants can help.

4.1 Testing for chemical analysis

A 'healthy', well structured soil is vital for organic production and it is important to monitor pH, organic matter and major and trace soil nutrients on a regular basis. Soil analysis can tell you the adequacy of the soil nutrient status for growing particular crops and, importantly, measure changes over time. However, it is really important to understand exactly what soil analysis tells you and how it is best used.

Standard soil analysis for phosphorus (P), potassium (K) and magnesium (Mg), or other nutrients (except nitrogen), estimates the quantity of these nutrients likely to be available to a growing crop, often termed 'plant-available nutrients'. The estimate is based on a chemical extraction of available nutrients. But it cannot predict precisely what will happen in the field, given the important influences of weather and soil biology on nutrient uptake. This is a shortfall for biological systems where much of the nutrient supply at any one time is stored in humus and soil organisms and is therefore not detected through chemical soil analysis.

When interpreting soil analysis it is also important to have an idea of the stone content in the field as this can have a major effect on nutrient supply. Most stones are removed before analysis, so if the soil contains 50 per cent stones the actual nutrient supply available to plants is only half that indicated by the analysis. Soil analysis indicates high, medium or low availability of nutrients, and is best interpreted with the help of a consultant who knows the soil type on your farm. Extractable P and K can change rapidly from year to year. The pools of soil organic matter and total N are so large in soils that changes can only be picked up over a longer time period.

Soil analysis is usually reported as the quantity of available P, K and Mg in terms of milligrams per litre of soil (mg/l). However, these are usually described in terms of indices which can be either numerical, as in the DEFRA system used in England and Wales, or descriptive, as in the SAC system used in Scotland (see Table 5, above right).

The indices indicate the amount of each nutrient available to the crop and, in the DEFRA system, range from 0 (deficient) to 9 (excessive). In addition, '+' and '-' index values indicate whether values are at the lower end of the index range or at the higher end.

Table 5: DEFRA and SAC soil nutrient levels

DEFRA (index)	*SAC (description)*
0	Very low
1	Low
2	Moderate
3	High
4	High
5	High

There are also alternative analytical and interpretive techniques for soil analysis that differ from the conventional approach. These alternative chemical soil analysis can point to causes of nutrient imbalances in the soil, determine the kind and amounts of nutrient inputs required, and could indicate the reason for deficiency symptoms in crops. This is particularly important during the period of conversion from a conventional to an organic system.

The soil analysis generally used by, and appropriate, to conventional systems often gives insufficient information for biological systems as it is possible that despite high rates of fertiliser being applied crops still continue to show deficiency symptoms. For this reason, a soil analysis must be as comprehensive as possible. There are a number of comprehensive soil analysis methods available, from a variety of service providers and laboratories in the UK.

One alternative method for determining soil P is the series of Balzer-P extractions. The Balzer extraction procedure involves the extraction of P by three different solutions; two per cent citric acid, double lactate, and sodium acetate and is thought to provide additional information on soil P by determining soil reserve, plant available and water soluble P (Balzer & Balzer-Graf, 1984). These extractions are not carried out sequentially. This may be particularly appropriate as the K extracted in the double lactate extraction is also thought to represent plant-available K.

For arable cropping and grassland, acceptable levels of P and K to maintain productivity are between 100 and 300 mg P per kg soil and between 100 and 200 mg K per kg soil, respectively, extracted in the double lactate extraction (EFRC, 1999).

Another common approach to determine 'soil health' was developed by Albrecht in 1916. This approach looks at the chemical balance and not just available quantities of elements such as P, K, Mg. The Albrecht method is based upon measuring the cation exchange capacity of the soil. Guideline targets for a correctly balanced soil should be 60–70 per cent calcium, 10–20 per cent magnesium, 3–5 per cent potassium, 10–15 per cent hydrogen and the remaining 2–4 per cent being made up of other bases including trace elements.

Soil mineral nitrogen tests may be appropriate to assess soils which have high N residues; for example, if high residues of organic manures, following outdoor pigs, or if soils were previously under long term grassland before cultivation. Soil N tests may also be useful to define the status to avoid excessive N application for narrow range N crops, such as milling wheat. However, soil N levels are very variable and testing has largely been used for the supplementary addition of N fertilisers in non-organic systems. Under organic management, where the addition of N fertilisers is prohibited, soil N measurement is less likely to be justified.

4.2 Sampling for chemical analysis

Soil analysis should be carried out at the start of the conversion period, as it provides a baseline for measuring future changes. Thereafter, soil analysis should be carried out regularly. As a minimum, soil analysis should be carried out twice during a rotation – once at the end of the fertility building phase and again at the end of the cash cropping phase. Extra analysis can be useful where you plan to grow a very demanding crop, such as brassicas or root crops like potatoes, when planning a new crop for the farm, or if you suspect that nutrient deficiency is occurring. You will get maximum value out of soil analysis by always sampling at the same time of the year and using the same sampling technique. Request that the laboratory uses the same methology as for previous analysis.

The best time of year for sampling is November to March when crop growth and soil microbial activity are limited. However, it is best to avoid times when the soil is extremely wet or dry. Walk across the field in a 'W' pattern taking at least five cores per leg of the 'W'. Aim for a total of 25 sub-samples per hectare.

Sample the top 20 cm of cultivated land and the top 15 cm of grassland. The aim of this is to get a sample which is representative of the field as a whole, so it is best to avoid areas that may be compacted or receive particularly high levels of dung and urine. In other words, avoid areas around troughs, feeders, gateways and trees. In addition, avoid sampling for at least two months after manure spreading.

The best tool to use is an auger or soil corer (3.5 cm diameter). If you do not have either of these you can use a trowel but this takes longer and requires very careful mixing to get a representative sample. Sample should be thoroughly mixed and sent for analysis in clean, well labelled plastic bags. Most labs require 300–500g of fresh soil for analysis. It is advisable to discuss procedures and requirements with the laboratory that will be undertaking the analysis prior to carrying out the sampling.

4.3 Interpreting results

Soil organic matter (SOM)

The organic matter content of soils is determined by analysing the total carbon content and applying a conversion factor. Arable soils generally contain between 1–5 per cent SOM. Regular additions of FYM and composts together with crop residues, such as green manures, cover crops and grass/clover leys, will increase soil organic matter over time.

Annual changes in soil organic matter are small and the effects of short-term leys or green manures are unlikely to be measurable. In a ley/arable rotation, soil organic matter will build up during the ley phase and decline during the arable phase. Crop choice during the arable phase will affect the rate of decline.

pH

Soil pH is a measure of hydrogen ion activity which influences root growth, biological activity and the availability of nutrients to crops.

The pH of the soil has a significant bearing on the availability of nutrients to plants. Crops have different pH requirements, as shown in Table 6 (below). It is important to note that in England and Wales pH is normally measured in water, giving a target of 6.5 for arable crops and 6 for grassland. The standard technique in Scotland is to use calcium chloride, giving a target of 6–6.5 for arable crops and 5.7–6.2 for grassland.

Table 6: Optimum pH (water) for crops

Potatoes, oats, rye	5.5–6.0
Grassland	6.0–6.5
Wheat, beans, brassicas	6.3–7.0
Peas, barley, lucerne	6.5–7.5

Annual crop losses may be up to 250 kg/ha calcium oxide (CaO), depending on crop and lime status, while leaching may lead to additional losses. Liming may be required every 3–5 years on non-calciferous soils but this should be in accordance with pH analysis recommendations. Chalk, limestone and magnesium limestone can all be used freely to raise soil pH on organic farms. Be aware that quick lime and slaked lime are prohibited. For advice contact Soil Association producer services.

The efficiency of different materials can be assessed from their quoted neutralising values, or CaO equivalent (neutralising value of CaO=100). A quicker response will be achieved from more finely ground products. However, it is important not to overlime, that is to raise the pH too high, as the plant availability of many trace elements is limited above pH 7.

Phosphorus

The two most commonly used reagents for extractable phosphorous (P) are Olsen, which is generally used in England and Wales, and Modified Morgans reagent used by SAC in Scotland. When using the actual values of P in mg/l as opposed to indices it is very important to distinguish between reagents, as the two scales are not directly comparable.

Table 7: DEFRA index phosphorus

	Desired minimum
Arable crops	2
Grassland	1+
Intensive organic horticulture	2+

Soil analysis does not predict the availability of P over time in organic systems. The routine measurement gives a snapshot value for the pool of available soil P but does not detect residues of rock P or the potential for P to be supplied from soil organic matter. However, by looking at changes in soil P levels over time and using nutrient budgets (see section 6.3, 'Nutrient losses and gains') it is possible to assess whether the rotation needs additional P to balance crop off-take.

Many soils are well supplied with P, particularly if they have recently been converted from well fertilised non-organic systems. Phosphate is tightly held by clays and so tends to be less available in clay soils than in loamy soils. Root crops have a much higher demand for P than cereals.

There are a number of sources of supplementary nutrients such as rock phosphate, which can improve soil P contents. Rock phosphate will not produce instant results, as it is very slowly released into plant available forms. This means that rock phosphate is not normally targeted at supplying P to one particular crop, but applied once in a rotation to maintain supply over the period of the whole rotation. In a ley/arable rotation rock P is normally applied during the ley phase. Rock phosphate should not be applied within four months of liming, because it is most available in soils with pH less than 6.5. Calcined aluminium rock phosphate is appropriate for alkaline soils; for example, with a pH of 6.9 or more. Some rock phosphate contains cadmium (Cd) and you should check the permitted Cd content with your certification body.

Composts release P slowly over time meaning that it is best to plan their application on a rotation rather than an individual crop basis. Manures (see section 5.2, 'Manures') and other organic materials usually give a much quicker result, for a number of reasons. Firstly, they contain some plant available P, and some P which is made rapidly available by soil microorganisms. The second reason is more complex: in low nutrient situations, P applied alone may not give a crop response because the crop is limited by the availability of N rather than simple P deficiency. By adding organic manure, you are supplying nitrogen and other nutrients that boost growth, as well as P.

