RESEARCH TOPIC REVIEW: Nitrogen supply and management in organic farming

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1. Scope and Objectives of the Research Topic Review

This topic review aims to summarise knowledge and experience of Nitrogen supply and management in organic farming systems, including : Nitrogen fixation; Nitrogen recycling; the effect of the length of the fertility building phase or ley and the effect of green cover management; green manures – type and management; soil management; the impact of undersowing; seasonality of crops and the impact of manure use and management. It is based on a review of the organic research commissioned by Defra and that undertaken elsewhere and incorporates field experiences in the conclusions.

2. Summary of Research Projects and the Results

2.1 N Prediction & Nitrogen fixation

In typical organic farming systems Nitrogen is accumulated during a fertility building phase of a rotation or from leguminous green manures or cash crops, where N is accumulated in the soil and in unharvested crop residues. Although recycled plant residues and animal manures help to maintain the overall nutrient balance on the farm, the only true import of N (to compensate for removal in sold products and losses to the atmosphere and in leaching) comes from imported manures from outside of the holding and by fixation of atmospheric N2 by legumes (Briggs et al 2005).

Nitrogen exists in two main forms: organic and inorganic. Inorganic N is readily available to plants in the forms in which it commonly occurs (mostly ammonium and nitrate). However, over 90% of the N in most soils is held in organic forms which must first undergo mineralisation, through the action of soil microbes, to release available N. Nitrogen represents about 5% of the dry weight of soil organic matter (SOM) and so the content of SOM will largely determine the N supplying capacity of soils (Briggs et al 2005).

The amounts of N that can be accumulated by a green manure or a ley will not only depend on how well the legume grows, but also where it gets its N from, since legumes tend to prefer to obtain N from the soil, rather than fix N from the atmosphere. In an N rich soil, the amount of N a legume fixes from the atmosphere is much reduced compared to that of a legume in a soil with low levels of N (Briggs et al 2005).

2.2 Soil Organic Matter (SOM) and influence on Nitrogen

Soil fertility is linked intrinsically to soil organic matter (SOM), because it is important in maintaining good soil physical conditions (e.g. soil structure, aeration and water holding capacity), which contribute to soil fertility, and it is an important nutrient reserve. Organic matter also contains most of the soil reserve of N and large proportions of other nutrients such as P and sulphur (Shepherd 2002). Typical ranges for SOM are from as little as 1.5% (of dry soil weight) in sandy soils under arable cultivation, to as much as 10% in clay soils under permanent pasture. At the upper end of this range, this can amount to between 5 and 15 t organic N/ha in the top 15 cm (Briggs et al 2005) Peat soils can have upward of 15% organic matter.

Stolze et al. (2000), in their review of the environmental effects of organic farming, concur with the view that soil organic matter, biological activity and soil structure are all important aspects of soil quality (chemical status not specifically mentioned), but also include susceptibility to soil erosion.

SOM also plays a pivotal role in soil structure management. Young SOM is especially important for soil structural development, improving ephemeral stability through fungal hyphae, extra cellular polysaccharides, etc (Shepherd et al 2002). To achieve better soil structure, workability and soil aggregate stability and the advantages that this conveys, frequent input of fresh organic matter is required. Practices that add organic material are routinely a feature of organically farmed soils and the literature generally shows that, comparing like with like, organic farms have at least as good and sometimes better soil structure than conventionally managed farms (Shepherd et al 2002).

With regular additions of fresh organic residues, the *light fraction SOM* that is important for soil structural development will improve. It can be argued that it is not the farming system per se that is important in promoting better physical condition, but the amount and quality of organic matter returned to a soil (Shepherd et al 2002).

Generally, organic farming practices are reported to have a positive effect on soil microbial numbers, processes and activities. Research has made direct comparisons between organic and/or biodynamic and conventionally managed soils and the evidence generally supports the view of greater microbial population size, diversity and activity, and benefits to other soil organisms too (Shepherd 2003). However, little is currently known about the influence of changes in biomass size/activity/diversity on soil processes and rates of processes. Nor is it possible to conclude that all organic farming practices have beneficial effects and that conventional practices have negative effects. Pasture is the main element of agricultural systems where least difference would be likely to be seen in soil quality between organic and conventional systems, since both will accumulate organic matter. The majority of literature showing no benefit to microbial activity from organic systems is found in studies of pasture. In the few arable comparisons where lack of differences or greater activity in conventional systems were found, this might be related to greater residue returns in the conventionally fertilised systems. If so, this provides a pointer to the key factor that differentiates between conventional and organic systems as being return of organic matter.

This correlates with the observation that aggregate stability is greatest under grass, where there is continuous production of these components, and decreases rapidly under arable cultivation. This suggests that optimal aggregate stability requires the frequent turnover of transient organic matter residues, although humic substances also offer some long-term stabilisation of structure. Therefore, a ‘biologically active’ soil is better predisposed to better aggregate stability (Shepherd 2002).

Crop rotation also modifies the physical characteristics of the soil both directly and indirectly. The accumulation of organic matter during the ley phase plays a major direct role in soil structure formation (Clement & Williams 1967; Grace et al. 1995). This results from the production of organic binding agents, such as polysaccharides, by microorganisms breaking down organic matter, and the enmeshing effects of the clover and grass roots and fungal hyphae (Wild 1988; Breland 1995). Conversely, soil organic matter and aggregate stability decline during the arable phase (Tisdall & Oades 1982). The architectural characteristics of the root systems of different crops included in the rotation also influence soil structure formation (e.g. Chan & Heenan 1991). Indirectly, the timing and use of different cultivation techniques and manure application at different points in the rotation influence soil structure.

Rotation design modifies both the size and activity of the soil microbial biomass. Indicators of biomass activity such as basal respiration and enzymatic activity suggest that there is a more active microbial biomass associated with grass-clover leys than with arable cropping (Watson et al. 1996; Haynes 1999), which is in turn linked to the decomposition of organic matter and nutrient mineralization (Haynes 1999). Currently the possibilities for manipulating individual components of the soil microbial biomass using agricultural practices are limited by our understanding of the functional significance of different organisms or groups of organisms.

2.3 Soil biology

The soil hosts complex interactions between vast numbers of organisms, with each functional group playing an important role in nutrient cycling: from the macrofauna (e.g. earthworms) responsible for initial incorporation and breakdown of litter through to the bacteria with specific roles in mobilising nutrients. Earthworms have many direct and indirect effects on soil fertility, both in terms of their effects on soil physical properties (e.g. porosity) and nutrient cycling through their effects on micro-floral and -faunal populations (density, diversity, activity and community structure). Thus, although micro-organisms predominantly drive nutrient cycling, mesofauna, earthworms and other macrofauna play a key role in soil organic matter turnover. Factors that reduce their abundance, be it natural environmental factors (e.g. soil drying) or management factors (e.g. cultivation, biocides), will therefore also affect nutrient cycling rates. Organic farming’s reliance on soil nutrient supply requires the presence of an active meso- and macro-faunal population.

The soil microbial biomass (the living part of the soil organic matter excluding plant roots and fauna larger than amoeba) performs at least three critical functions in soil and the environment: acting as a labile source of carbon (C), nitrogen (N), phosphorus (P), and sulphur (S), an immediate sink of C, N, P and S and an agent of nutrient transformation and pesticide degradation. In addition, micro-organisms form symbiotic associations with roots, act as biological agents against plant pathogens, contribute towards soil aggregation and participate in soil formation.

Generally, organic farming practices have been reported to have a positive effect on soil microbial numbers, processes and activities. Much of the cited literature has made direct comparisons between organic/biodynamic and non-organically managed soils. The evidence generally supports the view of greater microbial population size, diversity and activity, and benefits to other soil organisms too. However, little is currently known about the influence of changes in biomass size/activity/diversity on soil processes and rates of processes. Nor is it possible to conclude that all organic farming practices have beneficial effects and non-organic practices negative effects (Shepherd 2002).

2.4 Earthworms as indicators

Earthworms have many direct and indirect effects on soil fertility, both in terms of their effects on soil physical properties (e.g. porosity) and nutrient cycling through their effects on micro-floral and -faunal populations (density, diversity, activity and community structure) (shepherd 2003). Thus, although microorganisms predominantly drive nutrient cycling, mesofauna, earthworms and other macrofauna play a key role in soil organic matter turnover. Factors that reduce their abundance, be it natural environmental factors (e.g. soil drying) or management factors (e.g. cultivation, biocides), will therefore also affect nutrient cycling rates. Organic farming's greater reliance on biological processing of minerals for soil nutrient supply, benefits from an active meso- and macro-faunal population. These effects are complex, though many of the resultant effects are beneficial:

• reduction of plant parasitic nematodes and pathogenic fungi
• increased enzymatic activities
• increased nutrient release
• spread of biocontrol agents
• spread of mycorrhiza and Rhizobium species

Although micro-organisms predominantly drive nutrient cycling, earthworms play a key role in soil organic matter turnover. Factors that reduce their abundance, be it natural environmental factors (e.g. soil drying) or management factors (e.g. cultivation, biocides), will therefore also affect organic matter turnover (Shepherd 2003). Simple measurements of organic systems have showed more earthworms under the organic systems (compared with conventional) and generally more worms immediately after a ley compared with later in the rotation. Greater populations of beneficial nematodes have also been found in organic systems. (Shepherd 2002).

There is no straightforward relationship between soil management and earthworm populations because there tends to be an interaction between several factors. For example, fertilisers can reduce worm populations, Edwards & Lofty (1982b) and white clover has been found to inhibit worm activity (Lampkin, 1992) but, overall, organic rotations tend to favour earthworms because of the other beneficial effects of management: organic matter additions, leys, no biocides, etc. Ramesh et al. (1997) has linked low populations of earthworms to lack of adequate moisture in the soil surface, intensive pesticide use, frequent tillage, and absence of ground cover.

Siegrist et al. (1998) and Gerhardt (1997) found greater earthworm abundance and activity on the organic farms. Although Whalen et al. (1998) found earthworm populations declined during 5 years of continuous cereal production. Arable soils usually contain a smaller biomass of earthworms than pasture soils, unless the soil is given regular applications of FYM (Newman, 1988). It seems, therefore, that cultivation in some way reduces earthworm populations. Larger populations under direct
drilled crops (Edwards, 1983) suggest that the physical act of ploughing reduces the population. Thus, because organic rotations tend to plough less frequently (because of the fertility building stages) this is likely to be an advantage for earthworm populations. However, conversely, there is less scope for reduced cultivation systems in organic farming, which would work against earthworm populations (Shepherd et al 2003).

2.5 How much N is fixed?

Nitrogen in legumes comes from the uptake of both soil N and fixation of N from the atmosphere. The amount of N fixed by different legumes is determined by how well the symbiotic association is functioning between the

N-fixing bacteria (Rhizobia) and the legume host. The efficiency with which N is fixed will depend on the crop's growing conditions (e.g. soil, climate, disease), crop management and length of time for which it is grown. Consequently, the influence of all of these factors means that a wide range of values have been reported. However, for a particular legume species there is usually a close relationship between yield and the quantity of N fixed. Figure 1.0 indicates the range of fixation estimates quoted for a number of leguminous crops.

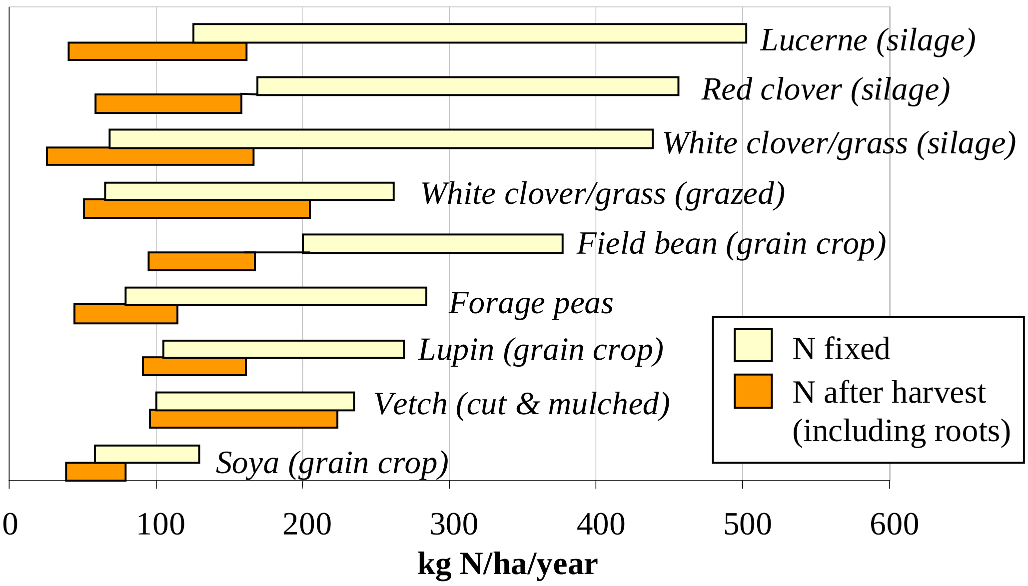

Figure 1.0 Ranges for quantities of N fixed and remaining after harvest (Briggs et al 2005)

A small supplementary boost of N during the fertility-depleting phase may be obtained by growing a leguminous cash crop, such as field beans or peas. It is important to remember that harvesting forage or grain will remove much of the fixed N and reduce the benefit to following crops (see Figure 1.0). The benefit will be further reduced if straw and other crop residues are removed from the field. However, if the crop is retained and fed on-farm the nitrogen can be effectively recycled and benefit subsequent crops.

