Chapter 4
Plant Nutrients in Organic Farming

Keith Goulding, Elizabeth Stockdale and Christine Watson

Abstract Effective nutrient management is essential in organic farming systems. Processed soluble fertilisers such as ammonium nitrate, which feed the plant directly and are thought to bypass the natural processes of the soil, are not generally acceptable. Nutrient supply to crop plants is supported through recycling, the management of biologically-related processes such as nitrogen fixation by clover and other legumes, and the limited use of unrefined, slowly-soluble off-farm materials that decompose in the same way as soil minerals or organic matter. The aim is to achieve as far as possible a closed nutrient cycle on the farm and to minimise adverse environmental impact. Effective management of any 'waste' materials such as manures and crop residues is a key to nutrient cycling on organic farms. However, not all organic farms have easy access to manures and recycling is limited by the prohibition of the use of sewage sludge because of current concerns over the introduction of potentially toxic elements, organic pollutants and disease transmission. In addition, the current global market, in which food is transported large distances from the farm, results in a significant export of nutrients. Exported nutrients must be replaced to avoid nutrient depletion of soils. Nutrient budgeting suggests some cause for concern over the sustainability of organic systems because of their dependence on feedstuffs and bedding for inputs of phosphorus (P) and potassium (K), and on the very variable fixation by legumes or imports of manure or compost for nitrogen (N); air pollution and net mineralisation 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 and, being dependent on cultivation and the weather, they are even more difficult to control than those from fertilisers applied to conventional farms. There is some evidence of P deficiency in soils under organic production, and replacing K sold off the farm in produce is especially difficult. Organic farming systems may be sustainable and have the potential to deliver significant environmental benefits, but these depend on specific cropping and management practices on each farm. It is important that we study

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and improve nutrient management on *all* farm systems and in the context of plant, animal and human health in order to develop more sustainable farming systems.

Keywords Organic farming · Plant nutrients · Nitrogen (N) · Potassium (K) · Phosphorus (P) · Nutrient budgets · Nutrient management · Soils

4.1 Introduction

Organic farming systems are very diverse and are found across the world, with a range of crop and animal enterprises often linked together. However, strong unifying principles link this wide range of systems and management practices (IFOAM, 1998, 2006). In many countries organic farming has a clear legislative basis and certification schemes for production and processing. Within the European Union (EU), crop and livestock products sold as organic must be certified as such under EC Regulations 2092/91 and 1804/99. In the EU (including the new member states) there was 5.7 million ha land under organic management (3.4% of the agricultural land area) and 143,000 organic farms at the end of 2003 (Willer and Yussefi, 2005). Organic farming systems fall into similar categories to those of conventional agriculture: mixed, livestock, stockless and horticultural. In the EU15 (i.e. excluding the new member states) around 26% of the organic land area was under arable crops in 2003 (Nic Lampkin, personal communication). In the UK, 89% of fully organic land is under grass, 7.7% arable and 1.2% horticulture (Soil Association, 2004). This is in marked contrast with countries like Denmark where 53% of the organic land was in arable cultivation in 2003 (Nic Lampkin, personal communication).

In his book 'The Control of Soil Fertility', Cooke (1967) began by reminding his readers that 'The inevitable result of farming is always to diminish *natural* fertility because portions of the total supply of plant nutrients ... are removed.' Cooke believed that the use of fertilisers within agriculture was necessary to meet food requirements and regarded such systems as efficient and productive. Organic farmers disagree. Processed soluble fertilisers such as ammonium nitrate, which feed the plant directly are thought to bypass the natural processes of the soil and are not generally acceptable (although some soluble materials are permitted under certain circumstances).