Potassium (K)

Soil analysis measures the amount of plant-available K in soils. The two most commonly used reagents for extractable K are ammonium nitrate (England and Wales) and Modified Morgans (Scotland). As with P, when using the actual values of K in mg/l, as opposed to indices, it is very important to distinguish between reagents, as they are not directly comparable.

Reserves and long-term release of K is generally good on clay soils. Potassium deficiencies are more likely on sandy soils where K contents are low, and added K is readily leached. Root crops, such as potatoes, sugar beet and green fodder crops, have a much higher demand for K than cereal crops. Maintaining levels within an organic system is dependent upon operating a good rotation, maximising nutrient recycling and balancing potassium off-take in the crops against the returns through careful manure management, and returning all crop residues. As potassium levels are high in the straw of cereal crops, it is therefore important to retain and incorporate straw on K deficient soils.

FYM, compost, slurry and silage effluent are all useful sources of potassium. As with P, response to K can be limited by the availability of N, so crop responses may be more obvious from manure than from K alone. Covering heaps or windrows to prevent leaching by rainwater conserves potassium in manures and composts.

In some circumstances where there is a proven K deficiency, and the soil has a clay content of less than 20 per cent, supplementary additions of K may be allowed. Rock-based products are very slowly made available to plants. Natural potash products such as adularian rock-potash are restricted. Sulphate of potash is highly soluble and provides a quickly available source of K; however, for this reason its use is more highly restricted in organic farming.

Potassium derived as bi-product of crop processing such as Kali Vanesse and Raphinate is released to plants much more quickly than from rock forms. This means that application rates of these products should be matched against expected crop off-take and provided when crops are growing vigorously. It is important to

Table 8: Tolerance levels for trace elements

Element	Very low	Low	Medium/normal	High	Very high
Copper (Cu) (mg/l)	0–1.8	1.8–2.3	2.3–3.0 (risk) 3.1–4.0 (normal)		10.0+
Boron (B) (mg/l) (hot water soluble boron)	0–0.3	0.4–0.6	0.7–1.2	1.3–2.0	2.0+
Available cobalt (Co) (mg/l)	0.02–0.3	0.31–1.0	1.1–4.0	4.1–10	10.0+
Total selenium (Se) (mg/kg)	n/a	n/a	0.4	n/a	n/a

Note: Selenium – In sandy soils/podzols levels as low as 0.15–0.24 mg/kg are sufficient. In excess, levels of up to 7.0 mg/kg have been reported without deleterious effects on livestock health.

discuss forms and rates of added K with your certification body before application.

Magnesium (Mg)
Soil analysis indicates how much Mg is plant available. The two most commonly used reagents for extractable Mg are ammonium nitrate (England and Wales) and Modified Morgans (Scotland). As with P and K, when using the actual values of Mg in mg/l as opposed to indices it is very important to distinguish between reagents, as the two reagents are not directly comparable.

As magnesium is required by plants in much smaller amounts than either P or K, soil reserves are generally adequate. However, deficiencies may occur in sensitive crops, such as potatoes. Maintaining good levels of Mg is also important for livestock health.

Magnesium reserves tend to be low in sandy soils. As with all nutrients poor soil structure and drought can also cause deficiencies. The amount of available K can also affect Mg availability to plants; a very high ratio of K to Mg can cause Mg deficiency in plants. A ratio greater than 5:1 can cause problems in arable crops, and most horticultural crops are less tolerant. High K:Mg ratios can also cause problems for grazing animals; for example, staggers in dairy cows.

Recycling of manures is important for maintaining soil Mg content. Dolomitic limestone and magnesium rock, such as kieserite, are useful Mg sources. Epsom salts can also be used in cases of extreme Mg deficiency.

Trace element deficiencies
Soil analysis is not always the best method of diagnosing or confirming trace element deficiencies, especially where livestock are concerned. If you suspect crop trace element deficiency then tissue analysis or forage analysis is the best option. Similarly for livestock, blood analysis will show up trace element problems. Analysis of soil, forage and livestock in combination will help you in understanding the mineral transfer process from the soil, to crop, to livestock.

4.4 Testing for compaction

There are a number of methods for assessing soil compaction. Perhaps one of the most common methods is the ‘spade diagnosis method’, widely used in Germany, Switzerland and Denmark. It provides a simple method for assessing soil structure, identifying problems such as compaction, impeded drainage and restrictions to roots. The test helps to develop measures to maintain and improve soil health and productivity on the farm. The physical examination should be done with the help of an experienced adviser, but the skills can be quickly learnt. Once acquired this test should be done on a regular basis much like any other soil analysis.

Taking a sample
The samples taken should be representative of the field. You might need to do several tests if the field is very variable and especially if you know the field contains more than one soil type. In all cases, soil should be examined where there is good crop development, which is representative of the field.

To use the spade diagnosis method, at least one – and preferably two – spades are required. One spade will be used to lift out the soil sample. This spade should be flat, rectangular and have a smooth face. Insert it into the ground vertically using side to side, rather than backwards and forwards movements to avoid compressing the sample. Use the other spade to dig a trench in front of the sample. The result should be a block of soil about 30 x 20 x 10 cm which can be moved without undue disturbance or compaction.

Remove the block using the flat spade and a block of wood or your hands at the front to hold it together. Use a simple claw tool to separate the various parts of the soil without damaging the structure of the block. It is useful to have some form of support to hold the spade horizontally at a level suitable for working at while standing in the field.

Time of sampling

It is really important to do this when the soil is moist, so that compaction problems are obvious. Autumn or spring is the best time.

Examining the sample

The assessment should concentrate on the following key points. The observations should be noted immediately in the field including photographic evidence for use in future years.

Within the layer of coarse material identify

- Soil type, sand, loam and clay
- Stone content
- Soil layers, depth and colour of topsoil, subsoil, compaction layers
- Size of clumps if the block is thrown onto the ground.

Within the layer of fine material (tilth) assess

- True crumbs and false crumbs. True crumbs have large and irregular surfaces, are loosely put together with a lot of small air spaces. False crumbs have flat surfaces, are pressed close together and with hardly any air spaces
- Air spaces. They should vary in size, with many small and medium-sized ones
- Waterlogged layers. They create anaerobic conditions
- State of decomposition of plants, straw or manure. Yellow hard straw is an indication of low biological activity. Black, hard straw indicates lack of oxygen or waterlogging.

Assess root development

- Root system: fine and deep roots show high productivity of the root system and of the plant
- Branching of roots. They should be regular
- Root penetration and any impenetrable layers
- Thickness of roots
- Rhizobia on roots of legumes
- White roots indicate good aerobic activity.

Assess soil life

- Number of earthworm burrows
- Extent of visible soil-life activity.

5. Building soil fertility

Soil fertility should be maintained through balancing the processes of growth and the process of regeneration. In any agricultural or horticultural system, nutrients are removed from the system when crops and livestock are harvested and sold off the farm. This removal needs to be carefully balanced through good management to ensure that the fertility of the soil is not depleted.

Recycling of organic matter through manure and plant wastes, together with the use of leguminous crops to fix nitrogen from the atmosphere and a balanced rotation, should form the basis of a soil fertility management plan for organic farms. Organic matter, following microbial decomposition, not only provides a vital food source for soil life but is a well balanced source of all the nutrients needed by plants. It also helps to improve soil structure. Organic matter is most often returned to the soil through ploughing in grass leys and crop residues, or the direct application of manures. However, for many years organic farmers have promoted the benefits of compost as a better material for developing a healthy fertile soil.

5.1 Compost

Good compost is a source of stabilised nutrients generated through the microbial decomposition of organic matter in an aerobic environment to produce humus. The final product of an effective aerobic composting process is a stable and slowly degradable material, which provides a long-term source of soil nutrients.

The stability of the final compost means that losses through run off or leaching are much lower when compared with equivalent applications of fresh manure or slurry, which have a greater proportion of readily soluble nutrients. Apart from being environmentally beneficial, this also means that more nutrients are retained in the soil for use by subsequent crops. Furthermore, an effective composting process will destroy pests, pathogens, weeds and weed seeds, and toxins that may be present in fresh or stacked manure. Composts have also been shown to contain beneficial microorganisms that help to protect crops from disease causing organisms.

The process

Compost is produced as a result of an aerobic biological process. Initially, this is a break down process with organisms degrading large complex pieces of organic matter into simple molecules.

During this phase the organisms generate heat. Within about a week the temperature in the compost heap rises significantly from ambient to approximately 60ºC. If maintained at above 55ºC and below 70ºC for three days in an aerobic condition, this will kill human and plant pathogens. After this initial phase of about 14 days the temperature of the heap will start to drop as all organic matter in the heap is broken down.

In the second phase, new groups of organisms colonise the heap, feeding on the heat loving organisms. It is during this phase that long chain humic acid substances develop to bind to clay particles in the heap to form the clay-humus crumb. The addition of clay to the compost heap is important for this. In ideal circumstances, this build up phase takes a further four weeks.

Good compost production requires:

- Selection of appropriate ingredients. This is necessary to give the appropriate balance of carbon to nitrogen. The more diverse the ingredients, the more diverse the range of nutrients that are likely to be held in the end product compost
- Active management. Heaping manure in a field and leaving it for four months is not composting
- Oxygen throughout the heap. If the heap becomes anaerobic (without oxygen), beneficial organisms will die and toxin-producing anaerobic organisms will begin to colonise
- Water. Not too much to drive out oxygen but enough to support microbial activity
- Clay. To allow the clay-humus crumb to develop.

The practice

The most commonly adopted on-farm composting practice involves turning 'windrows' of organic matter regularly, usually with a front-end loader and a FYM spreader fitted with rear doors to form the windrows, or with specialist windrow turning equipment.

Windrows should be no bigger than 4 m in width and 2 m in height. Ideally, they should be covered with a breathable membrane in between turning operations. This cover helps to conserve moisture and limits emissions of ammonia in the early stages. It also prevents the ingress of rainwater and leaching of the valuable nutrients from the compost.

Where possible, the composting operation should be carried out either on concrete or hard standing with a slight slope. This will allow for machinery movement without soil damage and will prevent excess water accumulation. Where this is not possible it is recommend that composting is carried out in a designated site on the farm. This will help limit the severe soil compaction associated with turning operations and the spread of weed seeds from the bases of the compost heaps to isolated areas. It is also important that the ingredients, particularly those with a relatively high carbon content like wood chips, are well shredded. This increases the surface area on which microorganisms can act to degrade the material.