Predicting the actual amount of nitrogen fixed is notoriously difficult as it depends on many factors including legume species and cultivar, proportion of legume in the ley, management, weather conditions and the age of the ley (Ledgard & Steele 1992; Watson et al. 2002). White clover-grass leys can fix up to 250 kg N ha-1yr-1 (Kristensen et al. 1995), red clover leys up to 240 kg N ha-1yr-1 (Schmidt et al. 1999) and lucerne up to 500 kg N ha-1yr-1 (Spiertz & Sibma 1986). Field beans have been estimated to fix up to approximately 200 kg N ha-1 yr-1 (van Kessel & Hartley 2000). In terms of increasing soil nitrogen, grain legumes are of limited value since only 50% of their N requirement is derived from fixation (compared with >80% in forage legumes) and much of the fixed N is removed in the grain harvest. This can sometimes result in net removal of nitrogen from the soil (van Kessel & Hartley 2000).

The values of annual accumulated nitrogen from a year's red clover green manure have been reported at similar levels by a number of researchers i.e 250-292 kg N ha-1 and 371 kg N ha-1 (Bulson et al., 1996; Stopes et al., 1996 and Sparkes et al 2003, respectively). A two-year red clover green manure has been reported to accumulate up to 660 kg N ha-1 (Cormack, 1999), and 741 kg N ha-1 (Stopes et al., 1996); both values are far higher than those measured by other researchers. Sparkes et al (2003) concludes that these figures are somewhat misleading, in that they do not account for the cycling of nitrogen within the plant-soil system, especially in systems containing leguminous plants, that can lead to nitrogen being counted more than once, and thus an over-estimate of net nitrogen addition.

2.6 Where is the Nitrogen?

In cut or grazed swards of grass/clover, large amounts of herbage, stubble and roots are not harvested and return to the soil to be incorporated in the SOM. This can represent more than the amount of organic matter actually consumed by grazing animals. At the end of the fertility building phase, there are also large amounts of N in unharvested plant material and in roots (including nodules on clover roots which can represent over a third of the total root weight) which are returned when the legume-based sward is ploughed in (Briggs et al 2005).

N accumulation will vary widely between sites (i.e between 150 - 450 kg N/ha/yr) and a large proportion of this N is found below ground in the rooting system. Not all the N contained in the plant residues is immediately available to a following crop. As the plant residues break down over time the N is released. The time to break down is determined by the C:N ration of the material, the biological activity of the soil and local climate. It is important to ensure that the N released is held in the upper soil profile so that it is within reach of the next crop, rather than being leached out of the rooting zone of plants.

2.7 N Supply & Nitrogen recycling

Nutrient supply to crops depends on the use of legumes to add nitrogen to the system and limited inputs of supplementary nutrients, added in acceptable forms. Manures and crop residues are carefully managed to recycle nutrients around the farm. Management of soil organic matter, primarily through the use of short-term leys, helps ensure good soil structure and biological activity, important for nutrient supply, health and productivity of both crops and livestock. Carefully planned diverse rotations help reduce the incidence of pests and diseases and allow for cultural methods of weed control (Watson et al 2002).

When managing legumes for N supply, we need to consider 'capture' (fixation) and 'use' of N: both have to be managed effectively. Many factors can affect N fixation, e.g. levels of N in the soil or cutting and removal versus cutting and mulching. Efficient use of N by the following crops relies on management practices and cropping patterns that make best use of the N released by mineralisation of the residues (Briggs et al 2005).

Although nutrient management in organically managed soils is fundamentally different to soils managed non-organically, the underlying processes supporting soil fertility are not. The same nutrient cycling processes operate in organically farmed soils as those that are farmed non-organically although their relative importance and rates may differ. Nutrient pools in organically farmed soils are also essentially the same as in non-organically managed soils but, in the absence of regular fertiliser inputs, nutrient reserves in less-available pools might, in some circumstances be of greater significance (Shepherd 2002).

2.8 N Use

The amount of N which is built up by fertility building is only part of the challenge of good N management. Good management of the soil, crop and rotation is of paramount importance to maximise the efficient use of the N built up. How effectively the N is used by the subsequent crops in the rotation will depend on many factors, including: the rate of release ('mineralisation'); the efficiency of uptake by crops; the N removal in harvested products; the N return in plant residues; losses of N; timing or cropping (spring vs winter); timing and type of cultivation and location and rainfall of the site. The rate of depletion will be reduced if manure is applied or if the rotation includes further legumes during this phase (Briggs et al 2005).

The factors affecting N release from the soil, interaction with crop uptake and loss processes, and the methods of predicting N release are complex. After a ley is incorporated and before the next crop can use the accumulated N, it has to be converted ('mineralised') into plant available forms (nitrate and ammonium). Some will already be in this form; most will need to be mineralised by microbial action after cultivation. Generally, the organic forms of N associated with the fertility-building crop are termed 'residue N'. It should also be noted that not all of the residue N will necessarily be fixed N – some will have derived from uptake of (a) N released from the native soil organic matter, some will be from atmospheric N deposition and some will be from (c) soil mineral N in the soil at the time of establishment of the fertility-building crop. The proportion of non-fixed N will depend on many factors as described above.

The release of Nitrogen via mineralisation is performed by soil micro-organisms when they use organic N compounds as energy sources. Plant available N is a by-product of this microbial degradation.

The rate at which they undertake the mineralisation is affected by many components including ; soil temperature and moisture; soil biological 'health'; Soil texture; Soil physical condition; Soil disturbance; and the type of residue (described in crop and green manure residue section).

Temporal patterns of N uptake by the crop may be particularly important in organic systems where N is released gradually by mineralisation of organic matter. For example, maximum uptake of N by winter wheat occurs in spring when soils are only beginning to warm and mineralisation is still slow (see Figure). This is likely to limit the supply of N at a critical time for wheat crops on organic farms (Shepherd 2002). Mycorrhizal fungi have been shown to absorb and translocate some N to the host plant, so maintaining good mycorrhizal fungi populations can be beneficial in N utilisation.

2.9 Nitrogen use by crops

Conventional crop production uses highly soluble and mobile Nitrogen fertilisers, matched the demand of crop growth and late spring leaf production. Leaves are the most nitrogen-rich tissue in a higher plant and consequently there is a relatively sudden heavy requirement for nitrate to produce leaf protein for chloroplasts and photosynthesis. The vegetative reserves laid down during canopy expansion help provision the seeds when they form. Therefore maximal seed yields are likely to be obtained only when the provision of soil nitrate and the associated crop requirements for leaf production are synchronised. This temporally uneven requirement for N in springtime is matched by the application of high levels of very soluble fertiliser in conventional production.

In organic production N release is governed by biological and chemical processes, deriving N from material which is only slowly degraded over many months or even years. These processes are less able to release minerals in the short intense burst required for rapid plant growth. The provision of nitrogen by decay of organic material (mineralization) throughout the season may produce nitrate when it is little needed if the soil is tilled and oxidation and mineralisation occurs, when there is no plant or only a young plant with a low N requirement present. Therefore ploughing months ahead of the time required for planting and well ahead of the main N requirement for crop development should be avoided as the mineralization that occurs with cultivations well ahead to crop growth can lead to N loss.

In a detailed examination of mineral availability, Berry et al. (2002) determined that the amount of N in organic soils should be equivalent to 300 kgN/ha based on soil analysis. However, organic wheat plants act as though there is only about 50 kgN/ha available for growth and seed formation. Berry et al. (2002) also indicate that the common practice of applying manure or slurries to ley legumes simply diminishes the amount of N fixed by the legumes resulting in a waste of manure. More crucially these measurements indicate that the analysis of total N in organic soils is misleading when such a mismatch between unavailable and available N is so clear.

2.10 Seasonality of crops and N use

The mismatch of N mineralisation in the soil and crop uptake requires careful management to avoid N losses and optimise utilisation. A good example of this is that winter wheat develops slowly during the autumn, and significant levels of nitrate may be lost by leaching before the spring, when the main demand from cereals occur. This is shown in figure 2.

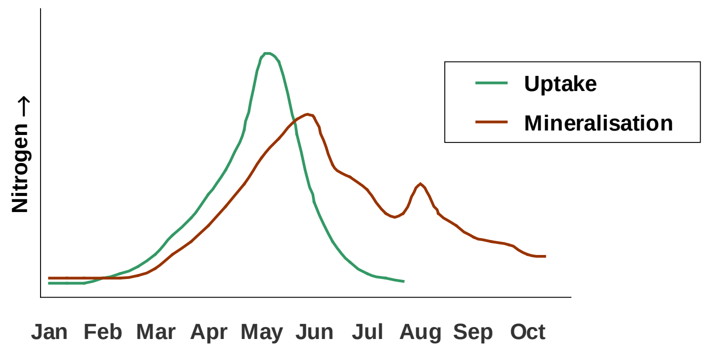

Figure 2 Soil N mineralisation and uptake by W Wheat (Source Shepherd M)

Adopting systems utilising spring cultivations and planting or autumn cultivations followed by catch crops and then spring planting, or potentially catch crops intercropped with winter wheat could improve the utilization of N for crop performance (Thorup-Kristensen 2006, Shepherd et al 2002).
However the research did suggest that winter wheat had a much deeper root system (c. 2.0 m) than spring wheat (c. 1.0 m), and that the N loss from the winter wheat crops therefore became smaller than expected. A combination of using catch crops and spring wheat is more ideal for N resource utilisation and subsequently has the potential to improve the baking quality characteristics in wheat (Thorup-Kristensen 2006).

Organic systems have the potential to supply adequate amounts of available N to meet crop demand through the incorporation of leys, N rich cash crop residues and applied manures. However, this is seldom achieved because leys are only incorporated once every few years and organically produced crop residues and manures tend to have low N contents and slow mineralization rates. N availability could be improved by delaying ley incorporation until spring, applying uncomposted manures at the start of spring growth, transferring some manure applications from the ley phase to arable crops, preventing cover crops from reaching a wide C:N ratio and better matching crop type with the dynamics of N availability (Berry et al 2004).

2.11.1 Nitrogen leaching and loss

If the available N is not utilised or its availability is mismatched to crop demand, losses may occur. The main loss of N in drainage is by leaching of nitrate: ammonium is less mobile. Leaching occurs when water drains through the soil, taking with it nitrate from the soil profile. Consequently, most nitrate leaching occurs during the autumn/winter drainage period, though nitrate can be lost at anytime if there is sufficient rain to fully wet the soil (Shepherd et al 2003). Thus, the amount of nitrate lost depends on soil-type and rainfall, and is modified by management practices. In short, to minimise nitrate losses, management practices that minimise the amount of nitrate in the soil during the main drainage event must be adopted. Goulding (2000) produced a thorough review of the main techniques.

Nitrate leaching can be split into 'direct' and 'indirect losses'. Direct loss results from adding nitrate (or materials that are quickly converted to nitrate) when drainage is occurring: late summer/early autumn applications of slurries, for example. Indirect loss occurs when nitrate has accumulated in the soil in the autumn as a result of crop/soil/management activities in the previous growing season. Examples are:

- A crop is supplied with too much nitrogen for its needs (e.g. from fertiliser and/or manure, or from ploughed out grass)

- Lack of synchrony between N supply and crop uptake, e.g. if ploughed grass residues are mineralised after the crop has matured.

Farming systems therefore need to manage nitrogen carefully, to avoid these circumstances wherever possible.

Nitrogen is difficult to manage and control in any farming system given its mobility in soils as nitrate and the huge amount of potentially oxidisable organic nitrogen in soils. Losses depend on many factors, not all of which are under the control of the farmer. Weather plays an important role. Practices that minimise risk of loss must be adopted, and it must be recognised that it is impossible to avoid some loss. Since nitrogen is often the limiting nutrient in organic systems and is expensive to replace, it seems sensible that growers aim to avoid losing as much as possible to the wider environment (Shepherd 2002).