From the early days of research into organic farming systems, holistic approaches were held to be more appropriate for organic systems than reductionist ones, embracing the whole philosophy of organic farming and the idea that the 'health of soil, plant, animal and man is one and indivisible' (Howard, 1943; Woodward, 2002). This has, in part, led to the idea that holistic research is the only acceptable approach. If so, what are the most appropriate ways to research nutrient cycling in organic farming systems, and to what extent do they, and should they, differ from approaches in conventional agriculture? There has been a long-standing and unfruitful conflict between 'reductionist' and 'holistic' science in connection with agricultural and ecological research (for example, see Lockeretz and Anderson, 1993; Rowe, 1997). We need a combination of these approaches if we are to understand not only nutrient cycling processes in soils, but also their role in the efficiency of nutrient use at the whole farm level and beyond. In this context, very useful reviews are available from RASE (2000) and a Supplement to Soil Use and Management (Vol. 18, 2002).

Research into nutrient cycling on organic farms can be classified in several ways other than reductionist and holistic. For example, there is a clear split in research approaches between studies that compare organic and conventional systems (e.g. Mäder et al., 2002) and studies that compare different management systems within organic farming (e.g. Olesen et al., 1999). One of the complicating factors in interpreting results of the former approach is whether these trials truly compare farming systems or simply different rotations. Factorial crop rotation experiments (e.g. Mäder et al., 2002; Watson et al., 1999) and field scale testing of crop rotations (e.g. Cormack, 1999), which allow factorial experiments within them, contribute to different aspects of the understanding of nutrient cycling in crop rotations. As soon as the crops or even varieties within a rotation are changed, the impact of that rotation both in terms of yield and productivity, nutrient supply and environmental impact will change regardless of the production system. However, under given soil and climatic constraints, the most productive choice of crops and varieties in a rotation will differ depending on whether the system is managed conventionally or organically. It is also essential to remember that:

> ...although nutrient management in organically farmed soils is fundamentally different to soils managed conventionally, the underlying processes supporting soil fertility are not.
> (Stockdale et al., 2002)

Effective management of any ‘waste’ materials such as manures and crop residues is a key to nutrient cycling on organic farms. However, not all organic farms have easy access to manures, and recycling is limited by the prohibition of the use of sewage sludge because of current concerns over the introduction of potentially toxic elements, organic pollutants and disease transmission. In addition, the current global market, in which food is often transported large distances from the farm, results in a significant export of nutrients. These must be replaced otherwise, as Cooke (1967) said, soil is impoverished and the system unsustainable. Johnston (1991) has expressed concern that, on organic farms, phosphorus (P) and potassium (K) may be mined from soil reserves because of the paucity of acceptable sources to replace these nutrients. This dilemma is recognised by the organic farming movement and a list of allowed amendments is published (UKROFS, 1999). Most of these are organic materials such as calcified seaweed, or relatively insoluble mined products such as rock phosphate, and are not suitable in all circumstances. However, in certain circumstances, where plant or soil analysis clearly demonstrates a need and permission is obtained from the certifying organisation, more soluble materials such as potassium sulphate are allowed. Such exceptions can appear contradictory to conventional farmers. This problem is acknowledged by the organic movement, which is seeking to base its list of approved products on a more sound scientific footing (Peter Crofts, UKROFS, personal communication).

Organic farming is often characterised in terms of what it does not do. It is therefore described as a system which produces food without the use of fertilisers, pesticides or pharmaceuticals. More correctly, organic farming should be regarded as a system which is designed in order to minimise the need for external inputs of nutrients, crop protection aids and preventative medicines. This more accurate definition explains the existence of a list of last resort measures, such as those given above, that are available for use when the checks and balances of the normally balanced system have failed (reluctantly and only with appropriate safeguards). These two elements of the philosophy are critical to understanding research needs at a technical and scientific level. The elements in the definitions remind us that all agricultural systems, both organic and those most easily described as conventional, require mechanisms to appropriately regulate a balance in resource capture between the crop and other vegetation, micro-organisms and invertebrates, and the provision of a range of mineral nutrients for crop growth. In a conventional system these are provided largely through inputs of externally generated materials. The research needs of conventional farming systems have therefore dominantly related to the efficient use of external materials and the design of appropriate inputs. In an organic system these requirements are provided primarily through recycling within the total system. Consequently, the research needs of organic farming have been rather different, such that only the most basic of results from many studies, e.g. information on soil chemistry, have been directly of relevance to organic systems.