Getting things started

The nature of the ingredients at the start of the process will have a bearing on oxygen, moisture, carbon and nitrogen in the heap during the process.

It is important to choose appropriate ingredients to prevent problems developing during composting. The carbon to nitrogen ratio (C:N ratio) of the mixed ingredients should be between 20:1 and 40:1, and the moisture content 50-65 per cent. For further information on the C:N ratio of potential ingredients see Table 9 (below).

A front-end loader and FYM spreader fitted with rear doors can be used initially to construct the heap. However, regular turning of windrows to produce good compost may make the purchase of specialist turning equipment worthwhile. The cost of equipment will vary depending on the volume of compost to be produced.

Place carbon-based material such as straw at the base, followed by a layer of more nitrogenous material, such as vegetable waste, before another carbon-based layer and some clay to bind minerals and humic acids. It is advisable to add some soil and ready-made compost to the heap to ensure that the microorganisms needed for the process are present. It is possible to buy microbial starters that may also help ensure that compost is produced as quickly as possible.

Table 9: C:N ratio and moisture contents of compost ingredients

Material	*C:N Ratio*	*Per cent*
Vegetable matter	11:1–13:1	75
Cattle manure	11:1–30:1	67–87
Horse manure	22:1–50:1	59–79
Layer manure	3:1–10:1	62–75
Grass clippings	17:1	82
Hay	15:1–32:1	8–10
Straw	48:1–150:1	4–27
Paper pulp	90:1	82
Sawdust	200:1–750:1	19–65

Source: Northeast Regional Agricultural Engineering Service, 1992. Please note that values are representative.

During the first phase of the process, turning should take place regularly (twice a week) and temperature should be monitored. After the initial phase of heat build up, turnings can become less frequent, perhaps once a week. In order to ensure the process is progressing appropriately a number of parameters such as temperature and carbon dioxide should be recorded.

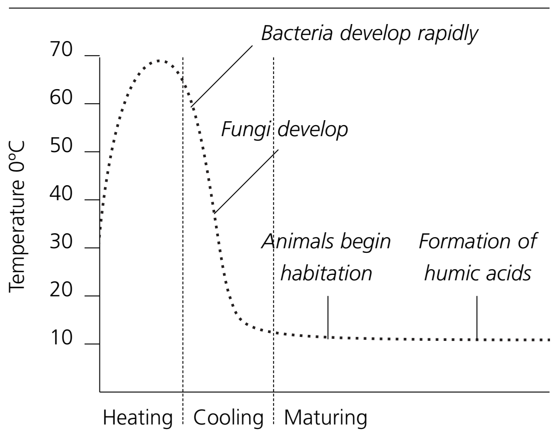
Aerobic windrow composting is the most popular composting method, and involves maintaining oxygen in the pile by regular turning

Assessing if composting has finished

There is some debate over the length of time needed to mature a compost, and Soil Association standards relating to compost are currently under review. If the process has been carried out effectively then the compost will contain stabilised nutrients and will be resistant to colonisation by pathogens. It will therefore remain of value for some time.

The key measure in assessing that the process is finished is temperature. After the initial rise, temperatures will fall before stabilising at ambient temperature. This is a good indication that the process is complete. Visually, the end product should resemble and smell like forest soils: dark brown in colour, friable and not giving off any unpleasant odour.

Figure 7: Typical temperature change in compost



Application

Compost has three great benefits in terms of application. It contains stabilised nutrients, so there is only a very low risk of leaching. It is free of human and plant pathogens, so timing of application in relation to ready to eat crops, such as salads, is not of concern, although new regulations may prohibit this. Lastly, the composting process can be very effective in destroying weed seeds, minimising the spread of weed seeds back to crop land.

However, nutrient release from compost will be gradual and is substantially influenced by the microbial status of the soil and soil temperature. Composting does not have a significant direct effect on K or P availability. The availability is more related to the amount of material applied than to whether it is applied in the form of manure or compost.

5.2 Manures

Careful use of manures and composts will supplement the effects of the rotation for managing soil organic matter and soil structure, and providing crop nutrients. The amount of organic matter and nutrients in manure will depend on livestock type and diet, bedding used and the manure production system (solid or slurry). Not all of the nutrients in farmyard manure become available in the year of application, about 80 per cent of K is available but only about one quarter of the N becomes available in this period.

The N:P ratio of manures is significantly smaller than the N:P uptake ratio of most crops. Manure application to provide N may therefore over supply P.

The following are examples of good manure management (for further information see Shepherd *et al*, 2001):

- Grassland. Apply solid manure in autumn/winter or slurries in spring
- Avoid applications on frozen ground and near water courses
- Arable crops. Rapid incorporation after application decreases the loss of nitrogen as ammonia
- Delaying applications (in particular those with a high proportion of readily available N) until late winter or spring will increase N utilisation by the crop
- Optimise manure storage.

Nitrogen is present in fresh manures in both soluble (plant-available) and more stable organic forms. The soluble forms, nitrate and ammonium, can be lost in run-off and leaching (see section 3.6, 'Nitrogen cycle, section 3.7, 'Phophorus cycle' and section 3.8, 'Potassium cycle'). Composts are stable products formed from manures and other organic materials where nitrogen is converted into more stable forms. Therefore, it is not as a good a source of instant nitrogen as fresh manure but releases nutrients slowly, thereby minimising nitrogen loss.

Table 10: Nitrogen content of manure

		Fresh manure	
	%DM	*kg N/t*	*kg P_2O_5/t*
Cattle FYM	25	6	3.5
Pig FYM	25	7	7.0
Dairy slurry	6	3	1.2
Pig slurry	4	4	2.0
Layer manure	30	16	13
Poultry litter	60	30	25

Source: Shepherd et al*, 2001*

5.3 Legumes, green manures and cover crops

As well as compost and farmyard manure, legumes and green manures are important sources of energy and nutrients, and will help support biological cycling and rich microbial diversity.

The benefit of legumes for soil fertility has been known for centuries. White clover has been part of the Norfolk four course rotation practised in England since the 17th century, and clover and other legumes form the key to nutrient management in organic farming today.

The legume root nodule is like a miniature biological factory: it contains large numbers of root nodule bacteria, known as Rhizobia. Rhizobia produce an enzyme called nitrogenase, which convert nitrogen gas in the atmosphere into ammonia. This association provides nitrogen in a form that plants can use, together with nitrate which is formed by another special group of soil bacteria, the nitrifiers.

Green manuring is the practice of incorporating plant material into the soil from a crop grown solely for the purpose of soil improvement. There are three different types of green manure: 'fixers', 'lifters' and 'retainers'. Fixers are legumes that can fix nitrogen from the atmosphere into their roots; lifters are plants that use up available nutrients in the soil, holding them in their leaf and stem structure; and retainers are quick growing plants which 'soak up' soil N and prevent leaching and loss.

Fixers produce nitrogen ready to be released into the soil 2–3 weeks after being incorporated. Fixers include species like red and white clover, vetches, crimson clover, lupins, lucerne and grain legumes, such as peas and beans. Lifters include crops like mustard, phacelia and ryegrass. Retainers include covers like forage rye, volunteers and even weeds. Green manures are usually, but not necessarily, incorporated in-situ and generally at the onset of flowering.

Cover crops are crops grown over winter to prevent loss of nitrate through leaching by using any available N in the soil as they grow while protecting the soil surface from erosion. The choice of plant species (lifter or fixer) and the length of time that the crop is allowed to stay in the ground will govern whether the cover crop provides any additional fertility to the soil.

Additional benefits of green manures and cover crops include improved soil structure through organic matter addition and varied rooting depth, as well as the control of weeds and pests. They can also have biodiversity benefits, providing food sources and habitats for both above and below ground vertebrates and invertebrates. In addition, the use of green manures over the winter period provides a living organic material in the form of root and above ground foliage which is a valuable source of food for soil microbial life. This helps to ensure that populations of soil organisms can be maintained during non-cropping phases.

Careful attention to the choice, timing and method of incorporation of green manures and cover crops can synchronise the mineralisation of the nutrients that they contain with periods of high crop demand. As with all recycled crop residues, depending on the C:N ratio of the green manure material and its breakdown characteristics, green manures and cover crops can increase availability of nutrients other than nitrogen to following crops. However, in some circumstances where the green manure material is highly lignified, for example grazing rye straw, incorporation can temporarily immobilise soil N in a carbon form. This could be detrimental to crops immediately following the green manure, but could help retain soil N for use by crops later in the rotation.

Green manure seeds can be expensive, so the place of green manures or cover crops in the rotation and their management should be carefully planned.

Although the incorporation of green manures or cover crops can have many beneficial effects, there may be associated disease risks. For example, plant pathogens with a saprophytic phase, such as *Rhizoctonia solani*, can multiply in plant debris. Factors that should be taken into account in choosing suitable green manures and cover crops include:

- Ability to fix N. Usually desired in a green manure rather than a cover crop
- Frost tolerance. Affects ability to retain N against loss
- Rooting depth. Influence on soil organic matter, nitrogen retention and soil structure
- Speed of establishment. Affects ability to prevent leaching and erosion
- Susceptibility to particular diseases. For example, the use of cruciferous green manures like mustard is not recommended before a susceptible crop, such as cabbages or in rotation with other brassicas
- Degree of ground cover. Affects ability to prevent leaching and erosion
- The C:N ratio of the green manure, breakdown characteristics and effect on immobilisation and release of soil N.

Grass/clover leys

Legume based leys are the principal fertility building crops in temperate organic systems. In mixed systems, white clover/grass leys are most common. Red clover is also frequently used, grown alone or with grass, and used for silage, grazing or as a green manure.

The choice of clover will be dependent on the situation and the length of time that the ley will be present. Red clover is recommended for short-term leys of up to two years. This tends to fix a greater amount of nitrogen than white clover in the first few years but after year three it is generally likely to be out-competed by other components of the mix. For leys that are intended to be present for a longer period of time (greater than three years), then white clover will be the preferred option. It is possible to mix both white and red clover in the mix to ensure that both short and long-term fertility building is taken into account.