It is estimated that direct soil N losses by denitrification can vary between system type with approximately 35, 120 and 70 kg N ha-1 yr-1 lost from upland farms, lowland dairy farms and stockless arable farms, respectively (Goulding 2000). Whilst these figures may be low, when added to product sales at the farm gate, the efficiency of N use is reduced to about 40% and an N deficit of 30 kg ha-1 yr-1 is found in stockless arable farms. An N deficit suggests net mineralization and the mining of soil reserves.

Organic farming aims to adopt many of the practices that should minimise loss – maximising green cover (leys, cover crops), use of straw-based manure or compost applications, lower stocking rates. Therefore, it might be expected that nitrate losses would be less than from conventional systems. The evidence, on balance, supports this. However, it must be said that there are few comprehensive studies making the comparison. Under UK conditions, a study by Stopes et al. (2002) perhaps provides the best evidence. However, even this study tended to compare organic and conventional farms at the same levels of intensity, i.e. low intensity conventional systems. It is known that nitrate losses are even greater from the more common highly intensive conventional farms and so it could be argued that the differential would be larger.

Variation in leaching losses from individual fields is large both in organic and conventional agriculture. Many organic systems operate at a lower level of nitrogen intensity than conventional systems, with nitrogen inputs from fixation by legumes, or from importation of animal feed onto the farm. Organic farming adopts many of the practices that should decrease losses: maximising periods of green cover, use of straw-based manure, lower stocking densities. Losses after ploughing the fertility building leys are one area where losses can be especially large (Shepherd 2002).

2.11.2 Leaching from grassland systems

Nitrate leaching losses from cut grassland, where herbage is removed from the field, are generally small. Tyson et al. (1996) reported annual leaching losses of 13 kg N/ha from grazed grass/clover pastures on a heavy clay soil in Devon and 50 kg/ha from equivalent grass swards receiving 200 kg fertiliser N/ha. Greater losses occur where pastures are grazed because of the large returns of N in excreta (Shepherd et al 2003). Urine deposition from grazing animals, though limited to only a proportion of the pasture area, can provide the equivalent of up to 1000 kg N/ha in urine patches . Much of the nitrate leached from grazed grassland originates from these localised 'hot-spots', irrespective of whether N is supplied as fertiliser or by biological fixation.

The productivity of grass/clover pastures is considered to be broadly equivalent to fertilised grass swards receiving 100-200 kg N/ha (Davies & Hopkins, 1996). At these levels of fertiliser input, leaching losses from grazed swards are typically in the range 1-12 kg N/ha (Barraclough et al., 1992) and are similar to those reported for grass/clover swards. Eriksen et al. (1999) reported that leaching losses were greater from second year grass/clover leys than in first-year leys on an organic farm in Denmark, presumably as N accumulated in the system.

2.11.3 Leaching from arable and horticulture rotations

Much emphasis is always placed on the ley-ploughing phase as the 'danger point' for N leaching in cultivated organic systems. Indeed, nitrate losses can be large after autumn ploughing and further research needs to examine other options. However, because organic production is a 'farming system', rather than the management of a limited set of variables, nitrate losses from the whole rotation need to be considered, not just this one aspect of the system. Because organic systems operate at a lower level of N input, losses are generally less – but this is not always guaranteed (Shepherd 2002).

There are many factors which influence the fate of N released from the ploughing of the ley. The transition from ley to arable cropping in the organic rotation is generally associated with the highest N loss (Philipps et al 1998 & Johnson et al 1994).

Research has shown that nitrate leaching can be substantially reduced by delaying the initial cultivation of the ley from the autumn until the spring and that this can be as significant as a four-fold reduction in leaching (Philipps et al 1995).

Spring cultivation of legume based pastures/leys and cropping is likely to release nitrogen in synchrony with demand, without the leaching risk associated with autumn ploughing and sowing of winter crops (Philipps et al 1995, Watson & Younie 1995). Other research has also shown that the rate of nitrate leaching was reduced when cultivation of the ley was delayed from October to December, especially in high rainfall areas (Watson et 1993, Gustafson 1987). This was attributed to the lower soil temperatures and reduced nitrogen mineralization in December. In response, mineralization only increased in the spring, by which time nitrate leaching approached zero as drainage volumes fell and both evapo-transpiration and plant nitrogen uptake increased in the spring.

When looking at the annual nitrate leaching over the three-year period, comparing an initial spring cultivation of the ley to that of autumn cultivation and planting, the N leaching after spring cultivation was almost half that observed after cultivation in the autumn.

Nitrate leaching from newly established swards of grass-clover vs ryegrass have been shown to be similar, but at increasing sward age between 4-7 years old, nitrate leaching from the fertilized ryegrass has been shown to increase dramatically compared to a constant low level from the unfertilized organic grass-clover situations (Eriksen and Vinther 2002). This was attributed to the clover component of grass-clover being able to equalize differences in soil nitrogen availability in swards of different age (Shepherd et al 2001).

The timing of sward establishment also has a significant impact on Nitrate-N leaching. Losses during the winter months following autumn incorporation of a clover ley can range between 60 and 350 kg N ha /yr , depending on soil type, sward management history and rainfall, whereas reseeding in spring had little effect on leaching losses in the following autumn, compared with undisturbed pasture. Similarly, leaching losses from autumn reseeds in the second winter after cultivation were the same as undisturbed pasture (1-19 kg N ha–1). The effect of ploughing grassland for reseeding was relatively short-term, in contrast to the effect of repeated annual cultivation associated with arable rotations (Shepherd et al 2001)

Trials by Olesen J. E. & Askegaard. M (2001) in Denmark between 1997-2001 looking at N leaching from cropped soils under three factors (1) crop rotation, (2) catch crop (with and without) and (3) manure (with and without animal manure applied as slurry), showed that Nitrate leaching declined with increasing soil clay content and with decreasing rainfall and nitrate leaching was reduced by catch crops on the sandy soils.

Lord et al. (1997) found no difference in N leaching from a number of comparable organic and conventional farms; all had an average loss of 50 kg N ha-1 yr-1 over a whole rotation. Using modelling approaches, the Organic Farming Study (Cobb et al., 1999) found losses from organic farms (52 kg N ha-1 yr-1) to be two-thirds those from conventional farms (78 kg N ha-1 yr-1) (Goulding et al., 2000). The amount of nitrate leaching was related to the timing of cultivation, crop patterns and management. Data presented by (Goulding et al 2000) suggest some cause for concern over the sustainability of organic systems because of their dependence on feedstuffs and bedding for inputs of P and K, and on the very variable fixation rates by legumes or imports of manure or compost for N supply.

Net mineralization from soil reserves appear to comprise a large part of the N supply on some organic farms. Losses of N from organic systems can also be as large as those from conventional systems when the timing of cultivations is inappropriate or when good soil management practise is not followed.

Nitrogen Loss through the subsequent rotation is not uniform. With average losses of 82kg N/ha reported at the transition from ley to arable cropping phase of the rotation (Philipps et al 1998) compared to a far lower N loss during the ley phase of an average of 21kg N/ha, regardless of the age of the ley. The method of establishment of new leys influenced the leaching loss in the first year with undersown leys loosing an average of 17kg N/ha compared to an average of 66kg N/ha loss when leys were established by drilling following cultivations to prepare a seedbed.

Season, timing and intensity and type of cultivation of the ley can have a substantial effect on nitrate leaching (Philipps & Stopes 1995). Rotations relying on the ley being cultivated in the spring demonstrate a reduced risk of N leaching.

Leaching from arable land is increased where N supply exceeds the crop's requirement
(MacDonald et al., 1989). In particular, losses are associated with the temporary nature of annual crops and, sometimes, the lack of synchrony between release of N from organic matter and crop uptake. If soils are left bare in autumn or crops are poorly developed, there will not be an effective rooting system to utilise the soil N that is mineralised after harvest and this will be at risk of leaching over the winter. Increasing the fertility of organically farmed soils by building up the content of SOM and incorporating organic residues and manures increases this risk (Shepherd et al 2003).

The risk of leaching during the arable phase was demonstrated in a study on 17 Norwegian farms that were either organic or in the process of converting to organic production (Solberg, 1995). The potential for nitrate leaching (determined as nitrate-N in the 0-60 soil depth in October) increased in the order; leys (6 kg N/ha) < undersown grain = green fodder (14 kg/ha) < turnips/vegetables (17 kg/ha) < grain without undersown ley (30 kg/ha) < potatoes (33 kg/ha) < fallow (100 kg/ha). Similar measurements (0-75 cm depth) on 26 organic farms in Denmark showed the potential for nitrate leaching to increase in the order; grass/clover or lucerne fields (12 kg N/ha) < bare fields following cereals (48 kg/ha) < fields cultivated with cereals (57 kg/ha) (Kristensen et al., 1994). Eriksen et al. (1999) demonstrated marked differences in nitrate leaching at different stages of a dairy/crop rotation on an organic farm in Denmark. The lowest losses were from first-year grass/clover leys (20 kg N/ha) and increased to 28 kg/ha for the second-year ley. Greater quantities of nitrate were leached (43- 61 kg/ha) during the three years of arable cropping after the ley was ploughed. The overall annual leaching loss from the farm was equivalent to 38 kg N/ha.

2.12 The effect of fertility building 'ley' length and crop rotation on N utilisation

In the UK, organic farming systems are typically based on ley-arable crop rotations, where the 'ley' is an annual or multi-annual green manure containing legumes which is either grazed, cut for forage, mulched or a combination of the former.

The legume component of the 'ley' offers a powerful mechanism for supplying nitrogen because of its potential to harvest biologically fixed nitrogen to support both animal production and a subsequent phase of arable cropping.

Watson et al (1997) calculated a range of Nitrogen input/output relationships for different organically managed lay/arable and stockless rotations from field trials in England and Scotland. The efficiency with which Nitrogen inputs were converted into produce varied from 35% to 63%, depending on crop sequence and the proportion of legumes in the rotation. During the 'ley' phase of the rotation, grazing livestock exhibit a very low efficiency of converting grazed nitrogen into produce. Sheep retain only 23% of the N ingested (Parsons et al 1991). Root crops in the rotation also have a relatively low output to input ratio as a result of FYM applied. However, the first cereal after the ley has a relatively high output to input ratio. This does however reflect the N released from the ploughing out of the ley. Assuming three years of cropping after a ley, N is released in a 4 : 3 : 2 ratio (Granstedt 1992).
With approx 60kg/ha N oftake by the first cereal after the ley, N loss from the system is likely. Several researchers have focused on this loss potential (NRA 1992, Watson et al 1993, Phillips and Stopes 1995) and where it is likely to occur in the ley-arable rotation. Watson et al (1997) suggest that with the greatest inputs of N in the legume rich 'ley' phase of the rotation, the risk of N loss is likely to increase with an increased proportion of ley to cropping in the rotation.

The length of the 'ley' or fertility building phase and its impact on N fixation and subsequent N availability has not been widely studied and more information is required in this area.
Sparkes et al (2003) showed that no more system nitrogen was measured after two years of red clover than after one year. This finding supports earlier work showing that, in terms of nitrogen accumulation, the length of the red clover green manure may be reduced without adverse effects on the subsequent crop (Stopes et al., 1996).

Sparkes et al (2003) demonstrated that when examining conversion strategies and crop performance, the residues added to the soil following (a) mulching Red clover and (b) harvesting Red clover for seed, treatment

(b) contained the highest levels of nitrogen, and, contrary to expectation, although some nitrogen was removed in the harvest of clover seed, there was no significant difference in nitrogen input between the two strategies (Table 7; P=0.001).

Growing the legume in a mixture with a non-fixing plant can increase the proportion per legume of N obtained from the atmosphere. For example, in grass/clover leys, the grass utilises soil N and thus avoids a build-up of soil N that might otherwise inhibit fixation from individual plants. However, competition from a companion crop also reduces the number of N-fixing plants per unit area by competing for space, light, water and nutrients and would therefore reduce the total N fixed per unit area.

Growing 100% legumes will increase the N fixation per unit area over a period of 2-4 years, until a sufficient build-up of soil N occurs to inhibit fixation from individual plants.

Such contradictions, make for difficult management decisions. For example, cutting and mulching leguminous green manures and leys is a standard practice in organic rotations, especially in stockless systems, but recent research (Shepherd et al 2006) with red clover/grass swards has shown that this can decrease the amount of N imported into the rotation compared to cutting and removal of the clover or grazing and removal, by limiting fixation from the atmosphere (by up to 50%) and may also lead to a reduction in the clover content over time.