In this chapter we examine the sustainability of nutrient cycling on organic farms, mostly using a nutrient budget or audit approach, including some consideration of losses to the environment, and focusing on the situation in Europe.

4.2 Nutrient Management on Organic Farms

The main methods of nutrient management in organic farming in Europe are set out in the EU Council Regulation 2092/91 (Table 4.1). Regulations differ between countries. The International Federation of Organic Agricultural Movements (IFOAM, 2006) has information for all participating countries. Though these approaches are only legally enforceable for food sold in Europe, the basic practices described within this regulation apply to a wide range of systems in temperate and Mediterranean climates. The emphasis is on the use of multi-annual rotations and organic materials of plant and animal origin from organic farms. Where these methods cannot provide adequate nutrition a limited range of other organic materials and mineral

Table 4.1 Extract from European Council regulation (EEC) No. 2092/91

2.1 The fertility and the biological activity of the soil must be maintained or increased, in the first instance by:
I a. cultivation of legumes, green manures or deep-rooting plants in an appropriate multi-annual rotation
II b. incorporation of livestock manure from organic livestock production in accordance with the provisions and within the restrictions of part B, point 7.1 of this annex;
III c. incorporation of other organic material, composted or not, from holdings producing according to the rules of this Regulation.

fertilisers can be used, although their use is permitted only where the need can be demonstrated to the certifying body (for example by soil analysis or by presentation of a nutrient budget). Amendments include rock phosphate, various ground rock products that contain K and magnesium (Mg) (see Fortune et al., 2004), and gypsum. Products such as rock phosphate release nutrients over a period of years rather than weeks (Rajan et al., 1996) and thus their use is planned to build fertility in the longer-term. Trace elements may also be applied, with approval, if they are necessary. The use of lime to maintain pH levels is also acceptable.

Research aimed at improving nutrient supply in organic systems therefore generally focuses on improved use of these technologies on farm. However, it is also important that research is able to challenge the organic standards and feed into the process of future standards development. This may involve working beyond the confines of organic farms, and the use of models may be particularly appropriate.

4.2.1 Nitrogen

Crop rotations, including a mixture of leguminous 'fertility building' and cash crops, are the main mechanism for nitrogen (N) supply within organic systems. Organic rotations are divided into phases that increase the level of soil N and phases that deplete it. The N building and depleting phases must be in balance, or show a slight surplus, if long-term fertility is to be maintained (Berry et al., 2002). Organic rotations must include legumes, usually in a ley phase, to provide N in the absence of soluble N fertiliser. The ratio of ley to arable will be determined by a combination of the system (stocked or stockless) and the soil type, being lower on N retentive soils and higher on sandy soils.

In North West Europe, a typical rotation on a mixed organic farm with a three-year grass and clover ley will support two or three years of arable cropping. This may be extended by including a N-fixing cash crop, such as beans, or by including a short period of N-fixing green manure, such as vetch, between cash crops. Cultivation itself leads to an increase in nutrient availability, particularly N, as microbial activity is stimulated and organic matter breakdown occurs (Silgram and Shepherd, 1999). Mechanical weed control, commonly used in organic horticultural systems, can thus provide a mid-season boost to crops by stimulating mineralisation, although at other times additional stimulation of mineralisation may cause losses by leaching or denitrification.

Nitrogen fixation represents a major input of N into organic farming systems. The amount of N fixed by leguminous crops is very variable, being dependent on such factors as climate, soil pH, available N, P and K, age of legume, species, cultivar and strain of symbiotic rhizobium (Ledgard and Steele, 1992). A number of empirical relationships have been proposed for estimating N fixation by legumes (e.g. Haraldsen et al., 2000; Høgh-Jensen et al., 2004). Some of the models have recently been tested against measured values (Topp et al., 2005). Their performance varies but, generally, their ability to predict N fixation is very good (Fig. 4.1).