It is recommended that adequate break periods between red clover are practiced. Ideally, these should be a minimum of five years to avoid the potential of soil borne pest build up associated with red clover, such as stem eelworm. This can be achieved by growing red clover in rotation with white clover or other leguminous green manures.

Grass/clover leys are also particularly beneficial in improving soil structure, due to the entrapping activity of roots, root hairs and fungal hyphae. Adding organic matter from root and leaf litter while the ley is growing, and after incorporation, is also important. The residual effects of leys can last for several years. As the improvement to soil structure from leys is largely confined to the surface layers of the soil where roots are concentrated, the use of deep rooting species in the mix, such as chicory or lucerne, can help to break up subsoil compaction.

Predicting the actual amount of nitrogen fixed by the green manure is difficult as it depends on many factors, including legume species and cultivar, proportion of legume in the ley, management (cut or grazed), weather conditions and the age of the ley. Clover/grass leys can fix up to 250 kg N/ha/year and lucerne up to 500 kg N/ha/year. DEFRA funded research (OF0316) is aiming to better understand N fixation rates, residual soil N and subsequent crop availability. Further information see www.organicsoilfertility.co.uk

Short season green manures

Other legumes, grown either as fodder or as green manures, may be used in the shorter term or under particular soil or climatic conditions. There are often opportunities within the rotation to sow summer or over winter green manures; for example, different types of vetches, lupins and trefoils. These do need to establish and grow rapidly.

Mustard, which is a lifter, is a common choice and provides a plentiful supply of organic matter to plough in. Mustard has an effect on limiting soil borne pests,

Table 11: Some key green manure crops and their characteristics

	Comments	Sowing rate (kg/ha)	Sowing depth (mm)	Sow by	Winter hardiness	Drought tolerance	pH tolerance (optimum)	Life cycle
N lifters								
Fodder rape *Brassica napus*	Good cover crop for growth and nitrate uptake	12	10	Early September	Good	Moderate	5.0–8.0 (6.5)	Annual
Mustard *Sinapis alba*	The best known quick growing cover crop. Can be killed by first frosts	24	10	Early September	Poor	Moderate	5.6–8.0 (6.5)	Annual
Stubble turnips *Brassica rapae*	Must be sown by early August	5	10	Early August	Good	Moderate	5.6–8.0 (6.5)	Annual
Phacelia *Phacelia tanacetifolia*	Known for its ability to smother weeds. Strong rooting system	10	10	Mid August	Poor	Moderate	5.8–8.0 (6.5)	Annual
Rye *Secale cereale*	A very popular winter hardy species	140	30	Early October	Good	Moderate	5.8–8.0 (6.5)	Annual
N Fixers								
Red clover *Trifolium pratensis*	Suitable for one or two years cover. Deep taproot improves soil	14	5	Early September	Good	Good	4.5-8.2 (6.2–7.0)	Perennial
White clover *Trifolium repens*	For longer term situation. A very good low growing fertility builder	10	5	Mid August	Good	Good	4.5–8.2 (6.2–7.0)	Perennial
Crimson clover *Trifolium incarnatum*	Tall growing species. Sown in summer for 2–3 months	14	10	Mid September	Poor	Moderate	4.8–8.2 (5.7–6.4)	Annual
Vetch *Vicia sativa*	A very good nitrogen fixer that can be sown with rye, ryegrass or cereals	60–120	30	End September	Good	Moderate	4.5–8.2 (6.2)	Annual

Source: Wilkinson I, 2002

such as wireworms, and is a useful green manure if these pests are a problem. It is important not to let the mustard flower as this may cause problems in future years from volunteers.

Phacelia is another lifter known for its ability to smother weeds. Like mustard, it grows rapidly and is only used for two months cover. It produces a mass of blue flowers, which are beneficial for bees, wasps and hover flies.

Crimson clover is an annual legume grown for two or three months. It fixes N and can be used as sheep keep, if required. Although it is usually recommended to incorporate green manures at the onset of flowering, you may feel inclined to let this one flower. It is the most visually attractive green manure with vivid crimson coloured flowers that will be attractive to insects, as well as humans.

Vetches can also make a good green crop within three months when sown in the spring or summer. Research work from HDRA has shown levels of 100–200 kg N/ha being available following vetches. Crops following after vetches tend to have higher yields. Vetches may also be ensiled or grazed with minimal effect on nitrogen availability for the next crop. Bear in mind that vetches can prevent seed germination when the seed is planted immediately after vetch incorporation.

For spring and summer sowing of green manures, sow the seeds just below the surface in a well prepared seedbed, rolling in to ensure consolidation and intimate contact with the soil. In wetter months, seeds can be broadcast directly onto a seedbed. Sowing may take place throughout the growing season until mid-August. Due to lack of frost hardiness, mustard, phacelia and crimson clover should not be sown beyond this date. Hardy plant species, such as winter vetch and rye, can allow late sowings to give good ground cover into colder winter weather.

Winter green manures

When sowing a green manure in the autumn to provide over winter cover before a spring crop, it is necessary to use a winter hardy species that will grow quickly.

There are only two species commonly used for this purpose – rye and vetches. Both can be sown as late as October, but they put on more growth when sown in August or September. Vetch fixes large amounts of N and is very easy to incorporate in the spring, while rye (not ryegrass) is a good lifter of nitrogen and creates a very good root mass, effectively increasing soil organic matter.

Both rye and vetches have large seeds and should be sown with a corn drill at a depth of 25–35 mm. Neither have any serious pest problems, nor is it important to use winter varieties. Rye should be incorporated in March or April before the seed heads can be felt at the base of the stem. Vetches may be left until the onset of flowering. It is possible to sow mixtures of rye and vetches to deliver a more balanced supply of nitrogen over the season.

6. Protecting soil fertility

6.1 Avoiding run-off and erosion

A top priority of organic farm management is to minimise soil and nutrient loss in run-off and erosion. Soil erosion can be detrimental to soil biodiversity, and affects crop yields and soil quality. It can result in reduced nutrient storage capacity, poorer soil structure, and decreased water holding capacity and soil depth. Soil can be eroded away by wind and water.

Nutrient loss and sediment erosion are also major contributors to the pollution of watercourses. Estimates for England and Wales suggest that around 2.3 million tonnes of soil was lost from arable soils in the period 1995-1998. A substantial proportion of this loss was associated with low levels of erosion from large areas of soil classified as being at low or negligible risk of water erosion. Good soil management can largely eliminate these low-level losses. For detailed advice see DEFRA's *Code of Good Agricultural Practice for the Protection of Soil*, DEFRA's *Controlling Soil Erosion*, the Environment Agency's *Best Farming Practices: Profiting from a good environment* and the Scottish Executive's *PEPFAA Code*.

Erosion by water

Soil texture, soil structure and slope are very important in determining erosion risk. Soils which are low in clay and high in silt, fine sands, and steeply sloping fields, are most at risk. Well structured soils are much less at risk than poorly structured soils. Identify areas of the farm or parts of fields where erosion is a risk and include measures for dealing with that risk in your conversion or management plan:

- Avoid inappropriate crops, such as maize and root crops on vulnerable fields
- Avoid cultivating slopes over nine degrees
- Cultivate across slopes, wherever possible
- Avoid cultivating and planting in wet conditions
- Avoid unnecessary fine seedbeds for late established crops
- Use grass and buffer strips to reduce downslope lengths
- Maintain soil organic matter levels and good soil structure
- Maintain ground cover for as much of the year as possible
- Reduce run-off from roads, tracks and concrete areas by ensuring adequate drains and ditches
- Maintain drainage systems and ditches.

Erosion by wind

The key to avoiding soil erosion and nutrient run-off is good management practice: sound rotations, maintaining cover, appropriate cultivation and efficient nutrient management. Measures to minimise wind erosion include maintaining the soil organic matter content and ensuring good soil structure, ground cover, trees and hedges.

Shelter belts can have an effect over a distance up to 20 times their height. These should be carefully sited in relation to the prevailing wind direction.

6.2 Crop rotations and crop diversity

Crop rotations play an essential role in maintaining soil fertility, as well as in controlling weeds, pests and disease.

Rotation design

Most organic rotations consist of a 'fertility building phase' and a 'fertility depleting phase'. The fertility building phase contains a high proportion of legumes (see section 5.3, 'Legumes, green manures and cover crops'). 'Fertility building' is a commonly used term but this is a nitrogen building phase as legumes cannot add P and K to the system. The fertility depleting phase normally comprises non-leguminous crops sustained by nitrogen mineralised from the residues of incorporated legumes and applications of manure and compost. Soil P and K levels can only be increased through bought-in nutrient sources. It is however very important that good management practices (see section 5.2, 'Manures' and section 6.3, 'Nutrient losses and gains') are employed to prevent loss of nutrients from the system.

Rooting patterns

Crops with different rooting depths and rooting structures are important for ensuring the whole soil profile is exploited. This can be particularly important in horticulture, where many crops are shallow rooted and there is the potential to deplete surface soil layers of nutrients.

Crops with different rooting patterns can be included either as individual courses of the rotation or as components of intercrops. Forage herbs, for example, are commonly mixed with several varieties of clover and grass to provide different sward structures both above and below ground.

Other important rooting characteristics include the ability to form mycorrhizal associations in low soil P situations. Non-mycorrhizal crops, such as *Chenopodiaceae* (goosefoot family) and brassicas, can decrease the growth, P uptake and yield of following mycorrhiza dependent crops, such as maize.

Cash crops

Once the ley is incorporated, nitrogen in the residues is released into plant-available forms by soil microorganisms (mineralisation). Nitrogen demanding cash crops, such as wheat, potatoes or cabbages, are usually grown immediately after the ley in order to maximise utilisation of the large amount of nitrogen released in the season after incorporation.

As a general guide, the amount of N available in the first year will be around 40–60 per cent of the total amount of N in the legume, with much smaller amounts of nitrogen available in following years. In the later years of the rotation, less nutrient demanding crops, such as oats, triticale or carrots, can be grown as the amount of nitrogen released from the incorporated ley declines each season.