2.13 Green manure and catch crop use for N management

Green manures are important to add to the diversity of crop types, and are often used in organic farming systems to reduce soil N losses, help crops out-compete weeds, and to improve soil structure and organic matter levels. Green manures also provide an important ground cover function to prevent soil erosion and minimise nutrient losses (Briggs et al 2006).

When land is cultivated or grass-clover is ploughed there is a high risk of nitrogen leaching. Catch crops are effective at reducing nitrate leaching from what would otherwise be bare soil (Stockdale et al., 1995; Rayns & Lennartsson, 1995; Reents et al., 1997; Aronsson & Torstensson, 1998). A lysimeter study in Denmark demonstrated that ryegrass undersown as a cover crop halved nitrate leaching from spring barley with average annual reductions of 20-35 kg N/ha (Thomsen & Christensen, 1999). On sandy soils in the UK, the average leaching loss of 47 kg N/ha from bare soils following cereals was reduced to 22 kg/ha by sowing an overwinter catch crop (Shepherd, 1999). The catch crops were only effective where they had become well established before the start of drainage in autumn. The objective of the study by Thomsen & Christensen (1999) was to measure the effectiveness of an early catch crop in reducing nitrogen leaching from coarse sandy soil. Barley as a green crop for silage was undersown with Italian ryegrass in spring and harvested at the beginning of early heading, and the Italian ryegrass was subsequently used for roughage production in autumn.

One common assumption is that organic soil management leads to an increase in levels of soil organic matter (SOM), resulting from large inputs of organic matter from leys and animal manure (Tinker 2000). A number of studies have measured higher levels of organic matter in organically managed soils (Reganold 1995) although other studies have failed to show this (Alfoldi et al.1995). Gosling & Shepherd undertook a comparative analysis of organic and conventionally managed soils in southern England in 2002 focusing on soil organic matter and discussed them in relation to other work. Results suggested no significant difference between the level of soil organic matter on established organic farms in Southern England and paired conventionally managed farms. They reported that the differences were largely down to large differentials in the volume of FYM and slurry applied in different experiments and that the influence of leys on SOM may also be overestimated. However this was from monitoring observation, rather than replicated trials. Where leys are cut for silage large amounts of organic matter are removed; also fresh organic matter added when the ley is incorporated breaks down very rapidly and may have little long-term effect on SOM levels (Campbell & Zentner 1993).

Crop residues can be an important source of nutrients to subsequent crops. It is well documented that different quantities of N, P, K and minor nutrients are removed from, and returned to, the soil depending on the crop species concerned (Wild 1988; Sylvester-Bradley 1993). The quantity and quality of crop residues will clearly influence the build up of soil organic matter (Jenkinson & Ladd 1981) and the subsequent availability and timing of release of nutrients to following crops (Jarvis et al. 1996). Cereal straw, for example, contains only around 35 kg N ha-1 compared with more than 150 kg N ha-1 for some vegetables residues (Rahn et al. 1992, Jarvis et al. 1996). Residues also contain variable amounts of lignin and polyphenols, which influence decomposition and mineralization rates (Jarvis et al. 1996; Vanlauwe et al. 1997).

Incorporation of N rich, low C:N ratio residues leads to rapid mineralization and a large rise in soil mineral N (Rahn et al. 1992), while residues low in N such as cereal straw can lead to net immobilization of N in the short to medium term (Jenkinson 1985). The latter can be advantageous in preventing N leaching between crops (Jenkinson 1985; Nicholson et al. 1997). The inclusion of crops with a diverse range of C:N ratios can help to conserve N within the system and, compared with monocropping, has the potential to increase the capacity of the soil to supply N in synchrony with crop demand (Drinkwater et al. 1998). Mixing residues of differing quality also has potential to synchronize mineralization with crop demands (Handayanto et al. 1997) though the practicalities of this on a farm scale are questionable.

Residues will break down and release N at different rates; much will depend on the chemical and physical properties of the residue. A key factor is the carbon : nitrogen ratio (C : N ratio) of the crop or green manure residue, which influences the rate of decomposition and nutrient availability.
As outlined above, green manures planted between crops, as over winter covers or as annual covers can be used to fix soil N (build fertility), retain soil N (holding and relocation) and reduce leaching (minimise loss). When these green manures are subsequently incorporated, their decomposition stimulates microbial activity and soil N release, which is available to the following crop. The ratio of the amount of carbon (C) to the amount of N in the green manure crop, or C:N ratio, influences the rate of decomposition of the green manure and nutrient availability. C:N ratios vary depending on the composition of different materials and their growth stages. Young green material with C:N ratios of 15 will break down rapidly and release N. Older more “woody” material with a C:N ratio of about 80 will break down more slowly and release N over a longer period. Material with a high C:N ratio has a low percentage of N and conversely a low C:N ratio has a high percentage of N. Generally, the more nitrogen to carbon (a narrow C:N ratio), the more rapid the N release.

Well-mulched young green manure residues decompose slowly in the soil because they are relatively stable, having undergone a significant amount of decomposition already. Residues with a C:N ratio in the mid-20’s will make soil N readily available as they decompose. However mature plant residues with a C:N ratio of over 40 **(Table 1**) may cause temporary problems in the supply of N to plants as microorganisms immobilize surrounding soil N to aid their growth and reproduction, thus diminishing the amount of nitrate and ammonium available for crop uptake. In some cases, the C:N ratio might be too simplistic a measure of degradability because it does not always reflect the accessibility of the C and N to the microbial population. For example, residues with a high lignin content will be difficult to break down. Therefore, although native soil organic matter and compost have narrow C:N ratios (and might be expected to ‘mineralise’), these materials are well humified and are difficult to break down further.

Material	C: N ratio
Soil microorganisms	7
Soil organic matter (SOM)	10 – 12
Clover	13
Compost	15
Grazing Rye	36
Maize stems	60
Wheat straw	80
Fresh sawdust	400

Table 1 **Typical C:N ratios in agricultural systems**

There is potential to use different green manures alone or in combination, which when incorporated decompose at different rates, so as to release soil N at different stages to the growing crop. This can be used to limit the size of the soil "N flush" after leguminous green manures are incorporated and better match the release of soil N to the demand of subsequent cash crops.

In predominantly livestock based systems, with a higher demand for grazing and forage rather than combinable crops, Nitrogen from legumes and FYM additions is often in good supply and not always fully utilised by cropping. In this situation, when grass-clover is ploughed, there is a high risk of nitrogen leaching especially in sandier soils. The effectiveness of catch crops and green manures for reducing nitrogen leaching from coarse sandy soil has been evaluated by a number of researchers.
Following incorporation of 3-5 year clover leys used in dairy systems, using spring barley as a green crop for silage undersown with Italian ryegrass and harvested at the beginning of early heading, can reduce leaching to a minimum compared to spring barley not undersown and taken to maturity as a combinable crop (Hansen et al 2005). In addition this has the benefit of being able to subsequently use the Italian ryegrass for roughage as autumn production.

2.14 Animal FYM - management of Nitrogen in manures

In organic farming manures are typically applied to pasture used for conservation and root crops, although it may be more beneficial from an N supply point of view to apply them in the spring to cash crops such as cereals or even vegetable crops (where legislation permits). Manure management within the rotation has been shown to have large effects on both yield and product quality, including protein levels in cereals (Stein- Bachinger 1996; Frederiksson et al. 1997).

The quantity of nutrients in manures varies with type of animal, feed composition, quality and quantity of bedding material, length of storage and storage conditions (Dewes & Hunsche 1998; Shepherd et al. 1999). A typical application of 25 t ha-1 of farmyard manure from housed organic cattle will contain 150 kg of N, 35 kg of P and 140 kg of K (Shepherd et al. 1999). In organic systems it is particularly important to conserve manure nutrients for both economic and environmental reasons.

Animal manures are the most common amendments applied to the soil. On mixed and livestock farms they are an important means of re-distributing nutrients as it is important to ensure that excessive fertility is not built in some fields at the expense of others. Manure use should be planned with regard to both farm system and field nutrient budgets (Berry et al. 2002). Manures play a key role in fertility building and maintenance in many organic rotations. Understanding their nutrient composition and nutrient availability is therefore important for optimising their use on farm (Shepherd & Philipps 2002).

Manures are a valuable source of nutrients (and organic matter), and can be seen as a method of transferring nutrients around the farm (for home produced manures) or as a method of importing fertility (imported manures or composts). Good manure management offers a 'win-win' opportunity: benefits to soil fertility and benefits to the environment (less pollution) (Shepherd & Philipps 2002).

Cattle manures from organic holdings have been shown to have slightly lower nutrient contents than their conventional equivalents, but variability is large. Therefore, much of what we know about managing conventional manures can be adapted to organic agriculture. Autumn application of slurry should be avoided in order to minimise nitrate leaching loss; rapid incorporation or soil injection will minimise ammonia loss, for example.

Once excreted, nutrient losses from manures (especially of N as ammonia) can occur during housing (Pain et al., 1998) and during manure storage (Kirchman, 1985). Additions of bedding material and/or water will also modify nutrient content (Shepherd & Philipps 2002). One of the biggest factors influencing N retention or loss is different approaches to manure storage across farms: the amount of straw added and whether the heap is composted or simply stacked, having a major effect on gaseous N losses (Shepherd & Philipps 2002). Their results also show that cattle manures from organic holdings can have slightly lower nutrient contents than their conventional equivalents, but variability is large.

Research evaluating the effectiveness of autumn, winter and spring application of straw-based FYM to a sandy loam soil at 300 kgN ha / yr in Denmark between 1999-2001 showed that FYM should be applied in spring to achieve the optimum use of nitrogen in the manure by spring barley (Hordeum vulgare L.), followed by ryegrass (Lolium perenne L.). Evaluating the incorporation of the FYM prior to ploughing with three different initial tillage strategies (harrowing, rotavating or no-tillage),crop yield and nitrogen uptake did not increase from harrowing or rotavating incorporation of the manure before ploughing (Hansen et al 2004).

When not applied appropriately, animal manures applied to agricultural soils can be significant contributors to nitrate leaching. The greatest risk is from late summer/early autumn applications of manures containing significant proportions of 'readily available N' (i.e. the fraction that can be nitrified quickly) (Shepherd et al 2003). Large amounts of N can also be lost from the soil in surface run-off when heavy rain falls in the first few days after slurry application (Sherwood & Fanning, 1981). It is the 'readily available' nitrogen fraction that is most at risk from leaching: ammonium-N, uric acid-N (poultry manures) and nitrate-N (generally only trace amounts in most manure) (Shepherd et al 2003).

In organic farming most manures are produced from either slurry or straw-based systems. The straw based systems have a relatively small readily available N content, thus presenting a small nitrate leaching risk (Shepherd et al 2003). Some manures are also composted, which tends to reduce their ammonium N content still further. However, it should be noted that nitrate can accumulate during composting and it may be that well-composted manures have potential to leach substantial nitrate (either from an uncovered heap or after application to land in autumn).

Another route for N loss is that of direct run-off of N in leachate from manure stores (Stockdale et al., 2001). Clearly, manures have to be managed in such a way as to minimise this risk by having facilities to collect the leachate. Covering the manure will not necessarily eradicate the risk, because much of the N is contained in the liquor that leaks from the FYM heap in the first few days (Shepherd 1999). The N content in leachate leaving the heap declines with time, because the readily available N becomes assimilated into the organic fraction of the manure heap.

2.15 Compost use in organic systems - nitrogen management

Composting is recommended in organic farming as a management tool for controlling weeds, pests and diseases. Organic standards promote composting, anaerobic digestion, aeration of slurry and correct storage of manure. These treatments greatly reduce pathogen loads in manure by increasing the range of biological activity, which helps to suppress pathogenic microbial populations, and by heat pasteurisation. A well-managed aerobic digester or aerobic compost heap will reach temperatures of 55°C to 65°C, and will be maintained at this temperature for three days to destroy weed seeds and pathogenic bacteria. In addition, aerobic composting results in the stabilisation of nutrients, giving the compost nutrient release characteristics that are more in tune with the demand of crops throughout the seasons (Rees 2005).

True composting of manures, i.e. aerobic decomposition at temperatures of around 60 Deg C, results in fundamental physical and chemical changes to the manure. Composting results in some losses of nitrogen through volatlisation in the form of ammonia however the soluble nutrients, partcilarly nitrogen, are stabaisled and hence subsequently less liable to leaching. Composted manure thus has a more long-term role in building soil fertility, and has been shown to be more effective in building soil microbial biomass and increasing activity than uncomposted manure (Fließbach & Mäder 2000).

As with FYM, the storage of composts must be undertaken to minimise water ingress from rainfall and subsequent leaching. When spreading, the same approach applies as with FYM, matching N release to crop demand and minimising the risk of leaching. However the relatively low N content of composts (typically 1%) reduces the potential risk of leaching significantly.