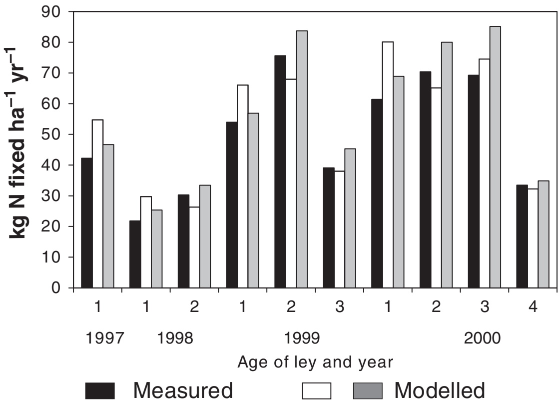

Fig. 4.1 N fixation measurements in different ages of grass-clover leys by year compared with the model predictions (Topp et al., 2005): 1997, 1-year ley only; 1998, 1- and 2-year leys; 1999, 1-, 2- and 3-year leys; 2000, 1-, 2-, 3- and 4-year leys

As Fig. 4.1 shows, sometimes as much as 250–300 kg N ha^{-1}, but often as little as 60–70 kg ha^{-1}, are fixed by a 3-year ley. The input of N through biological fixation is associated with seasonal changes in the availability of soil N. Studies at an organic rotation in the North East of Scotland (Watson et al., 1999), comparing flows of N in different ages of a grass-clover ley have identified a significant ($P < 0.001$) annual fluctuation in the soil nitrate pool (Fig. 4.2). This is likely to be a consequence of lower plant uptake during the winter months coupled with decomposition of residues from the clover. There was also a significant ($P < 0.05$) effect of the age of the grass-clover ley, with first and second year leys containing higher concentrations of NO_3 than third and fourth year leys. This was probably

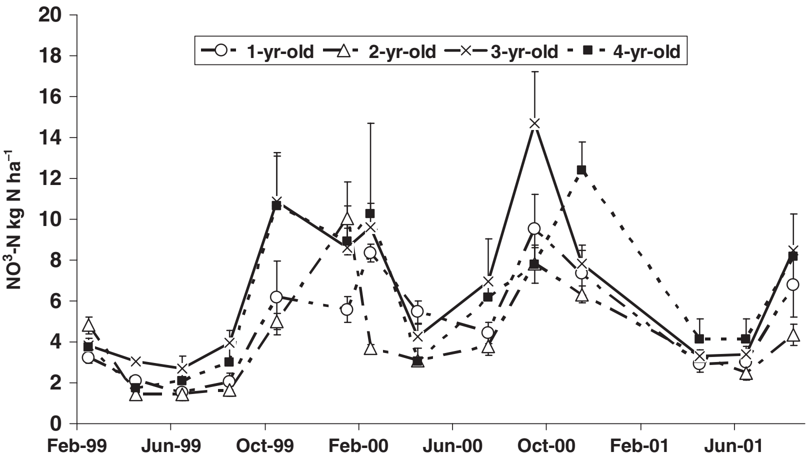

Fig. 4.2 Changes in the amounts of nitrate-N in the 0–15 cm layer of soil at the Tulloch organic rotation in NE Scotland between February 1999 and August 2001 during the growth of leys and following cultivation. Treatments compared are: One year old grass clover leys (1-yr-old), Two year old grass clover leys (2-yr-old), Three year old grass clover leys (3-yr-old), and Four year old grass clover leys (4-yr-old); Watson et al. (1999)

a consequence of the higher rates of N fixation associated with the former. Such information on the input and availability of N is invaluable in helping to design and predict the performance of organic cropping systems.

This seasonal variation in soil mineral N is common to all farm systems but is much more difficult to control in organic systems through cultivation of the ley. Poor matching of soil supply and crop demand for N can lead to losses by leaching or denitrification or both; the transition from ley to arable cropping in an organic rotation is generally associated with the highest loss, with up to 180 kg N ha^{-1} leached in the winter after ploughing (Philipps and Stopes, 1995; Lord et al., 1997). Season, timing and intensity of cultivation have been shown to have a substantial effect on this loss, but when comparable organic and conventional systems are examined over a rotation, losses of N per area are similar or a little smaller in organic systems (Watson et al., 1993; Silgram and Shepherd, 1999). Cultivation of leys in spring, followed immediately by spring cropping, reduced nitrate leaching considerably over a comparable conventional system (Watson et al., 1993). It should be noted, however, that the 'comparable' organic and conventional systems should also be representative of typical organic and conventional systems.