To avoid soil N loss, it is critical that the ley is incorporated appropriately. Incorporation in June or July when soils are warm and microbial activity is high followed by long periods of bare ground, should be avoided, to minimise leaching losses. Where possible, retaining leys to spring incorporation and following with spring established crops, which can grow and absorb soil N as the soils warm in the spring, should be considered.

Break crops

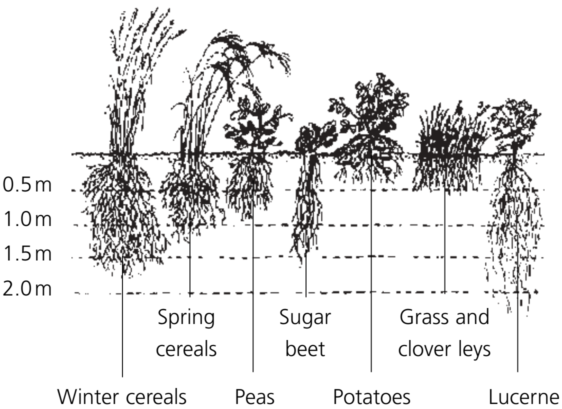
Break crops, such as non-cereal or grass crops, are important in the arable component of the rotation in mixed systems, as well as in stockless situations.

A break crop may perform several functions: nutrient addition, conservation and cycling, improvement in soil physical characteristics, pest or disease control, weed control as well as producing satisfactory yields.

Maintaining cover

Periods of bare ground between cash crops should be kept to a minimum, as bare soils are very vulnerable to erosion by wind and rain, as well as nitrate leaching. Careful rotation design, taking into account sowing and harvest dates and the use of cover crops, can minimise bare ground. Undersowing cereals with a new ley is a good way of establishing cover before harvest, preventing a period of bare soil.

Figure 8: Rooting patterns



Source: Boatfield G, 1964

Cultivations

Another factor to consider when designing rotations is cultivations. Although necessary for seed bed preparation and weed control, cultivation results in mineralisation of nitrogen and loss of organic matter. Cultivating in wet soil conditions, such as sowing spring cereals in a wet spring, can damage soil structure to such an extent that it may take several years to remedy.

Limiting the depth of cultivations can be important in minimising the disturbance to soil life and loss of soil N via mineralisation.

Excessive use of mechanical weed control in row crops can also be damaging, and increase the risk of soil erosion. Reducing frequency in the rotation of crops that are likely to lead to soil damage, and being flexible enough to change the rotation if weather and soil conditions dictate, can help reduce these problems.

Variety and species mixture

In organic systems, both variety mixtures and species mixtures (intercrops) are potentially useful for optimising nutrient use, controlling weeds, pests and diseases, and for reducing soil erosion and leaching through increased ground cover. This is because crops and species exploit different pools of soil nutrients, have different rooting patterns, growth dynamics and mycorrhizal status.

Intercropping leguminous and non-leguminous crops is of particular interest for organic systems and is commonly used in forage crops such as grass/clover leys, and arable silage crops such as cereals and peas. The inclusion of species such as forage herbs in leys has the added attraction that herbs have a different chemical profile to many other species, providing a wider range of micronutrients for livestock.

Intercropping is less common in arable crops, although undersowing of clover into cereals is a common practice for establishing leys, and there are successful examples of intercropping grain legumes and cereals. Cereal/legume intercrops can be particularly beneficial in increasing earthworm populations. This seems to be due in part to reduced soil disturbance in a semi-permanent white clover understorey, but also to increased food supply from clover roots (Schmidt *et al*, 2003).

Studies of intercropping of vegetables and fertility building crops indicate that competition between the crop and the legume can be a major problem. The understorey crop must be controlled by mowing or cultivation techniques and the cash crop must be more widely spaced than normal. This is an area that has great potential but requires development.

Multiple aims

A primary difficulty in designing rotations for organic farming is the complexity of managing soil fertility for multiple aims, which are often conflicting. Potatoes, for example, benefit from high nitrogen availability but can suffer from wireworm damage if grown immediately after incorporating a long grass/clover ley. As well as controlling pests and diseases, rotations can help to control weeds. Proportion of ley is particularly important for controlling arable weeds. Ultimately, a rotation needs to reflect a number of different factors, such as previous experience, soil type and climate constraints, markets and labour availability.

6.3 Nutrient losses and gains

Minimising pollution from agricultural activity is one of the basic principles of organic production. Sections 3.6, 'Nitrogen cycle', 3.7, 'Phosphorus cycle' and 3.8 'Potassium cycle' explain where N, P and K can be lost from the farming system and pollute the environment.

Organic farm management plans need to identify high-risk points for:

- Leaching
- Erosion
- Gaseous nutrient losses.

Gaseous and leaching losses also need to be considered when planning management of housed livestock and manure handling.

Agricultural pollution occurs either in a chemical form (nitrates or other nutrients) or in a physical form such as soil particles with soil-attached phosphorus, which are often associated. Pollution can occur from a single identifiable source when a pollutant such as manures or silage effluent contaminates surface or groundwater. More often, however, pollution is the cumulative effect of a number of minor incidences over time, or of a number of fields within a catchment area.

Nutrient budgets

A nutrient budget takes account of inputs versus outputs. The aim is to achieve an approximately neutral nutrient balance. If the balance is positive in excess, then nutrients may be lost to the environment; conversely if the balance is negative, this can lead to the depletion of soil fertility. The farm nutrient balance can also provide a guide to the efficiency with which imported nutrients are converted into produce.

A simple budget is constructed by taking account of inputs such as the nutrients contained in applied manures, composts, bought-in feed, atmospheric deposition and, in the case of N, fixation by legumes, together with crop residue returns. These are offset against export in cash crops, crop residue exports, such as straw, meat sales or milk, and estimated leaching losses. Inputs and outputs in commodities that are bought and sold can be calculated from farm records and the nutrient content of the materials noted.

Budgets will be most accurate where the nutrient content of different materials has been analysed. When this is not available standard figures can be used. Such figures are widely available for conventionally produced materials and more figures from organic farms are gradually becoming available. Care should be taken when using standard figures as materials can be highly variable and factors such as storage period before application can affect nutrient composition.

In stockless and upland systems, nitrogen fixation and atmospheric deposition are the most important sources of N. In the dairy system, livestock feed is an important source of N, P and K. DEFRA has funded the development of software to support farmers converting to organic production (ORGPLAN). This programme calculates farmgate nutrient budgets.

Other factors are also important to consider. P and K inputs are often made to the ley phase of the rotation and then released into plant-available forms throughout the whole rotation. Manure and slurry is often applied to the fields around the farm buildings, simply because it is easy. In the long-term, this can result in loss of nutrients from outlying parts of the farm, and high soil P and K indices and high risk of losses in soils near the buildings.

Nutrient budgets are not a substitute for soil analysis. However, using nutrient budgeting with soil analysis will provide great insights into nutrient management on your farm. Contact Soil Association producer services for further information.

6.4 Cultivations

The main reasons for cultivating soil:

- Control of weeds, diseases and, occasionally, pests
- Management of soil structure and creating of tilth for seedbed
- Repairing damage caused by compaction
- Incorporation of crop residues, green manures and leys
- Incorporation of manures and other amendments.

When planning cultivations the type and intensity, timing, appropriateness for soil type, and frequency need to be considered. A range of cultivations should be used in rotation to minimise the potential build up of detrimental cultivation layers, often called 'plough pans'.

Cultivation options

All of the objectives listed above can be achieved using cultivation based on the mouldboard plough. Mouldboard ploughing inverts soils, covering crop residues and weeds and exposing fresh soil at the surface. This allows a fine clean seedbed to be produced relatively easily with one or more secondary cultivations.

However, there is increasing concern that regular use of mouldboard ploughing may cause long-term damage to soil and plough pans (compacted layers) can occur after repeated ploughing to the same depth. Inversion of the top 30cm of soil can be highly detrimental to soil microorganisms, particularly the fungi and soil animals, especially earthworms. The inversion process places aerobic organisms in anaerobic conditions and visa versa. Ploughing should therefore seek to go no deeper than is necessary, ideally 10–15 cm. Good inversion and burial can be achieved with the right type of plough at this depth. However, using a semi-digger plough body is unlikely to be able to achieve adequate results as these ploughs are designed to invert at deeper depths of ploughing. Specialist advice should be sought about the suitability of equipment.

As all forms of cultivation lead to organic matter breakdown and the release of nitrogen it is important to achieve a balance between the benefits of cultivation and the loss of organic matter and nitrogen in designing rotations.

To achieve a seedbed, a combination of primary and secondary cultivations is normally used. Secondary cultivations can be combined with drilling which minimises ground pressure from machinery, reducing damage to soil structure. Overworking of the soil from the overuse of power harrows or stone separators,

Table 12: Main cultivation techniques with advantages and disadvantages

Cultivation method	Main uses	Advantages	Disadvantages
Mouldboard ploughing	Incorporation of crop residues and amendments	Produces clean field	Disrupts soil life; exposes organic matter; can cause plough pans; energy intensive
Disc plough	Incorporation of crop residues and amendments	Quicker than mould-board; no plough pans; useful in very hard soils	Does not completely bury residues; less effective in wet soils; can chop and spread rhizome weeds
Chisel plough	Tearing soils up at depth	Retains soil profile	Likely to require two passes at an angle, therefore energy intensive
Spading machine	Primary cultivation	Does not damage soil structure; especially useful on silts; low energy requirements	Expensive machine; low work rate
Disc harrow	Shallow cultivation for incorporation of residues; secondary cultivations on ploughed ground	Cover large areas quickly; useful for breaking up heavy soils	Does not incorporate residues well; can damage moist or compacted soils; can chop and spread rhizome weeds
Rotary cultivators	Incorporation of crop residues and amendments	Fair mixing of soil and residues	Poor burial of residues; very damaging to soil structure; high running cost; can chop and spread rhizome weeds
Power harrow	Rapid tilth production	'Force' seedbeds quickly; can work to 250 mm without bringing up clods or stones; power harrow/drill combinations can create seedbeds and plant in one pass	Not good at burying residues; can destroy soil structure; can be expensive to maintain; high horsepower requirements

for example, should be avoided to minimise soil structure damage.