2.16 Cultivations / tillage and Nitrogen management

Cultivation has a number of purposes, including incorporation of manures and crop residues and weed and disease control, as well as preparation of a seedbed for crops and for remediation of damaged soil structure caused by trafficking (Wild 1988). The choice of cultivation type will depend on both the principle aim and the soil type. Organic systems tend to utilise shallow rather than deep ploughing, as this retains crop residues near the soil surface, where they break down more rapidly and where most rooting occurs, while achieving sufficient aeration (Lampkin 1990, Lampkin, Measures & Padel 2007). Cultivation itself leads to an increase in nutrient availability, particularly N, as microbial activity is stimulated and organic matter breakdown occurs (Balloni & Favalli 1987; Torbet et al. 1998; Silgram & Shepherd 1999). Mechanical weed control can thus provide a mid-season boost to crops by stimulating mineralization although at other times additional stimulation of mineralization may cause losses by leaching or denitrification.

Tillage is known to decrease soil organic nitrogen (N) and carbon (C) pools with negative consequences for soil quality. This decrease is thought to be partly caused by exposure of protected organic matter to microbial degradation by the disturbance of the soil. Little is known, however, about the short-term effects of tillage on mineralization of N and C, and microbial activity.

Conventional plough vs non-inverting-tillage were studied by Kristensen et al (2003), focusing on mineralization and microbial N and C pools in a sandy loam under organic plough-tillage management. N release by tillage was further studied in the laboratory by use of 15N labelling of the active pool of soil N followed by *simulation* of tillage by sieving through a 2 mm sieve. The two types different types clarify of tillage (ploughed vs non-inversion tillage) and the *simulated* tillage had very few effects on mineralization and microbial pools. The simulation of tillage caused, however, a small release of N from a pool which was otherwise protected against microbial degradation. This suggests that the microbial pool is the main source of labile N which may be released by tillage, and thus to its importance for sustained soil fertility in agricultural systems (Kristensen et al 2003).

Generally, there are some indications that inversion ploughing and deep tillage reduces the numbers of invertebrates (Mäder et al., 1996a; Fuller, 1997), particularly earthworms (Edwards & Lofty, 1982; Scullion et al., 2002) and collembola and some oribatid mites (Wallwork, 1970). However, it may encourage small mammals (Brown, 1997). Both conventional and organic farming use inversion ploughing, though there is more scope for adopting minimal tillage regimes on some soil-types under conventional farming, where soil conditions are suitable and weed control can be achieved by herbicide use (Shepherd et al 2003).

2.17 Nutrient budgets

On organic farms, where the importation of materials to build/maintain soil fertility is restricted, it is important that a balance between inputs and outputs of nutrients is achieved to ensure both short-term productivity and long-term sustainability.

Berry et al (2003) considered different approaches to nutrient budgeting on organic farms and evaluated the sources of bias in the measurements and/or estimates of the nutrient inputs and outputs. The paper collated 88 nutrient budgets compiled at the farm scale in 9 temperate countries. All the nitrogen (N) budgets showed an N surplus (average 83.2 kg N ha-1 year-1). The efficiency of N use, defined as outputs/inputs, was highest (0.9) and lowest (0.2) in arable and beef systems respectively. The phosphorus (P) and potassium (K) budgets showed both surpluses and deficits (average 3.6 kg P ha-1 year-1, 14.2 kg K ha-1 year-1) with horticultural systems showing large surpluses resulting from purchased manure. The estimation of N fixation and quantities of nutrients in purchased manures may introduce significant errors in nutrient budgets. Overall, the data illustrated the diversity of management systems in place on organic farms, and suggest that used together with soil analysis, nutrient budgets are a useful tool for improving the long-term sustainability of organic systems (Berry et al 2003).

The budgets calculated for case studies by Berry et al (2003) indicated no reason for organic systems to be inherently unsustainable with regard to N, P or K. Rotations showed a wide range of nutrient balances, with differences arising from contrasting crop sequences, varied interactions with on-farm livestock and use of supplementary nutrients. There is therefore scope to increase the efficiency of individual organic systems and minimise losses to the environment. Simple rotational budgets were found to be a useful tool for farmers and their advisors to understand and manage nutrient flows at a rotational level. Their results and literature review clearly showed that the supply of available N must be increased during the period of rapid crop growth to improve arable crop productivity in organic systems (Berry et al 2003).

2.18 Soil analysis and use for monitoring N

As soil fertility management in organic systems is a longer term, more strategic process than in conventional systems, soil analysis and interpretation must be adapted to reflect this. Trends in soil nutrient and organic matter status are likely to be more important than snapshot analysis.

There has been considerable discussion over whether different methods of soil analysis are required for organic farming. Conventional soil analysis for advisory purposes relies on the interpretation of the chemical extraction of different nutrient pools from the soil to predict nutrient release to crops. This type of analysis is likely to be more difficult to interpret in organic than conventional systems where there is a much stronger reliance on biological processes for nutrient supply.

There is much interest in the development of indicators of soil health and quality although little agreement over what these should be (Doran & Zeiss 2000). Simple indicators of soil health would help organic farmers to solve problems on farm. Wander & Drinkwater (2000) suggest that organic matter and organic matter dependent properties show most promise for supporting management decisions.

3. Analysis and Conclusions

3.1 Introduction

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

Because of the fertility-building and fertility-depleting stages of organic rotations, it is difficult to define the overall fertility of an organically farmed soil from measurements at a single stage of the rotation. It is also more important to include measurements of the reserves of less-readily available nutrients (e.g. organic P and non-exchangeable K) in assessing fertility than with non-organically farmed soils. Thus, it can be concluded that although nutrient management in organically managed soils is fundamentally different to soils managed non-organically, the underlying processes supporting soil fertility are not. The same nutrient cycling processes operate in organically farmed soils as those that are farmed non-organically although their relative importance and rates may differ. Nutrient pools in organically farmed soils are also essentially the same as in non-organically managed soils but, in the absence of regular fertiliser inputs, nutrient reserves in less-available pools might, in some circumstances be of greater significance (Shepherd 2002).

3.2 Nitrogen prediction and fixation

The amounts of N that can be accumulated by a green manure or a ley will not only depend on how well the legume grows, but also where it gets its N from. In an N rich soil, the amount of N a legume fixes from the atmosphere is much reduced compared to that of a legume in a soil with low levels of N (Briggs et al 2005). For any particular legume species, there is usually a close relationship between the success of the biomass production, typically green matter yield, and the quantity of N fixed. Therefore the success of the green manure or 'ley' in terms of productivity is important for N fixation. Simply, don't expect to get good cash crops after a failing green manure.

A small supplementary boost of N during the fertility-depleting phase may be obtained by growing a leguminous cash crop, such as field beans or peas. However, it is important to remember that harvesting forage or grain will remove much of the fixed N and reduce the benefit to following crops The benefit will be further reduced if straw and other crop residues are removed from the field.

Predicting the actual amount of nitrogen fixed is notoriously difficult as it depends on many factors including their successful establishment, the legume species and cultivar, proportion of legume in the ley, management, weather conditions and the age of the ley.
N accumulation will vary widely between sites and a large proportion of this N is found below ground in the rooting system. Thus a good soil structure is important to allow the legume to put down deep roots so as to be able to grow more and fix more N.

Management factors for maximising N fixation and optimising legume management include:

- N fixation by Legumes is greater in N poor soils and less in N rich soils
- N fixation by legumes is directly proportionate to the success of the legume development, growth and biomass production or yield
- Slurry and FYM applied to legumes reduces N fixation
- Legumes fix more N when in growth mode, prior to flowering and changing to reproduction mode – to maximise, keep legumes in growth mode
- Mulching legume crops reduces N fixation by up to 50kg/ha/yr – to maximise N fixation remove the biomass to encourage N fixation
- Some seed production may be advantageous in clovers to prolong longevity in the sward and avoid dieback
- Treat grain legumes as N neutral with only a small amount of N left after harvest
- N fixation tends to decrease with legume age, mainly because the amount of soil N tends to increase over time
- Grow 100% legume to maximise N fix over shorter time periods 2-3 years
- Grow a mix of legumes and non legumes for longer periods so that the non legume utilises soil N and reduces the build-up of soil N that may inhibit fixation from individual plants

Factors that increase the soil N pool include:

- Legume and ley herbage should be cut for silage and, if possible, on stockless farms it would be better to remove the biomass rather than mulch
- Manure applications
- cutting and mulching
- grazing

Practical approaches to maintaining legumes:

- Correct any nutrient imbalances
- Maintain soil pH above 6.0
- Defoliate mixed swards regularly
- Graze appropriately: avoid over-grazing in spring and under-grazing in summer
- Autumn grazing of surplus forage reduces the risk of frost kill in susceptible regions but beware of excessive grazing reducing stolon length in white clover
- Choose appropriate white clover varieties: small-leaved for continuous grazing; medium for set-stocked and rotational grazing, *but include a greater proportion of medium and large-leaved varieties when there is likely to be more frequent cutting for conservation*

Light

- Shading the legume by a companion crop will reduce photosynthesis, which in turn restricts the supply of energy from the plant to the N-fixing nodules

- Regular defoliation of a mixed white clover is advantageous, but intensive grazing (especially by sheep) can impair the legume's ability to persist in the sward, mainly through reducing the leaf area and number of stolons, but also by removing flower heads, so that seed numbers often become too low for effective regeneration

Water

- Forage legumes are more affected by a lack of water than grasses (apart from Lucerne which is better able to withstand drought conditions), so in dry summers, irrigation would be beneficial to clovers in a mixed sward and the increase in their content and N fixation can be considerable, but depends largely on the amount of stolon material that has survived

Nutrients

- Legumes have a higher requirement for some macronutrients, e.g. P (and possibly for K, Ca and S) than grasses, especially in mixed swards. They compete less favourably with grasses which tend to have more finely branched and denser root systems concentrated in the upper soil layer. Legumes also have a greater need for some of the micronutrients involved directly, or indirectly in N-fixation, viz. Fe, Cu, Co and Mo and are more sensitive to soil acidity, mainly because of the sensitivity of N-fixation to aluminium toxicity

3.3 Soil Organic Matter (SOM) and influence on Soil biology and Nitrogen
Crop rotation design will modify both the size and activity of the soil microbial biomass and it will also modify the physical characteristics of the soil both directly and indirectly. The accumulation of organic matter during the ley phase plays a major direct role in soil structure formation. Soil organic matter (SOM) is intrinsically linked to soil fertility because it is important in maintaining good soil physical conditions (e.g. soil structure, aeration and water holding capacity), and it is an important nutrient reserve. It is the regular additions of fresh organic residues, the *light fraction SOM* that is important for soil structural development.

Arable soils usually contain a smaller biomass of earthworms than pasture soils. Cultivation is widely accepted to reduce earthworm populations. Because organic rotations *tend* to plough less frequently (because of the fertility building stages) this is likely to be an advantage for earthworm populations. However, conversely, there is less scope for reduced cultivation systems in organic farming, which would work against earthworm populations. Therefore when cultivating, aim to plough as shallow as is practicable in order top minimise the disturbance to soil life. Summary points to consider are:

- Regular additions of fresh organic residues are important to maintain healthy soil microbial activity and N mineralization
- Aim to cultivate as shallow as possible to reduce disturbance to soil microbes i.e deeper cultivations, especially when ploughing will have a bigger impact than shallow or non inversion cultivations.
- Consider alternative non-inversion cultivations when growing competitive crops in weed free situations

3.4 N Supply & Nitrogen recycling
When managing legumes for N supply, many factors can affect N fixation, e.g. levels of N in the soil or cutting and removal versus cutting and mulching.

The release of Nitrogen via mineralisation is performed by soil micro-organisms when they use organic N compounds as energy sources. Plant available N is a by-product of this microbial degradation. Mineralisation of N is affected by many factors including:

- soil temperature and moisture (warmer soils will mineralise N more)
- soil biological 'health' (the effects of soil organisms on the mineralisation of organic matter)
- Soil texture (higher clay content soils have more physically protected organic matter which reduces contact between residues and micro-organisms)
- Soil physical condition (good soil structure will allow good soil aeration and minimise water logging, which will benefit microbial activity and N mineralisation)
- Soil disturbance (cultivation practices affect SOM turnover because of the dramatic changes to the physical, chemical and biological interactions within the soil following ploughing)
- Type of residue (the chemical and physical quality of the returning residue has a large influence on the rate of decomposition)

Matching N uptake from soil N release (mineralisation) and crop uptake is particularly important in organic systems where N is released gradually by mineralisation of organic matter. For example, maximum uptake of N by winter wheat occurs in spring when soils are only beginning to warm and mineralisation is still slow . This is likely to limit the supply of N at a critical time for wheat crops on organic farms. Therefore ploughing months ahead of the time required for planting and the N requirement for crop development should be avoided as the mineralization that occurs with cultivations can lead to N loss. Adopting spring cultivations and planting or autumn cultivations followed by catch crops and then spring planting, or potentially catch crops intercropped with winter wheat could improve the utilization of N for crop performance.