Other management decisions also affect soil mineral N levels and the available of N to a growing crop or its risk of loss. Autumn and winter grazing of leys or other fodder crops can leave large amounts of mineral N at risk of loss when compared with an ungrazed winter cereal (Fig. 4.3), but this is true of all grazed pasture systems. This illustrates a key point: management rather than the system *per se* determines nutrient cycling, crop growth and losses.

In addition to symbiotic N fixation and atmospheric deposition, nutrients may be brought in to an organic system in imported animal feeds, manures, composts and permitted fertilisers. The nature and quantity of imported nutrients will depend on the farming system and the soil type. Manures from non-organic livestock production may be brought onto the holding but there are restrictions (e.g. it must originate from an 'ethical' source, i.e. the animals producing it must be kept un-

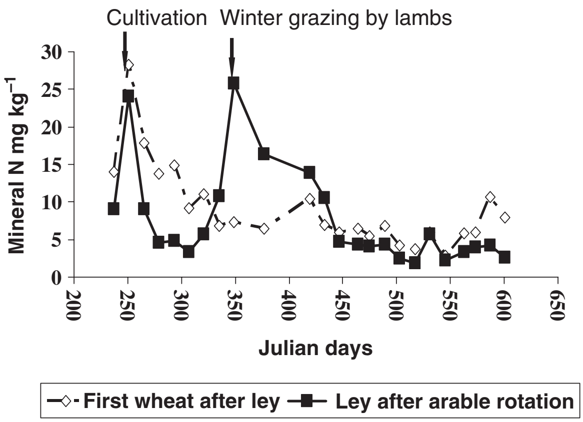

Fig. 4.3 Seasonal changes in mineral N levels in soil as affected by cultivation and grazing patterns

der high welfare standards and not have been fed on a diet containing Genetically Modified Organisms). EU legislation (Council Regulation (EC) No 1804/1999), which came into force in August 2000, requires that a maximum of 170 kg total N ha^{-1} yr^{-1} is applied in manure; where necessary, stocking rate must be reduced to meet this limit. The careful management of animal manure to minimise losses and optimise nutritional benefits is a key feature of stocked organic systems, on which the manure represents a valuable source of N. In this context, it should be noted that composting can lead to large losses of N via ammonia volatilisation.

Stockless systems present a challenge for organic farming. In an exemption to the ‘Set-aside’ rules in Europe (‘Set-aside’ is land taken out of production to reduce food surpluses), organic farmers are permitted to use green cover containing more than 5% legumes in the seed mixture (MAFF, 1999). Clearly, such systems are dependent on EU policy.

4.2.2 Phosphorus and Potassium

As noted above, the application of acceptable mineral nutrient sources are permitted only where the need can be demonstrated to the certifying body, e.g. by soil analysis or by presentation of a nutrient budget. The sources should be unrefined and slowly soluble (to avoid water pollution); in the case of P, rock phosphate is permitted. In mixed and animal-based systems, animal feeds and bedding import relatively large amounts of P and K to organic farms (Fowler et al., 1993; Nolte and Werner, 1994). Any necessary additional P and K is applied strategically within the rotation, with one application of rock phosphate expected to supply P for a number of following crops. However, organic farming seeks to optimise the recycling of P and K and to keep imports as small as possible. In animal-based and mixed systems, good manure management is therefore essential. Manure and slurry are used to redistribute nutrients around the farm. However the grazing patterns of livestock, such as ‘camping’ under trees, next to hedges and at fixed feed troughs, can increase the spatial heterogeneity of P and K returns, which may persist for many years. Phosphorus occurs in organic and inorganic forms in manures (Peperzak et al., 1959; Gerritse and Vriesema, 1984; Sato et al., 2005) and little is lost by leaching; K is found in soluble forms, and large leaching losses of K can therefore occur during manure storage and composting (Fowler et al., 1993).