Less intensive cultivation
Research has shown that many of the objectives of ploughing can be achieved with less intensive cultivations. Non-organic farming has seen increased use of reduced and minimum tillage involving the use of tines or disks to a depth of 10 cm or less. However, there are challenges that may arise with reduced tillage. These include potentially increased weed burdens, increases in some diseases, such as fungal and viral diseases of cereals, more slug damage and more soil borne pests, such as wireworms.

Concentration of nutrients at the surface may also cause problems in drought conditions. Whether these problems actually arise will depend on many factors, but they can often be controlled by adjustments to the rotation. For instance, there is more potential for damage to the soil where late autumn harvested crops like carrots or sugar beet are grown, than where early autumn harvested cereals are the main crop.

However, systems of reduced and, in particular, minimum tillage used in non-organic agriculture are reliant on herbicides to achieve good weed control and this may limit their suitability to organic systems. In organic agriculture, an alternative approach is to use shallow ploughing at 10–15 cm in combination with deeper cultivations or chisel ploughing to loosen lower soil horizons and create ideal crop rooting conditions. This can achieve a relatively clean seedbed with minimum disruption to the soil profile.

The degree to which cultivations can be reduced without detrimental effects on soil structure is largely dependent on the soil type, but may be complicated by previous agricultural activity. Reduced and minimal cultivation result in more compaction, particularly near the surface, and therefore may not be applicable to soils prone to compaction, such light sands, clays and silts. Soils that contain free lime have a more robust structure and can often be minimally cultivated with no need to plough. Non-calcareous loams and sandy loams are less robust and need to undergo deep ploughing and possibly sub-soiling every few years to maintain good structure. Table 12 (see facing page) summarises the main cultivation options with some of their advantages and disadvantages.

Weed control
Mechanical weed control can be highly damaging to soil microorganisms, particularly fungi. The ideal is to limit cultivations as much as possible by optimising timing and making sure that the technique used is as benign as possible.

Weed control techniques, such as flaming, hand pulling (on bed weeders) or brush weeding, tend to be less disturbing to the top soil than using a tractor pulled hoe or mechanical cultivators.

Weed control by 'out competing' or avoiding weed seed germination should be considered as an alternative. Undersowing crops or bi-cropping offers suitable alternatives to mechanical intervention.

Subsoiling
Though it is usually possible to maintain good soil structure in the plough layer, deep compaction below this can be more difficult to recognise and manage. The chief cultivation method to address deep compaction is subsoiling.

Subsoiling can produce better drainage, better root penetration and, in some cases, increased water availability. Deep rooting green manures, such as lucerne and chicory, can also help to break up soil structure at depth and maintain soil structure if the problem has not been allowed to get too bad. Some soils have a tendency to form natural pans and these can also benefit from subsoiling.

Subsoiling is most effective in soils moist enough to produce a general loosening rather than splitting into blocks. If the soil is too wet there is minimal fracturing and heaving of the soils. To assess the effectiveness of subsoiling it is useful to dig a soil pit in a subsoiled area at the beginning of operations.

Where a field is mole drained subsoiling at the depth of the moles can cause serious damage, resulting in reduced drainage. Limiting the subsoiling depth to just above the moles, or running parallel to them, can avoid this problem. Subsoiling may also cause problems in undulating fields with poor natural drainage as it can lead to percolation of water to lower parts of the field.

After subsoiling, soils are in a weakened condition and susceptible to damage. Secondary cultivations should be delayed as long as possible after subsoiling.

Timing
As well as damage to soil structure the incorrect timing of cultivation can lead to nitrogen leaching.

Within an organic rotation the incorporation of the ley is the most vulnerable time for nitrate leaching because a large pulse of nitrate is released from mineralised organic matter. In particular, in the autumn when drainage may be high and crop growth is slow excess nitrate loss can be high. This not only reduces the availability of nitrogen for following crops but can also cause serious environmental damage, especially when fields are adjacent to watercourses.

Where possible, spring incorporation prior to spring cropping has been shown to minimise leaching loss at this vulnerable stage of the rotation. Consider fields adjacent to watercourses as priority for spring cropping. If autumn cultivation of the ley cannot be avoided then:

- Ensure that the period of bare soil before establishing the new crop is as short as possible
- Avoid early ley incorporation in June-August, for example
- Delay ley incorporation as late as possible as lower

soil temperatures reduce microbial activity. Note, however, that there is increased risk of leaching when mineralisation is stimulated by cultivation in the following autumn
- Reduce cultivation depth and minimise soil disturbance
- Consolidate soils as soon as possible after cultivation, for example with a plough press
- Optimise major and trace mineral status to ensure rapid crop development.

Soil types and appropriate cultivation techniques
Decisions about appropriate cultivations are also determined to a large extent by soil types. What may be appropriate for a chalky clay loam could cause major problems in a silt loam soil. The major soil textural classes and the most appropriate cultivation techniques are outlined as follows:

- *Sand*
  Ploughing followed by seedbed consolidation with furrow press is preferred. Minimise ground pressure from machinery to reduce compaction. Use deep tines or subsoiling on a regular basis to loosen plough pans and deep compaction
- *Silt*
  Bed systems for vegetables are useful to prevent widespread compaction. Reduced tillage is not appropriate on light and medium silts but may be possible on heavy silts. Mouldboard ploughing is preferred, especially in vegetable growing areas where more than one crop a year is grown and trash must be incorporated quickly. Seedbed should not be too fine otherwise capping is likely. Subsoiling or deep cultivation is required to break up plough pans and deep compaction caused by ground pressure from machinery. Avoid power harrows which destroy soil structure
- *Clay*
  Cultivations should be kept to a minimum. Reduced tillage is often appropriate, especially where free lime is present, with deeper loosening every 3–4 years and mole draining every 4–7 years. Spring cropping can be difficult and seedbeds should be achieved with one pass if possible. Ensure good soil drainage
- *Loam*
  Where free lime is present on heavier loams, reduced cultivation is suitable. On sandy and silty loams reduced cultivation is less appropriate. Deep loosening will be required, especially on lighter loams
- *Peat*
  Avoid excessive cultivations in spring as this can dry out surface layers, leaving soil vulnerable to wind erosion. Deep ploughing shallow peats can incorporate silts or clays from below the peat. This can help to stabilise peat and may reduce acidity.

Dealing with compaction
Compacted horizons in the soil should be loosened in dry weather by the use of a chisel plough, sub-soilers or similar equipment at a depth below the problem layer. Mechanical means should be combined with green manures, where possible; the green manure should then be mixed in with the top 10–15 cm of the soil. The principle of shallow turning combined with deeper loosening of the soil is important. The following should also be considered:

- Use dual wheels, flotation tyres or tracked machines to reduce ground pressure from machinery or equipment
- Apply manure and compost
- Grow green manures and incorporate crop residues to increase soil organic matter
- Time tillage carefully.

It usually takes several years before improvements can be seen clearly. However, it is of the utmost importance that the farmer regards soil structure and soil condition as one of the most important factors determining the timing and nature of tillage.

6.5 Drainage

As much as half of the farmland in the UK requires drainage in order to achieve its maximum potential. Investment in drainage usually gives good returns with the exception of pastural areas under high rainfall. During seedling germination and during other active growth periods, damage to crops due to waterlogging can occur in a few days. Wet soils are also more vulnerable to damage by the pressure from machinery, cultivations and animal poaching. A waterlogged soil will also be more prone to erosion by water, through overland flow.

Where drainage has been neglected there can be a spiral of soil degradation. Cultivations and drilling are more likely to occur in unsuitable conditions, leading to soil damage and reduced crop growth. This in turn reduces the drying effect of the crop on the soil, resulting in more damage from machinery or animals. In pasture, neglected drainage results in sward degradation with the invasion of species that are tolerant of wet conditions, such as sedges and rushes.

Evidence of drainage system failure can include fields slow to dry out, patchy crop growth and drains failing to flow after rain. Examination of the soil can show orange/yellow mottling or 'ochre' deposits and 'rotten egg' smells associated with anaerobic conditions. If moling or subsoiling fails to improve the situation, then consider renewing the tile or perforated pipe drains. The regular use of deep rooting green manures can assist, with decaying roots providing air and drainage channels in the soil. However, in fields or parts of fields that are low-lying and notoriously difficult to drain even with a working system, it may not be worth renewing drainage systems. An alternative use of such areas is to establish semi-natural habitats, such as extensive pasture or hay meadows, which is often rewarded under agri-environment schemes.

Mole drains, where used in combination with tile drains or used alone, need renewing at regular intervals. This can be as short as five years on weaker clays and silt, but as much as 12 years on calcareous clays. Where there are sand pockets in the subsoil this time period will be reduced.

For moling to be most effective, the soil needs to be wet enough to form a good clean channel but not so wet as to collapse. Usually this is in the spring (May or June) though moling in the autumn may also be possible. The soil above the moles also needs to be dry enough to fracture if the moles are to be effective. Subsoiling in combination with field drains is an alternative option to mole draining.

Where a drainage system is installed it requires constant maintenance to remain effective. Although drainage ditches should be cleared regularly, management planning should also consider the conservation aspects of organic standards. Clearing on a rotational basis and cutting of ditch side vegetation no more than once in three years improves the habitat value of ditches.

7. Farming systems

Soil management is a whole farm concept and consideration needs to be given to all farm activities on the land throughout the full production cycle. The main problem areas concern protecting soil fertility (see section 6, 'Protecting soil fertility').

When looking at specific potential problem areas for different farming systems it is vital that options are carefully considered and planned. Avoid getting into situations where options or timings are severely restricted.

7.1 Stock based systems

As cultivation in stock based systems is relatively infrequent, and crop cover is almost continuous, there tends to be more flexibility in timing cultivations. The nutrient balance is usually positive in these systems, although an excess of nitrogen is likely. This can be managed by growing more crops for sale, or by exporting manures or some grazing stock for periods of the year.

Stock based systems are frequently on medium to heavy soils, possibly with sloping ground, and often in higher rainfall areas. These characteristics can create potential problems when considering cultivations. Stock based systems also tend to use continuous forage production for grazing or conservation from grass/clover swards.