Organic farms should seek to maximise Nitrogen recycling within the farming system. This should include minimising losses via leaching by ensuring timely cultivations, careful use of green manures and matching crop demands to nitrogen availability within the rotation. Other than as cash crop sales, the export of biomas and N rich crop residues (i.e as forage or straw) should be avoided unless the export of nutrients can be balanced by importation of nutrients in the form of nitrogen fixation, deposition and importation in manures, composts and slurries. Recycling should also include retention of manures on the farm with targeted use for nutrient utilisation.

3.5 N Leaching and avoidance from cultivated land and grassland systems

Nitrate leaching losses from cut grassland, where herbage is removed from the field, are generally small. However, in both grassland and cultivated land, if the available N is not utilised or its availability is mismatched to crop demand, losses may occur.

Nitrogen is difficult to manage and control in any farming system given its mobility in soils as nitrate and the huge amount of potentially oxidisable organic nitrogen in soils. Losses depend on many factors, not all of which are under the control of the farmer. Weather plays an important role. Practices that minimise risk of loss should be adopted, and it must be recognised that it is impossible to avoid some loss. Maximising green cover (leys, cover crops) at all times, using straw-based manure or composted manures (which are generally more N stable) rather than slurries and fresh FYM (which have the potential for higher N leaching), and using lower stocking rates can all help reduce the potential for N leaching.

Much emphasis is always placed on the ley-ploughing phase as the ‘danger point’ for N leaching in cultivated organic systems. Research has shown that nitrate leaching can be substantially reduced by delaying the initial cultivation of the ley from the autumn until the spring and that this can be as significant as a four-fold reduction in leaching. Spring cultivation of legume based pastures/leys and cropping is likely to release nitrogen in synchrony with demand, without the leaching risk associated with autumn ploughing and sowing of winter crops.

Where autumn cultivations and autumn drilled crops are a necessary part of the rotation, leaching can be reduced when cultivation of the ley is delayed from October to December, especially in high rainfall areas. Reduction in leaching is likely to be greater in sandier soils than in clay based soils where nutrient retention will be far greater.. This is attributed to the lower soil temperatures and reduced nitrogen mineralization in December. Where heavier soils are ploughed in November or December and left to break down for improved structure from frosts over winter, prior to spring planting, nitrogen retention will greater on heavier clay soils than on lighter sandier soils, which are more prone to leaching. Reductions in leaching can be further assisted by sowing a green manure (i.e Mustard or grazing rye) into the ploughed land over winter to capture and retain and mobile soil N. This can then be subsequently incorporated in the spring.

The method of establishment of new leys also influences the leaching loss in the first year with undersown leys loosing an average of 17kg N/ha compared to an average of 66kg N/ha loss when leys were established by drilling following cultivations to prepare a seedbed. Therefore the season, timing and intensity and type of cultivation of the ley can have a substantial effect on nitrate leaching.

Organic systems should aim to utilise shallow rather than deep ploughing, as this retains crop residues near the soil surface, where they break down more rapidly and where most rooting occurs, while achieving sufficient aeration. Whilst the use of inversion ploughing may be unavoidable in organic systems, there is some limited scope for adopting no-inversion or reduced tillage regimes on some soil-types under organic farming, where soil conditions are suitable and weed control can be achieved.

Practical steps to reduce Nitrogen loss include:

- Losses of N as ammonia can be large following manure application (but can be controlled by rapid incorporation of the manure). Denitrification losses can also be large, particularly in warm moist soils following incorporation of N-rich residues or manure
- Nitrate leaching occurs predominantly during the autumn/winter. Nitrate losses can therefore be large if the fertility-building crop is ploughed in the autumn. Autumn manure applications (particularly those with a high mineral N content) also risk substantial loss after an autumn application
- Where autumn cultivations are unavoidable, leaching can be reduced when cultivation of the ley is delayed from October to December
- Aim to utilise shallow rather than deep ploughing

- Consider the method of establishment of new leys, with undersowing reducing N loss from reduced cultivations

3.6 The influence of fertility building ley length and crop rotation
In the UK, organic farming systems are typically based on ley-arable crop rotations, where the ley is an annual or multi-annual green manure containing legumes which is either grazed, cut for forage, mulched or a combination of the former. The legume component of the ley offers a powerful mechanism for supplying nitrogen because of its potential to harvest biologically fixed nitrogen to support both animal production and a subsequent phase of arable cropping.

The efficiency with which Nitrogen inputs can be accumulated and utilised are depending on the cropping sequence and the proportion of legumes in the rotation. The length of the ley or fertility building phase and its impact on N fixation and subsequent N availability has not been widely studied and more information is required in this area.

Limited numbers of studies have shown that no more nitrogen was measured in the system after two years of red clover than after one year. Showing that, in terms of nitrogen accumulation, the length of red clover green manure leys may be reduced from 3-4 years to 1-2 years without adverse effects on the subsequent crops.

Experience suggests that the red clover fixes most N during the period from *good* establishment to maturity. Once it is cut/grazed and allowed to remain at a mature level it is contributing proportionally less N compared to the phase between early growth and maturity. This suggests that for N fixation, shorter but more frequent Red clover green manure breaks are advantageous. However this needs to be balanced against the cost of establishment, weed control, effect on soil structure, etc.

Growing a legume in a mixture with a non-fixing plant (i.e grass) can increase the proportion per legume of N obtained from the atmosphere i.e in grass/clover leys, the grass utilises soil N and thus avoids a build-up of soil N that might otherwise inhibit fixation from individual plants. However, competition from the grass also reduces the number of N-fixing plants per unit area and would therefore reduce the total N fixed per unit area.

Growing 100% legumes increases the number of N-fixing plants per unit area and will increase the N field per unit area over a period of 2-4 years, until a sufficient build-up of soil N occurs to inhibit fixation from individual plants.

Cutting and mulching leguminous green manures and leys is a standard practice in organic rotations, especially in stockless systems. Research with red clover/grass swards has shown that this can decrease the amount of N imported into the rotation by limiting fixation from the atmosphere (by up to 50%) and may also lead to a reduction in the clover content over time.

When managing rotations to maximise use of this N, consider:
- Shorter green manure or ley phases used more often may be more N efficient
- 100% legumes may fix more N compared to legume plus-non legume mixtures
- Consider the timing of cultivation of ley – spring vs autumn breaking of ley though this can have practical applications
- Match crops with a high N demand with positions in the rotation that supply N; green cover; use of fertility boosting crops
- Manure use – consider if being supplied at the right point in the rotation, e.g. not to a point with already large N supply (unless P&K required – then use low N manure)

3.7 Green manure and catch crop use for N management
Green manures are important to add to the diversity of crop types, and are used in organic farming systems to reduce soil N losses, help crops out-compete weeds and to improve soil structure and organic matter levels. Green manures also provide an important ground cover function to prevent soil erosion and minimise nutrient losses.

Residues will break down and release N at different rates; much will depend on the chemical and physical properties of the residue. A key factor is the carbon : nitrogen ratio (C : N ratio) of the crop or green manure residue, which influences the rate of decomposition and nutrient availability.
Young green material with C:N ratios of 15 will break down rapidly and release N. Older more "woody" material with a C:N ratio of about 80 will break down more slowly and release N over a longer period. Material with a high C:N ratio has a low percentage of N and conversely a low C:N ratio has a high percentage of N. Generally, the more nitrogen to carbon (a narrow C:N ratio), the more rapid the N release.

There is potential to use different green manures alone or in combination, which when incorporated decompose at different rates, so as to release soil N at different stages to the growing crop. This can be used to limit the size of the soil "N flush" after leguminous green manures are incorporated and better match the release of soil N to the demand of subsequent cash crops. Incorporation of N rich, low C:N ratio residues leads to rapid mineralization and a large rise in soil mineral N, while residues low in N such as cereal straw can lead to net immobilization of N in the short to medium term.

In predominantly livestock based systems, with a higher demand for grazing and forage rather than combinable crops, Nitrogen from legumes and FYM additions is often in good supply and not always fully utilised by cropping. In this situation, when grass-clover is ploughed, there is a high risk of nitrogen leaching especially in sandier soils. The effectiveness of catch crops with a high N demand such as grazing rye, grass and rape/turnips is important for reducing nitrogen leaching. Many of these also have the benefit of being able to be subsequently used for autumn forage.

When selecting green manures for use in organic systems, in addition to their contribution to N management a range of issues related to their use, management and suitability to the system operated have to be considered:

- Use - will it be cut and mulched only, or is it required for grazing or forage production?
- How long is it programmed to remain in place, between summer crops? Over winter? As an annual green manure cover?
- How rapid is the development of the green cover from sowing?
- Will the cover be frost hardy if used over winter?
- What form of management will be required, single or multiple cutting and mulching, or grazing?
- Select green manure type in relation to other crops in the rotation, weeds, usage, management and length of time in place
- Avoid green manures of the same family as cash crops in the rotation
- Consider green manure C:N ration - generally, the more nitrogen to carbon (a narrow C:N ratio), the more rapid the N release
- Match green manure breakdown characteristics to N requirement and time of uptake of subsequent cash crops

3.8 Animal FYM - management of N in manures

Organic manures are traditionally applied to silage and root crops although it may be more beneficial to apply them to cash crops such as cereals or even vegetable crops (where legislation permits). Manure use should be planned with regard to both farm system and field nutrient budgets. Cattle manures from organic holdings have been shown to have slightly lower nutrient contents than their conventional equivalents, but variability is large. The application of manures not only plays an important role in allowing targeted inputs of nitrogen to different parts of the rotation, different crops and different soils on the farm, but also allows re-cycling of P & K around the farm. As crops (forage and grain crops) are harvested, and livestock meat and milk products sold from the farm, N, P and K are removed from the system. Manure applications can go some way to redressing this loss. The beneficial impact of manures on soil biological activity is also an important component of their use. Targeting manures to soils which have lower soil biological activity can help stimulate increased biological activity and in turn improved nutrient minersalisation.

A route for N loss that must be also considered carefully is that of direct run-off of N in leachate from manure stores.Manures that are stored and managed in such a way so as to minimise the risk of leaching i.e by having facilities to collect the leachate, or by covering the manure to minimise water ingress from rainfall, have better nutrient retention and are therefore more valuable to the organic farmer.

Good management of animal manures in organic systems should include:

Storage
- Cover yards and slurry tanks to prevent nutrient dilution and reduce the creation of dirty water – another natural 'waste' that will have to be dealt with
- Cover slurry stores in order to minimise gaseous losses
- Where possible, storage and composting of manure should be conducted indoors, under plastic sheeting or on hard standing where run-off can be collected. This will prevent leaching of nutrients during periods of heavy rainfall
- Steel and concrete slurry tanks and slurry lagoons should be built to the British Standard BS5502 part 50:1989

Application
- Wherever possible, use a band spreader, trailing shoe spreader or injector to apply slurry. Where this is not possible, use a broadcast slurry spreader that gives a low trajectory and large droplets. Band spreaders, trailing shoe spreaders, injectors or rapid incorporation will reduce odours and ammonia losses, whereas low trajectory broadcast spreaders will only reduce some of the odour
- After surface application of slurry or solid manure to bare land, incorporate the material into the soil within twenty-four hours of spreading and, where practical, within four hours
- Organic standards state that the total amount of manure applied to the holding must not exceed the equivalent of 170 kg of nitrogen per hectare of agricultural area used, calculated over the whole area of the holding or linked units
- Avoiding autumn applications of slurry to reduce nitrate leaching loss. If unavoidable rapid incorporation will minimise ammonia loss
- When spreading, match N release to crop demand and minimising the risk of leaching and incorporate rapidly
- Target manures where the greatest nutrient export has been identified by nutrient budgets. I.e for forage, large exports of P & K can be balanced with manure or slurry applications
- Where forage is not produced as part of the system, consider targeting applications to cash crops and leys with low legume contents

Do not spread . . .
- within at least 10 metres of a ditch or watercourse or within 50 metres of a spring, well or borehole that supplies water for human consumption or a farm dairy
- more than 50 m3 per hectare or 50 tonnes per hectare at one time, to reduce the risk of runoff. Reduce these rates as necessary, so that the amount of total nitrogen applied from organic manures does not exceed 250 kg per hectare per year. Poultry manure will usually reach this loading at 5 to 15 tonnes per hectare. Under organic standards, farmers are restricted to applications that do not exceed 170kg/ha N per year over the entire holding. With Cattle manure this is typically at an application rate of 25t/ha (10t/acre)
- Do not spread on steeply sloping fields where there is a risk of run-off, or on land that is waterlogged or has a compacted surface
- when soils are frozen hard, that is, frozen for 12 hours or longer in the preceding 24-hour period
- when the field is snow-covered
- when the soil is cracked down to field drains or backfill
- when fields have been pipe or mole drained, or sub-soiled over existing drains within the last 12 months

Timing of application: for optimum use of the available nutrients in manures, they should be spread as close as possible before maximum crop growth and nutrient uptake occur. Remember, many people complain about unpleasant smells from farms. Therefore, consider the following points before spreading.
- Do not spread in the evenings or at weekends, when people are more likely to be at home
- Pay attention to wind direction in relation to neighbouring houses
- Avoid spreading under warm, humid conditions
- Use spreading systems which minimise the production of dust or fine droplets
- Do not spread between September and January when nutrient uptake by growing crops is reduced and the potential for losses is greater

3.9 Nutrient budgeting & Soil analysis and use for monitoring N
On organic farms, where the importation of materials to build/maintain soil fertility is restricted, it is important that a balance between inputs and outputs of nutrients is achieved to ensure both short-term productivity and long-term sustainability.