Potassium is potentially the most difficult major nutrient to manage in organic systems since K sold in produce must be replaced, but there is no obvious sustainable source of K available to organic farmers. Where deficiency can be demonstrated, organic certification bodies will allow the use of materials such as sulphate of potash, MSL-K (volcanic tuff) and Kali vinasse (by-product of the sugar beet industry). There is a need for information on the long- and short-term effects of newly available materials on soil K status, such as the latter two products. However,

Table 4.2 Yield of grass/clover (g pot^{-1}) in a pot experiment (sum of 4 cuts) with a range of organically acceptable K sources applied at 41.5 kg ha^{-1} −/+ additional N (Fortune et al., 2004)

Treatment	−N	+N
Control	7.24	18.85
DKSI	10.46	21.63
Kali vinasse	8.97	17.2
MSL-K	8.29	19.17
Rapemeal	15.69	24.29
Sulphate of potash	9.4	26.35
Sylvinite	8.1	20.54
LSD	4.96	

as already shown by Fortune et al. (2004), yield responses to many of these materials are small, particularly in situations where N is limiting (Table 4.2). In North America, where products like MSL-K and Kali vinasse are not available, potassium sulphate is allowed (from a mined source or from evaporative sources such as the Dead Sea or Great Salt Lake) and even potassium chloride is allowed if 'derived from a mined source and applied in a manner that minimizes chloride accumulation in the soil'.

In the UK and Western Europe, adequate P and K levels in soils have been achieved through many years of applications of fertilisers. A strong hypothesis exists that these are supporting P and K supply to organic crops on converted land. It is possible to take data from several organic farms of different ages that would appear to support the hypothesis that the lack of inputs of P and K is causing the decline in these nutrients in soils now that fertilisers are no longer applied (Fig. 4.4; the data points in Fig. 4.4 are for measured 'Available P' values according to Olsen's method on three farms under organic management for different periods; the line represents a measured decay curve for available P in soils; Johnston et al., 2001). The analyses from the organic farms fit well onto the P decay curve, supporting the hypothesis that available P declines as the duration of the organic rotation increases and P is exported.

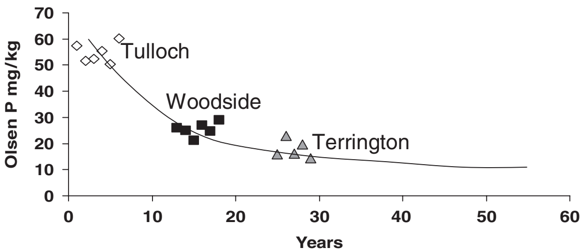

Fig. 4.4 The data points show available P as measured by Olsen's method in soils from three farms in organic rotations for 1 (Tulloch), 15 (Woodside) and 29 (Terrington) years. The line beyond the data points is extrapolated from data of Johnston et al. (2001)

4.3 Sustainability of Nutrient Supplies in Organic Farm Systems

4.3.1 Nutrient Budgets

Nutrient budgets have been compiled around the world, using a variety of scales and methodological approaches (Scoones and Toulmin, 1998; Watson and Atkinson, 1999). They measure or estimate the inputs and outputs of nutrients (usually N, P and K) to a field, farm or system, usually at the 'farm gate'. Farm gate budgets do not usually include the necessarily very detailed measurements of losses such as leaching, denitrification and ammonia volatilisation (but see below), consider each field separately, or measure transfers between fields. Nor do they provide information on soil processes or biological inputs and outputs of nutrients, which are particularly important for N.

Where N fixation is the major external source of N, the balance between N fixing and exploitative arable cropping periods is critical in determining not only productivity but also environmental impact. Figure 4.5 shows that, for a stockless organic rotation, even on what is a very fertile soil, matching N removals in crops with N fixation is difficult.