Reseeding
For a reseed you will need to have a suitable period of about 4–6 weeks without a host for ley pests, such as frit fly and leatherjackets. However, this could present a risk for nutrient leaching or soil erosion. To minimise this risk, a late summer reseed is preferable to the spring or autumn as rainfall – and therefore leaching or run-off – is likely to be at its lowest. As moisture conservation in cultivated ground at this time of year will be vital to ensure good take of new seeds, pressing or rolling should take place simultaneously with each cultivation or immediately after. Cultivate and roll with contours, wherever possible.

Maize
Maize will grow perfectly well if sown in May after a first cut silage or early bite, so the ley can be left until late spring before ploughing in. If there is a high risk of frit damage then the grass should be ploughed at least four weeks before the maize is sown. This gap could be used to repeat cultivations to exhaust rootstocks of perennial weeds, if required.

Winter wheat
As an entry for winter wheat as whole crop silage or for grain and straw production, the sward could be ploughed in mid-summer. A crop of stubble turnips, resistant to frit and other ley pests, can be grown to be fed before the wheat is sown in the autumn.

The above options fit well with the cultivation requirements of all soils as they will be carried out when the soils are relatively dry and workable. This also coincides with the lowest risk months for water erosion and leaching. There is sometimes a wind erosion risk, especially in late spring. If the soil type and site are at risk then use a coarse ring press to consolidate cultivations, leaving a rough finish less likely to blow.

Poaching
Protecting grazing swards from the risk of poaching requires good management of stocking densities, feeding procedures, sufficient forage supplies, and appropriate housing to accommodate stock when field conditions are unsuitable for grazing.

Poaching is a problem as it causes direct physical damage to the crop and the soil leading to bare patches and an increased risk of erosion and leaching, and invasive weeds. Damage to the soil structure can affect drainage and rooting of the remaining crop. Ponding of water that cannot penetrate the poached layer of soil can lead to semi-permanent wet areas, making subsequent re-establishment of crop difficult.

Poaching is most frequently caused by cattle at feeding and watering points, or heavy traffic areas such as gateways, tracks and paths. Outdoor pigs can also cause serious destruction of crop and shallow structural damage, although they also require an area to wallow for welfare reasons, particularly in summer. Sheep are perhaps least likely to cause poaching although consideration must be given to feeding of forage in the field as this can lead to poaching.

To maximise the efficiency of field-fed forage, access to the crop should be regulated by a series of paddocks or the use of moveable fences. This will allow access to fresh, untrampled forage whilst providing a 'lie-back' area to minimise traffic. If an area of the field is identified as 'at risk' from poaching then a back fence could be used to prevent access.

Basic action
- Give careful consideration to stocking density
- Rotate grazing areas
- Have a contingency plan for unanticipated or extended wet weather periods
- Provide tracks and paths to avoid heavy traffic on fields
- Use portable feeding and watering equipment, or provide hard standing areas for these high risk points.

7.2 Mixed systems

The information given for stock based systems and stockless systems both apply to this category since, by definition, each scenario may occur in a mixed farm.

In this system grass/clover leys often precede winter cereals. Therefore, utilising the ley in the first half of the summer before replacing it with a summer forage crop is well suited to this system. Crops such as chicory, with its good drought resistance for light land sites, and forage rape or stubble turnips to be grazed off ahead of sowing the winter cereal, are good options.

This approach has a number of benefits. Firstly, it ensures almost continuous green cover to minimise the risks of nutrient loss and erosion. Secondly, it provides a suitable gap to reduce ley pests. Thirdly, it offers an alternative forage source in late summer when grass can be less plentiful and of lower quality. Finally, it provides an opportunity to apply stored manures and slurries before ploughing in the grass at a time of year when the soil conditions will allow heavy machinery with minimum damage, and the cover crop will quickly establish to utilise incorporated nutrients. These cultivation opportunities can also help reduce troublesome perennial weeds that may develop during the grass/clover part of the rotation.

Exemplary rotation

- Years one, two and three: grass/clover ley (note that the ley could be ploughed in the summer, followed by a crop of stubble turnips before wheat in the autumn. This gives a suitable pest break and allows weeding, if required)
- Year four: winter wheat (alternatively spring sown root crop, depending on market requirements – see section 7.3, 'Stockless systems')
- Year five: spring cereal, or forage maize.

A winter cover forage crop should be sown after the wheat is harvested, before the following spring cereal. Chicory could be used on light soils, with either forage rape or stubble turnips on other soils. Beware of over-committing to the use of winter forage if the soil is at risk from poaching. It is better to mulch the crop as a green manure than damage the soil by feeding it. This risk will vary with site and season.

Depending on the requirement for forage, either go back into grass/clover ley in year six or, if more arable is required, sow a pulse crop followed by another cereal prior to reseeding in year seven/eight. On medium/heavy land, winter beans would be a suitable pulse while wintered rye followed by peas or spring beans would be most appropriate for medium/light land. As this is a very flexible system, there are many cropping combinations available.

Forage crops

Spring sown root forage crops, such as fodder beet and swedes, have different considerations. They are generally sown mid to late spring in April and sometimes early May. As they are traditionally sown in rows, mechanical weeding is widely practised. In particular on light soil sites there can be a risk of soil erosion and crop damage. The use of inter-row straw will minimise this risk (see section 7.4, 'Field scale horticultural crops').

Perhaps the greatest challenge with these crops from a soil management perspective is at the harvesting, and the utilisation end of the cropping season. While the crops are winter hardy and can be fed in the field, particularly to sheep, if the site is anything other than light and free-draining then the risk of poaching and subsequent soil structure damage and erosion is likely to prevent this. Often the roots will be harvested mechanically and stored in clamps for subsequent feeding. This harvesting process can take place at almost any time during the autumn/winter period. However, harvesting at this time of year can risk leaving the soil in a fragile condition at a time when winter rainfall can leach nutrients and cause soil erosion. Harvesting should therefore take place when the soil conditions are suitable and the risk of damage to soil structure is low. It is quite feasible to sow winter rye (September/October) or a winter cereal (September to January) after autumn/winter harvested roots to minimise these risks.

The soil management risks associated with other forage crops, such as the leafy forage crops, are considerably lower, since the timing of their establishment and utilisation is far more flexible. They can also be managed to minimise risks to both soil and the environment. For example, chicory and clover crops can be sown at any time during spring, summer or early autumn and can be utilised within 8–12 weeks, or over wintered in suitable areas. Forage rape and stubble turnips can be sown in summer or early autumn for utilisation in autumn, ahead of reseeding or sowing a winter cereal. Sainfoin and lucerne crops are sown spring or summer, and can be left down for up to four years for cutting or grazing.

7.3 Stockless systems

Since the need for cultivation is greatest in these systems due to a greater proportion of annual cropping, the attention to detail required to manage cultivation is also greatest. Nutrient management is also most demanding since without livestock enterprises the recycling of nutrients from forage is limited.

Depletion of soil phosphate and potash reserves is possible on certain soils, particularly light textured soils low in organic matter, although many soils have considerable reserves. While a limited range of slow release phosphate and potash compounds are available, it should be a priority for the managers of stockless systems to import manure and compost, or stock for temporary grazing in parts of the rotation.

Light to medium soils with root cropping

It is important that the fertility building crops are mulched and incorporated as close as practical to the establishment date of the following crop, usually during the spring ahead of potatoes for example. This should not present serious timing or soil condition issues as if conditions are suitable for the proposed crop planting then they must, by default, be suitable for incorporating the manure crop.

Potatoes have a reputation of being prone to nutrient leaching, but in well structured soils where the crop is not drought stressed, the active roots of most varieties can penetrate to 1–1.5 m or more. If an early maturing potato crop is grown then a summer green manure should be considered ahead of the autumn cereal to prevent nutrients being lost. After harvesting a main crop variety, usually late September or early October, the wheat will be sown within a very short time.

If a sugar beet crop is grown then the timing of its harvest in relation to other proposed cropping requires careful consideration. If harvested in the first part of the campaign, a winter cover crop may be sown in October or November. If conditions are poor, and if possible, consider delaying the harvesting of the beet until conditions improve. A spring cereal could be sown straight afterwards from mid-December, although more usually late January to early February.

Exemplary rotation

- Year one: grass/clover/vetch as fertility building
- Year two: potatoes
- Year three: winter wheat, followed by winter cover of phacelia or chicory
- Year four: spring peas or beans. An early pea harvest may allow time for mustard green manure. Otherwise rye or westerwolds ryegrass would be more suitable
- Year five: spring barley undersown with ley.

Basic action

- Mulch and incorporate green manures and cover crops, using a plough and press-based system
- Proposed cropping requires a range of plough and cultivation depths, from deep for potatoes, to relatively shallow for pulses
- Subject to soil and weather conditions it may be possible to establish cereals following potatoes and pulses without the use of the plough.

Light to medium soils without root cropping

Avoiding root crops and stockless rotations on light land can help to protect soil structure and conserve soil nutrients. This will have a bearing on cultivation techniques and rotation design.

Exemplary rotation

- Year one/two: grass/clover/vetch as fertility building
- Year three: winter wheat
- Year four: winter oat or rye as alternative winter cereal which is less susceptible to take-all, followed by winter cover of phacelia or chicory
- Year five: spring peas or beans. An early pea harvest may allow time for mustard green manure before sowing wheat
- Year six: winter wheat, followed by winter cover green manure of vetch
- Year seven: spring barley undersown with ley.

Basic action

- Use a plough and press-based system for incorporating green manures and cover crops
- Opportunities to use non-inversion tillage to establish covers, second cereal and first wheat after pulse, subject to soil and weather conditions.

Medium to heavy soils

On medium to heavy soils the considerations may be different. Generally, there is a lower risk from leaching and run-off because of a coarser crumb structure and greater water holding capacity, although there is a higher risk of soil structural damage if cultivated wet. This risk increases as the autumn progresses.