With a huge diversity of management systems in place on organic farms, used together with soil analysis, nutrient budgets are a useful tool for improving the long-term sustainability of organic systems. There is scope to increase the efficiency of individual organic systems and minimise losses to the environment. Simple rotational budgets can be used as a useful tool for farmers and their advisors to understand and manage nutrient flows at a rotational level.

As soil fertility management in organic systems is a longer term, more strategic process than in conventional systems, soil analysis and interpretation must be adapted to reflect this. Trends in soil nutrient and organic matter status are likely to be more important than snapshot analysis.

- Use nutrient budgets to create a balance between inputs and outputs to ensure both short-term productivity and long-term sustainability
- Nutrient budgets can be used to increase the efficiency of organic systems and minimise losses
- Nutrient budgets can be used to modify and plan rotations
- Use soil analysis and interpretation to support longer term, more strategic monitoring of soil fertility in organic systems, particularly of P, K, Mg etc
- The use of N sampling is of limited use in organic systems as N is very mobile and measurements can result in large variations in measured total and available soil N

4. References

A
Alfoldi T; Mader P; Besson J M & Niggli U (1995) DOC–trial: Long-term effects of bio-dynamic, bio-organic and conventional farming systems on soil conditions, yield and product quality. In: Main effects of various organic and mineral fertilization on soil organic matter and turnover and plant growth. Proceedings of the first meeting in Darmstadt, Germany, 8th-10th May 1995. ed J Raupp pp. 3-15. Institute for Biodynamic Research, Darmstadt, Germany.

Anon, (2002) Improving N use and performance of arable crops on organic arable farms using an expert group approach (Final report to Defra proj OF0178). Report, Boxworth, ADAS

Aronsson, H. & Torstensson, G. (1998). Measured and simulated availability and leaching of nitrogen associated with frequent use of catch crops. Soil Use and Management 14, 6-13.

B
Balloni W & Favalli F (1987). Effects of agricultural practice on the physical, chemical and biological properties of soils. Part I Effect of some agricultural practices on the biological soil fertility. In: Scientific basis for soil protection in the EC eds H Barth & P L'Hermite, Elsevier Applied Science London.

Barraclough, D., Jarvis, S.C., Davies, G.P. & Williams, J. (1992). The relation between fertiliser nitrogen applications and nitrate leaching from grazed grassland. Soil Use and Management 8, 51-56.

Berry PM Stockdale EA Sylvester-Bradley R Philipps L Smith KA Lord EI Watson CA & Fortune S (2002) N, P and K budgets for crop rotations on nine organic farms in the UK. Soil Use and Management.

Berry, P.M.; Stockdale, E.A.; Sylvester-Bradley, R.; Philipps, L.; Smith, K.A.; Lord, E.I.; Watson, C.A and Fortune, S. (2003) N, P and K budgets for crop rotations on nine organic farms in the UK. Soil Use and Management 19(2).

Berry M, Sylvester-Bradley R, Philipps L, Hatch D, Cuttle S P, Raynes F and Gosling P (2002) Is the productivity of organic farms restricted by the supply of available nitrogen? Soil Use Manage. 18, 248–256 - Special issue of Soil Use and Management. British Society of Soil Science

Breland TA (1995). Green manuring with clover and ryegrass catch crops undersown in spring wheat: effects on soil structure. Soil Use and Management 11, 136-167.

Briggs S.R., Cuttle S, Goodlass G, Hatch D, King J, Roderick S & Shepherd M (2005) Soil Nitrogen Building Crops in Organic Farming – Defra research project OF0316 project publication

Brown, R.W. (1997). A Review of the Rhone-Poulenc Farm Management Study. Rhone Poulenc Agriculture, pp 50.

Bulson, H.A., Welsh, J.P., Stopes, C.E. and Woodward, L. (1996) Agronomic viability and potential economic performance of three organic four year rotations without livestock, 1988-1995. Aspects of Applied Biology 47, 277-286.

C

Campbell C A & Zentner R P (1993) Soil organic matter as influenced by crop rotations and fertilisation. Soil Science Society of America Journal 57, 1034-1040.

Chan KY & Heenan DP (1991). Differences in surface soil aggregation under six different crops. Australian journal of Experimental Agriculture 31, 683-686.

Clement CR & Williams TE (1967). Leys and soil organic matter II. The accumulation of nitrogen in soils under different leys. Journal of Agricultural Science, Cambridge 59, 133-138.

Cormack, W.F. (1999) Testing a stockless arable organic rotation on a fertile soil. In: Designing and Testing Crop Rotations for Organic Farming: Conference Proceedings, J. E. Olesen, R. Eltun, M. J. Gooding, E. S. Jensen, and U. Köpke (eds.), pp. 115-123. Danish Research Centre for Organic Farming, Denmark.

D

Davies, D.A. & Hopkins, A. (1996). Production benefits of legumes in grassland. In: Younie, D. (ed.) Legumes in Sustainable Farming Systems. Occasional Symposium No. 30, British Grassland Society, Reading. Pp 234-246.

Dewes T & Hunsche E (1998). Composition and microbial degradability in the soil of farmyard manure from ecologically-managed farms. Biological Agriculture and Horticulture 16, 251-258.

Doran JW & Zeiss MR (2000). Soil health and sustainability: managing the biotic component of soil quality. Applied Soil Ecology 15, 3-11.

Drinkwater LE Wagoner P & Sarrantonio M (1998). Legume-based cropping systems have reduced carbon and nitrogen losses. Nature 396, 262-265.

E

Edwards, C.A. & Lofty, J.R. (1982a). The effect of direct drilling and minimal cultivation on earthworm populations. Journal of Applied Ecology 19, 723-734.

Edwards, C.A. (1983). Earthworm ecology in cultivated soils. In: Satchell, J.E. (ed.), Earthworm Ecology -from Darwin to Vermiculture. Chapman & Hall, London, pp 123-137.

Eriksen, J., Askegaard, M. & Vinther, F.P. (1999). Nitrate leaching in an organic dairy/crop rotation as affected by organic matter type, livestock density and crop. Soil Use and Management 15, 176-182.

Eriksen, J and Vinther, FP (2002) Nitrate leaching in grazed grasslands of different composition and age. Grassland Science in Europe 7:pp. 682-683.

F

Fließbach A & Mäder P (2000). Microbial biomass and size-density fractions differ between soils of organic and conventional agricultural systems. Soil Biology and Biochemistry 32, 757-768.

Fuller, R.J. (1997). Responses of Birds to Organic Arable Farming: Mechanisms and Evidence. Proceedings of Brighton crop protection conference: Weeds, 1997, Volume 3, 897-906.

Frederiksson H Salomonsson L & Salomonsson AC (1997). Wheat cultivated with organic fertilizers and urea. Acta Agriculturae Scandinavica Section B 47, 35-42.

G

Gardner, S.M., Hartley, S.E., Davies, A. & Palmer, S.C.F. (1997). Carabid communities on heather moorlands in northeast Scotland: the consequences of grazing pressure for community diversity. Biological Conservation 81, 275-286.

Gosling P and Shepherd M (2002) Theory and reality of organic soil fertility – organic matter- report from DEFRA Project OF0164 : from Powell et al. (eds), UK Organic Research 2002: Proceedings of the COR Conference, 26-28th March 2002, Aberystwyth, pp. 137-138.

Goulding K, Stockdale E, Fortune S, Watson C (2000) Nutrient Cycling on Organic Farms

Goulding, K.W.T. (2000). Nitrate leaching from arable and horticultural land. Soil Use and Management 16, 145-151.

Grace PR Oades JM Keith H & Hancock TW (1995). Trends in wheat yields and soil organic carbon in the Permanent Rotation Trial at the Waite Agricultural Institute, South Australia. Australian Journal of Experimental Agriculture 35, 857-864.

Granstedt A (1992) Case studied on the flow and supply of nitrogen in alternative farming in Sweden. L. Skilleby farm 1981-1987. biological Agriculture and Horticulture 9 : 15-63

Gustafson A (1987) Nitrate leaching from arable land in Sweden under four cropping systems. Swedish Journal of Agricultural research 17; 169-177

H

Haynes RJ (1999). Size and activity of the soil microbial biomass under grass and arable management. Biology and Fertility of Soils 30, 210-216.

Handayanto E Cadish G & Giller KE (1997). Regulating N mineralisation from plant residues by manipulation of quality. In: Driven By Nature: Plant Litter Quality and Decomposition, eds G Cadish & KE Giller, CAB International Wallingford UK pp175-185. 22

Hansen, Elly M.; Thomsen, Ingrid K. and Hansen, Martin N. (2004) Optimising farmyard manure utilization by varying the application time and tillage strategy. Soil Use and Management 20:pp. 173-177.

Hansen, E.M.; Eriksen, J. and Vinther, F.P. (2005) Nitrogen leaching following cultivation of grazed grass-clover on coarse sandy soil. Poster presented at N-workshop, Maastricht, 23-26 Sept.

I, J

Jarvis SC Stockdale EA Shepherd MA & Powlson DS. (1996). Nitrogen mineralization in temperate agricultural soils: processes and measurement. Advances in Agronomy 57, 187-235.

Jenkinson DS & Ladd JN (1981). Microbial biomass in soil: measurement and turnover. In: Soil Biochemistry Volume 5, eds EA Paul & AD McLaren, Marcel Dekker 5 New York pp 415-471

Jenkinson DS (1985) How straw incorporation affects the nitrogen cycle. In: Straw, soils and science, ed J Hardcastle, AFRC London pp 14-15.

K

Keatinge, Ray (2001) Efficient use of animal manures within an upland organic system (OF0187). Report, Redesdale, ADAS Consulting Ltd

Kirchman, H (1985). Losses, plant uptake and utilisation of manure nitrogen during a production cycle. Acta Agriculturæ Scandinavica 24.

Kristensen, S.P., Mathiasen, J., Lassen, J., Madsen, H.B. & Reenberg, A. (1994). A comparison of the leachable inorganic nitrogen content in organic and conventional farming systems. Acta Agriculturae Scandinavica Section B-Soil & Plant Science 44, 19-27.

Kristensen ES Hogh-Jensen H & Kristensen IS (1995). A simple-model for estimation of atmospherically-derived nitrogen in grass-clover systems Biological Agriculture and Horticulture 12, 263-276.

Kristensen, Hanne L.; Debosz, Kasia and McCarty, Greg W. (2003) Short-term effects of tillage on mineralization of nitrogen and carbon in soil. Soil Biology and Biochemistry 35:pp. 979-986.

L

Lampkin N (1990). Organic Farming. Farming Press Books Ipswich UK.

Lampkin, N. (1992). Organic Farming. Farming Press, Ipswich, UK, 701 pp.

Lampkin N, Measures M and Padel S (eds) (2007). Organic Farm Management Handbook 7th Edition, University of Wales Aberystwyth.

Ledgard SF & Steele KW (1992). Biological nitrogen fixation in mixed legume/grass pastures. Plant and Soil 141, 137-153.

M

MacDonald, A.J., Powlson, D.S., Poulton, P.R. & Jenkinson, D.S. (1989). Unused fertiliser nitrogen in arable soils - its contribution to nitrate leaching. Journal of the Science of Food and Agriculture 49, 407-419.