Goss and Goorahoo (1995) and Halberg et al. (1995) concluded that N budgets were generally positive for organic farms but were probably smaller than for conventional farms (e.g. Watson and Younie, 1995). Leach et al. (2005) calculated a wide range of N surpluses for a series of organic farms from 20 to 120 kg N ha^{-1} yr^{-1}, which is indicative of a wide range of potential N losses.

Looking more widely at N, P and K budgets, the data for the stockless organic system adopted at Terrington farm in the UK show how difficult it can be to balance removals when animals (and their feed and bedding) are not part of the system (Table 4.3). The K deficit on this farm is particularly worrying. Although a detailed

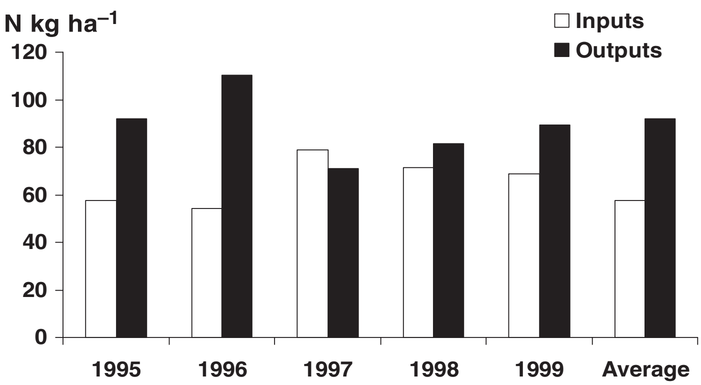

Fig. 4.5 N inputs from biological fixation and N outputs in saleable produce for Terrington stockless organic farm

Table 4.3 N, P and K budgets averaged over the period 1995–1999 on the Terrington stockless organic farm in the UK

	N ($kg\ ha^{-1}\ yr^{-1}$)	P ($kg\ ha^{-1}\ yr^{-1}$)	K ($kg\ ha^{-1}\ yr^{-1}$)
Inputs			
Deposition	30	0.04	3.5
Seed	4.3	1.2	2.6
N fixation	31.9	–	–
Fertiliser	–	9.3	–
Outputs			
Crop offtake	88.8	13.1	45.3
Balance	**−22.6**	**−2.6**	**−39.2**

analysis of the soil might reveal a long-term potential to release K from clay minerals, it would be unwise to rely on this for too long.

Many stockless small-scale organic farms cannot use cover crops to meet their N need, because the land cannot be taken out of production for extended periods of time, and their sole nutrient source is compost. The use of compost in stockless systems can present particular problems because, when added to meet the N requirement of crops, a large surplus of P is usually added at the same time, with accompanying water quality problems.

Where organic systems include animals then nutrient budgets suggest greater sustainability, but with problems remaining for P and especially K (Table 4.4).

Table 4.4 N, P and K budgets ($kg\ ha^{-1}\ yr^{-1}$) averaged over 1993–1998 for two Scottish stocked farm rotations. ('Grazing returns' are for nutrients brought onto the farm in stock; 'Straw for bedding' and 'Silage' are sold off the farm)

	Tulloch			Woodside		
	N	P	K	N	P	K
Inputs						
Deposition	12.0	0.02	2.1	12.0	0.02	2.1
Seed	2.1	0.1	0.7	4.1	1.4	3.2
N fixation	45.0	–	–	35.0	–	–
Manures	56.2	11.9	50.8	57.6	12.2	52.1
Grazing returns	22.1	2.1	29.6	23.0	2.2	30.9
Total	**137.4**	**14.4**	**83.2**	**129.8**	**15.8**	**87.9**
Outputs						
Crop outputs	37.3	11.3	37.3	34.0	10.1	30.8
Straw for bedding	6.5	2.2	19.0	7.4	1.8	15.4
Silage	51.7	13.1	82.0	36.3	7.7	48.0
Liveweight gain	5.5	4.0	8.7	5.8	4.2	9.1
Volatilisation	9.3	–	–	9.9	–	–
Total	**110.4**	**30.6**	**147.0**	**95.4**	**23.7**	**103.3**
Balance	**+27.0**	**−16.2**	**−63.9**	**+34.4**	**−7.9**	**−15.4**