Aim to complete drilling by mid-October at the latest. Plough and press when incorporating the grass/clover ley in late summer and use a mustard crop to bridge the gap between ley and wheat. This will reduce the risk of ley pests invading wheat and prevent nutrient loss or soil erosion. Disc and pack to incorporate mustard prior to drilling wheat.

There may be time for a green manure between wheat crops, perhaps 4–6 weeks maximum. However, if this is not possible then the aim should be to cultivate stubble according to weed control priorities. Cultivate immediately after harvest to encourage cereal volunteers, black-grass, sterile brome, ryegrass and broad-leaved weeds. For soft, meadow and rye bromes a period of ripening is required after seeds are shed, so delay cultivating for up to one month after harvest. This is important as it is these grasses that are likely to compromise the sustainability of an organic approach to cereals on heavy land.

Exemplary rotation
- Year one/two: grass/clover ley as fertility building
- Year three: winter wheat, with stubble cultivation according to weed species present
- Year four: winter wheat
- Year five: winter beans
- Year six: winter oats undersown with ley.

Basic action
- Plough after grass/clover ley and to establish beans, otherwise use non-inversion tillage. If grass weeds increase, incorporate plough where required to clean between cereal crops. Alternatively, consider a spring sown break, such as beans (these may not be ideal on heaviest sites) or a summer fallow to clean
- Consider sowing a white clover or yellow trefoil understorey in first wheat to build fertility for second wheat
- The incorporation of cereal crop residues will reduce nutrient removal and slowly increase organic matter return to the soil, although this may also cause some short-term lock-up of mineralised nitrogen in the autumn and winter.

7.4 Field scale horticultural crops

Growing a range of horticultural crops helps to manage soil structure and meet the rotational requirements for pest, disease and weed management.

Exemplary rotation
- Year one/two: grass/clover/vetch as fertility building
- Year three: potato, followed by rye cover crop ahead of planting or sowing alliums
- Year four: leek/onion, drilled spring/summer or leek transplanted summer/autumn, followed by rye cover ahead of legume sowing February/March
- Year five: legume – beans
- Year six: brassicas or umbellifers (carrots/parsnips) sown in spring/summer.

Basic action
- Use cover and manure crops carefully to fit in with sowing, transplanting and harvesting schedule to ensure ground is left bare for the minimum period, if there is time. Select appropriate cover for interval and time of year. For example if a longer interval (8–12 weeks) and winter hardiness is required, sow chicory on light land or rye
- Minimise the risk of wind soil erosion. Small, sensitive and slow growing plants on susceptible soils can pose a considerable soil erosion risk at certain times of year. Aim to develop field boundaries and hedgerows to offer as much protection from wind as possible. Try to keep field sizes small and where practical grow rows of different species in each field. This will also help to protect against pests and diseases. Cereal straw can also be pressed into the soil in rows between the crop to create a physical barrier to the wind at the soil surface.

8. Summary

Soil analysis

- Ensure that samples are representative of the field
- Soil analysis is a snapshot. Successive sampling will help build up a picture of the effects of management on soil fertility over time
- Changes in soil organic matter are much longer-term than changes in available P, K and Mg
- It is important to consider the balance between nutrients, as deficiency of one nutrient can affect the uptake of others
- If you suspect crop trace element deficiency then tissue analysis or forage analysis is recommended.

See section 4, 'Soil analysis'.

Nutrient management

- Manure application to provide nitrogen may over supply phosphorus. Ensure good manure management such as avoiding applications during the autumn or early winter period
- Losses through run-off or leaching from compost are much lower when compared with equivalent applications of fresh manure or slurry
- Within the rotation the incorporation of the ley is the most vulnerable time for nitrate leaching. Where possible, retain leys to spring incorporation and follow with spring established crops. Where leys are to be followed by autumn sown crops, aim to establish crops early
- Phosphorus is mainly lost by surface run-off, in association either with soil particles or manure
- The effect of crop removal on soil potassium differs according to soil type. On very sandy soils one forage crop can have a significant depletion effect, while on clay soils that contain high potassium reserves, deficiencies take much longer to appear
- Although magnesium reserves in the soil are generally adequate deficiencies may occur in sensitive crops, such as potatoes
- In stockless systems depletion of soil phosphate and potash reserves is possible on certain soils. Make it a priority to import manure and compost, or stock for temporary grazing in parts of the rotation.

See sections 3.6, 'Nitrogen cycle', 3.7, 'Phosphorus cycle', 3.8, 'Potassium cycle', 5, 'Building soil fertility' and 6.3, 'Nutrient losses and gains'.

Soil fertility

- Regular additions of FYM and composts together with crop residues, such as green manures, cover crops and grass/clover leys, will increase soil organic matter over time
- Grass/clover leys are particularly beneficial in improving soil structure. Deep-rooting species in the mix, such as chicory or lucerne, can help to break-up subsoil compaction
- Soil erosion can be detrimental to soil biodiversity. It can reduce nutrient storage capacity, lead to poorer soil structure, decrease water holding capacity and soil depth. Well structured soils are much less at risk than poorly structured soils. Measures to protect from soil erosion include avoiding cultivations in wet conditions and on slopes of more than nine degrees
- Particularly in horticulture where there is the potential to deplete surface soil layers of nutrients, crops with different rooting depths and rooting structures are important for ensuring the whole soil profile is exploited
- Minimise the risk of wind erosion in horticultural field crops. Maintain hedgerows and field margins and avoid having very large field sizes. Also try to have rows of different crop species in each field.
- To protect soil structure avoid cultivation in wet conditions, limit the depth of cultivations and avoid excessive use of mechanical weed control in row crops
- Don't plough any deeper than is necessary
- To achieve a relatively clean seedbed with minimum disruption to the soil profile use shallow ploughing (10–15 cm) in combination with deeper cultivations or chisel ploughing to loosen lower soil horizons and create ideal rooting conditions
- Minimise compaction problems through the use of dual wheels, applications of compost or manures and by ensuring careful timing of tillage
- Remediation of deep compaction can be achieved through deep rooting green manures such as lucerne or subsoiling
- To protect soil structure avoid overworking of the soil, such as overuse of power harrows or stone separators
- Weed control techniques, such as flaming or brush weeding, tend to be less disturbing to the top soil than a tractor pulled hoe or mechanical cultivators. Non-mechanical alternatives, such as weed control via 'out competeing', could be considered
- Ensure maintenance of drainage. Neglected drainage can lead to cultivations and drilling in unsuitable conditions, damaging soil structure and reducing crop growth
- Minimise the risk of poaching through operating a contingency plan for unanticipated or extended wet weather periods. Consider using portable feeding and watering equipment.

See sections 6, 'Protecting soil fertility' and 7, 'Farming systems'.

9. Further information

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- Earthcare Ltd: 48 Queens Road, Coventry CV1 3EH T 024 7663 0832 • E info@solvita.co.uk www.solvita.co.uk/products/soil-life-test-kit.htm
- Elm Farm Research Centre (EFRC): Hamstead Marshall, Newbury, Berkshire RG20 0HR • T 01488 658298 www.efrc.com
- English Nature: Northminster House, Northminster Road, Peterborough, PE1 1UA • T 01733 455000 www.english-nature.org.uk
- Environment Agency (England and Wales) T 0845 933 3111 • www.environment-agency.gov.uk
- Environment and Heritage Service (Northern Ireland): Environmental Protection, Calvert House, Calvert House, 23 Castle Place, Belfast BT1 1FY T 028 9025 4754 • www.ehsni.gov.uk
- HDRA: Ryton Organic Gardens, Coventry CV8 3LG T 024 7630 3517 • www.hdra.org.uk
- National Soil Resources Institute: Cranfield University, Silsoe, Bedfordshire MK45 4DT • T 01525 863242 www.silsoe.cranfield.ac.uk/nsri
- The National Trust: The Estates Department, 33 Sheep Street, Cirencester, Gloucestershire GL7 1RQ T 01285 651818 • www.nationaltrust.org
- Organic Conversion Information Service (OCIS): England: T 0117 922 7707 • Scotland: T 01224 711072 Wales: T 01970 622100 • N. Ireland (crops and horticulture): T 028 9070 1115 N. Ireland (livestock): T 028 9442 6752
- Organic Soil Fertility: www.organicsoilfertility.co.uk
- Scottish Agricultural College, Crop and Soil Management Group: Craibstone Estate, Aberdeen AB21 9YA • T 01224 711000 www.sac.ac.uk/cropsci/external/orgserv
- Scottish Environmental Protection Agency: Corporate Office, Erskine Court, Castle Business Park, Stirling FK9 4TR • T 01786 457700 • www.sepa.org.uk
- Soil Association Certification Ltd: 40–56 Victoria Street, Bristol BS1 6BY • T 0117 914 2412

The Soil Association

Established in 1946 as a charity, the Soil Association is the UK's leading organisation for organic production, inspection, certification and promotion of organic food and farming. Soil Association Certification Ltd is the most professional, practical and respected certification service for producers, retailers and processors, implementing organic standards which have been developed over 25 years.

Soil Association producer services

The Soil Association producer services department represents the interests of organic producers. It provides high quality, affordable support and information to its members. Membership is available to anyone interested in technical or marketing information about organics. Benefits include:

- Telephone helpline with free advice and support on the interpretation and application of organic standards, information and market contacts.
- An extensive range of fact sheets, technical guides and briefing papers.
- Our excellent quarterly magazines, *Organic Farming* and *Living Earth*.
- The respected annual *Organic Food and Farming Report* at a discount.
- Representation – we promote producers' interests at industry and government levels.
- A varied national programme of training events and farm walks where farmers and growers meet to share information, see organic farming demonstrations and socialise.
- Organic market development – we support a range of initiatives helping UK producers to succeed.

Organic farming

The main components of an organic farming system are the avoidance of artificial fertilisers and pesticides, the use of crop rotations and other forms of husbandry to maintain fertility and control weeds, pests and diseases. A written conversion plan, including detailed cropping plans, rotations, a livestock management plan and budgets, is also an essential part of a successful move into organic farming.

Standards for organic farming, horticulture and food processing are subject to EU regulation – and within the EU only certified produce may be legally sold as 'organic'. UK certification bodies and standards are regulated by the government's United Kingdom Register of Organic Food Standards (UKROFS).

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