Mäder, P., Pfiffner, L., Fließbach, A., von Lutzow, M. & Munch, J.C. (1996). Soil ecology - The impact of organic and conventional agriculture on soil biota and its significance for soil fertility. Taken from the proceedings vol. 1, of the 11th IFOAM international scientific conference, August 11-15, 1996, Copenhagen. In: Ostergaard, T.V. (ed.) Fundamentals of organic agriculture. Okozentrum Imsbach, Germany.

N

Newman, J. (1988). The soil fauna other than Protozoa. In: Wild, A. (ed.) Russell's Soil Conditions and Plant Growth, 11th edition. Longman, UK, pp 500-525.

Nicholson FA Chambers BJ Mills AR & Strachan PJ (1997). Effects of repeated straw incorporation on crop fertilizer nitrogen requirements, soil mineral nitrogen and nitrate leaching losses. Soil Use and Management 13, 136-142.

NRA (1992) Nitrate reduction for protected zones: the role of alternative farming systems. NRA Research Note 108. NRA. Bristol.

O

Olesen J. E. & Askegaard. M (2001) Nitrate leaching from arable crop rotations in organic farming. Acta Agriculturae Scandinavica, Department of Agroecology, Danish Institute of Agricultural Sciences, Box 50, DK-8830 Tjele, Denmark

P

Pain B F; Van der Weerden T J; Chambers B J; Phillips V R; Jarvis S C (1998) A new inventory for ammonia emissions from UK agriculture. Atmospheric Environment 32, 309-313.

Parsons A J Orr R J Penning P D & Lockyer D R (1991) Uptake, cycling and fate of nitrogen in grass-clover swards continuously grazed by sheep. Journal of Ag Science, Cambridge 116: 47-61

Philipps L & Stopes C E (1995) The impact of rotational practice on nitrate leaching losses in organic farming systems in the UK. Biological Agriculture & Horticulture, 11: 123-134.

Philipps L, Stopes C E & Woodward L (1995) The impact of cultivation practice on nitrate leaching from organic farming systems. Soil management in sustainable agriculture (ed by HF Cook and HC Lee) pp 488-496. Wye College press

Philipps L, Stockdale E A, Watson C A (1998) Nitrogen leaching losses from mixed organic farming systems in the UK. From Mixed farming systems in Europe – workshop proceedings, Dronten, - The Netherlands 25-28 May 1998 (eds Van Keulen H, Lantinga E Aand Van Laar H H)

Q, R

Rahn CR Vaidyanthan LV & Paterson CD (1992). Nitrogen residues from brassica crops. Aspects of Applied Biology 30, 263-270.

Ramesh, P.T., Alfred, R.S. & Gunathilagaraj, K. (1997). Population density of earthworms under different crop ecosystems. Madras Agricultural Journal 84, 219-222.

Rayns, F.W. & Lennartsson, E.K.M. (1995). The nitrogen dynamics of winter green manures. In: Cook, H.F. & Lee, H.C. (eds) Soil Management in Sustainable agriculture. Proceedings of the 3rd International Conference on Sustainable Agriculture, Wye College, 31 August-4 September 1993. Wye College Press, Wye, Ashford. pp 308-311.

Reents, H.J., Moller, K. & Maidl, F.X. (1997). Use of soil nitrate through differentiated growing strategies of cereals following potatoes. [Nutzung des Bodennitrats durch differenzierte Anbaustrategien von Getreide als Nachfrucht von Kartoffeln.] Schriftenreihe - Institut fur Organischen Landbau 4, 129-135.

Rees L (2005) Making the most of farm waste - Soil Association technical guides

Reganold J P (1995) Soil quality and farm profitability studies of biodynamic and conventional farming. In: Soil Management in Sustainable Agriculture. eds. H F Cook & H C Lee, pp 1-11, Wye College Press: Wye UK.

Roderick, Stephen and Hovi, Malla (2001), Organic Livestock: Animal Health, Welfare and Husbandry Assessment of existing knowledge and production of an advisory resource compendium. Report, Veterinary Epidemiology and Economics Research Unit (VEERU), University of Reading. *Orgprints website ref: http://orgprints.org/6663*

S

Schmidt H Philipps L Welsh JP & von Fragstein P (1999). Legume breaks in stockless organic farming rotations: nitrogen accumulation and influence on the following crops. Biological Agriculture and Horticulture 17, 159-170.

Scullion, J., Neale, S. & Philipps, L. (2002). Comparison of earthworm populations and cast properties in conventional and organic arable rotations. Soil Use and management 18, 293-300.

Shepherd M (2002) Understanding soil fertility in organically farmed soils
DEFRA project code OF0164 ADAS, Gleadthorpe Research Centre, Meden Vale,
Mansfield, Notts NG20 9PF

Shepherd M.A, Hatch D.J, Jarvis S.C, Bhogal A. (2001) Nitrate leaching from reseeded pasture. Soil Use and Management, Volume 17, Number 2, June 2001, pp. 97-105(9)

Shepherd M.A, Harrison R, & Webb J (2002) Managing soil organic matter – implications for soil structure on organic farms. Special issue of Soil Use and Management. British Society of Soil Science

Shepherd & Philipps (2002) Tools for managing manure nutrients. From: Powell et al. (eds), UK Organic Research 2002: Proceedings of the COR Conference, 26-28th March 2002, Aberystwyth, pp. 165-168.

Shepherd M, Pearce B, Cormack B, Philipps L, Cuttle S, Bhogal1 A, Costigan P & Unwin R (2003) An assessment of the environmental impacts of organic farming
A review for Defra-funded project OF0405 – Defra.

Shepherd M.A, Goodlass G, Hatch D, King J, Cuttle S, Briggs S.R & Roderick S (2006) Defra Project OF0316 'The development of improved guidance on the use of fertility building crops in organic farming' final report – Defra research project OF0316 project publication

Shepherd MA Bhogal A Philipps L Rayns F Lennartsson M & Pain B (1999) The
environmental impacts of manure use in organic agriculture. Report to MAFF for project no. OF0161.

Shepherd, M.A. (1999). The effectiveness of cover crops during eight years of a UK sandland rotation. Soil Use & Management 15, 41-48.

Shepherd MA (2002) Understanding soil fertility in organically farmed soils. Final project report OF0164. Defra Research Policy and International Division, Final Reports Unit & ADAS, Gleadthorpe Research Centre, Meden Vale,
Mansfield, Notts NG20 9PF

Sherwood, M & Fanning, A. (1981). Nutrient content of surface run-off water from land treated with animal wastes. In: Brogan, J.C. (ed.) Nitrogen losses and surface run-off from landspreading of manures, Martinus Nijhoff Publishers, Hague, Netherlands, pp 5-17.

Silgram M & Shepherd MA (1999). The effect of cultivation on soil nitrogen
mineralisation. Advances in Agronomy 65, 267-311.

Siegrist, S., Schaub, D., Pfiffner, L. & Mäder, P. (1998). Does organic agriculture reduce soil erodibility? The results of a long-term field study on loess in Switzerland. Agriculture, Ecosystems and the Environment 69, 253-264.

Solberg, S.O. (1995). Influence of crops and cultivation management on the nitrogen leaching potential on ecological farms in southeast Norway. Biological Agriculture and Horticulture 11, 115-121.

Sparkes D L, Wilson P & Huxham S K (2003) Organic conversion strategies for stockless farming - University of Nottingham, School of Biosciences, Loughborough,
Leicestershire LE12 5RD – HGCA project 2313 - March 2000 to March 2003.

Spiertz JHJ & Sibma L (1986). Dry-matter production and utilization in cropping
systems with grass, lucerne and maize. 2. Nitrogen yield and utilization. Netherlands Journal Of Agricultural Science 34, 37-47.

Stein-Bachinger K (1996). Strategies to improve yield and crop quality by different distribution of limited amounts of farmyard and liquid manure applied to subsequent crops after grass-clover. Proceedings of the 3rd meeting of Fertilization Systems in Organic Farming, Copenhagen pp 64-74.

Stopes, C., Millington, S. and Woodward, L. (1996) Dry matter and nitrogen accumulation by three leguminous green manure species and the yield of a following wheat crop in an organic production system. Agriculture, Ecosystems and Environment 57 (2-3), 189- 196.

Stopes, C., Lord, E.I., Philipps, L. & Woodward, L. (2002). Nitrate leaching from organic farms and conventional farms following best practice. Soil Use and Management 18, 256-264.

Stockdale, E.A., Rees, R.M. & Davies, M.G. (1995). Nitrogen supply for organic cereal production in Scotland. In: Cook, H.F. & Lee, H.C. (eds) Soil Management in Sustainable Agriculture. Proceedings of the third International Conference on Sustainable Agriculture, Wye College, Wye College Press, Ashford, UK, pp 254-264.

Stockdale, E.A., Lampkin, N.H., Hovi, M., Keatinge, R., Lennartsson, E.K.M., Macdonald, D.W., Padel, S., Tattersall, F.H., Wolfe, M.S. & Watson, C.A. (2001). Agronomic and environmental implications for organic farming systems. Advances in Agronomy 70, 261-327.

Stolze, M., Piorr, A., Häring, A. & Dabbert, S. (2000). The environmental impacts of organic farming in Europe. Organic Farming in Europe: Economics and Policy (volume 6), University of Hohenheim, 127 pp.

Sylvester-Bradley R (1993). Scope for more efficient use of fertilizer nitrogen. Soil Use and Management 9, 112-117.

T

Thomsen, I.K. & Christensen, B.T. (1999). Nitrogen conserving potential of successive ryegrass catch crops in continuous spring barley. Soil Use and Management 15, 195-200.

Thorup-Kristensen , Kristian and Pedersen, Lene (2006) Cropping systems with winter wheat or spring wheat? Root growth, catch crops, nitrogen leaching and baking quality. Paper presented at Joint Organic Congress, Odense, Denmark, May 30-31, 2006.

Tinker PB (2000) Conclusions. In Shades of green- A review of UK farming systems ed P B Tinker pp. 91-96. RASE; Warwickshire UK.

Tisdall JM & Oades JM (1982). Organic matter and water stable aggregates in soils. Journal of Soil Science 33, 141-163.

Torbet HA Potter KN & Morrison JE (1998). Tillage intensity and crop residue effects on nitrogen and carbon cycling in a vertisol. Plant and Soil 29, 717-727

Tyson, K.C., Stone, A.C., Scholefield, D. & Jarvis, S.C. (1996). A comparison of animal output and nitrogen leaching losses from grassland receiving 200 kg N/ha/annum and grass/clover receiving no fertiliser nitrogen. In: Younie, D. (ed.) Legumes in Sustainable Farming Systems. Occasional Symposium No. 30, British Grassland Society, Reading, pp 273-274.

U, V

Vanlauwe B Diels J Sanginga N & Merckx R (1997) Residue quality and decomposition: An unsteady relationship? In:Driven By Nature: Plant Litter Quality and Decomposition eds G Cadish & KE Giller, CAB International Wallingford UK pp157-166.

Van Kessel C & Hartley C 2000. Agricultural management of grain legumes: has it led to an increase in nitrogen fixation? Field Crops Research 65, 165-181.

W
Wallwork, A. (1970). The Ecology of Soils. Longmans, London.

Wander MM & Drinkwater LE (2000). Fostering soil stewardship through soil quality assessment. Applied Soil Ecology 15, 61-73.

Watson C.A, Atkinson D, Gosling P, Jackson L R, & Rayns F.W. (2002) Managing soil fertility in organic farming systems

Watson C A, Fowler S M and Wilman D (1993) Soil inorganic N and nitrate leaching on organic farms. Journal of Agricultural Science. Cambridge 120 : 361-369

Watson CA Bengtsson H Løes A-K Myrbeck A Salomon E Schroder J & Stockdale EA (2002) A review of farm-scale nutrient budgets for organic farms in temperate regions. Soil Use and Management

Watson C A & Younie D (1995) Nutrient cycling in rotational cropping systems. Soil management in sustainable agriculture (ed by HF Cook and HC Lee) pp 346-353. Wye College press

Watson CA Ritz K Younie D & Franklin M (1996) Nitrogen and soil biomass dynamics in two crop rotations. Aspects of Applied Biology 47, 43-50.

Watson C A, Stopes C & Philipps (1997) Nitrogen cycling in organic managed crop rotations : Importance of rotation design. From Resource use in organic farming – proceedings of the third ENOF workshop: Ancona 5-6 June 1997

Whalen, J.K., Parmalee, R.W. & Edwards, C.A. (1998). Population dynamics of earthworm communities in corn agroecosystems receiving organic and inorganic fertiliser amendments. Biology and Fertility of Soils 27, 400-407.

Wild A (1988). Russell's Soil conditions and plant growth. Longman Scientific & Technical Harlow UK.