4.3.2 Impact of Nutrient Losses

Data such as those in Table. 4.3 and 4.4 present quite comprehensive budgets including inputs from atmospheric deposition, seed, feed and imported fertilisers, and manures and outputs in saleable produce, but with little information on losses. Measuring full nutrient budgets, including losses and internal flows, is essential for a proper measure of farm sustainability. However, as the complexity of the approach increases there is a need to measure or estimate increasing numbers of variables, and either costs or errors increase. Table 4.5 shows full nitrogen budgets for three organic farms in which an earlier, simple farm gate N budget has been modified by including losses (Goulding et al., 2000). The full budgets, including losses, are very different from the original simple budgets and show that the upland/hill farm (i.e. an extensive mixed farm on poor soil 250 m above sea level) has a small N deficit, the lowland dairy farm is in balance, and the stockless system still has a small N surplus. Clearly nutrient budgets that lack any consideration of losses, especially for N, are likely to provide misleading conclusions on the sustainability of the systems.

Table 4.5 Nitrogen budgets for three organic farms including estimated losses (Goulding et al., 2000)

Farm type	Upland/hill farm	Lowland dairy	Stockless arable
Loss process		N loss (kg ha^{-1} yr^{-1})	
Leaching	5	50	50
Ammonia volatilisation	25	50	0
Denitrification	5	20	20
Total loss	35	120	70
Previous N budget	+18	+122	+96
New N budget	−17	+2	+26

4.4 Discussion

4.4.1 Long-Term Trends

Care must be taken when reaching conclusions about the sustainability of farming from single year farm-gate nutrient budgets. Applications of P and K are often made during the ley phase of an organic rotation to supply the whole multi-year rotation. The weather also has an important effect through its impact on losses. It is likely that there would be a net immobilization of N in soil organic matter in dry years and net mineralisation in wet years. Thus annual deficits and surpluses may be temporary and balanced by corresponding surpluses and deficits in other years. However, where budgets are the averages of 4–5 years (i.e. a rotation), as in Table. 4.3 and 4.4, they can be viewed more confidently and show deficits for N, P and K on the organic farms investigated.

4.4.2 Nutrient Cycling at the Wider Scale

Organic produce is sold into the national and international markets that dominate food production, leading to a net export of plant nutrients from most organic farms. Some organic farms appear to remain sustainable only through the use of feed, bedding and composts brought onto the farm and, in some cases, air pollution (Goulding et al., 2000; Watson et al., 2002). The wider aspects of nutrient cycling urgently need attention, with critical questions such as the sources of nutrients brought onto organic farms: if they originate from conventional farms, are these organic farms sustainable?

At a wider scale there are issues concerning the import of nutrients in fertilising materials over long-distances. The concept of food miles, that is the distance travelled by food products between production and consumption, is now in common use (Paxton, 1994). There is a similar issue in relation to sustainability in terms of 'resource miles' or the distance travelled and energy costs associated with freight of products such as rock phosphate being brought from as far away as Tunisia and Morocco to the UK for use on organic farms. In the long-term, organic farming standards may need to consider more fully the use of locally sourced by-products and waste materials for nutrient supply. The ideal of sustainable organic farms that do not consume non-renewable resources or pollute the environment will remain elusive while the global market economy dominates agriculture.

4.5 Conclusions

The data presented here 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 by legumes or imports of manure or compost for N. Air pollution and net mineralisation from soil reserves appear to comprise a large part of the N supply on some organic farms, and there is some evidence pointing to P and K depletion in soils.

Although nutrient management in organically managed soils is fundamentally different to soils managed conventionally, the underlying processes supporting soil fertility are not. It is farm management decisions about the timing of cultivation and the application of inputs that will have the largest affect on nutrient availability and the potential for losses, not the farming systems per se, so research on nutrient cycling in both organic and conventional systems requires similar approaches and scientific rigor. In addition, management determines the *risk* of loss to the environment but the weather generally determines the actual loss. Even with the best management possible, the weather can negate even the best practices. With these difficulties and uncertainties, questions need to be asked about whether it is generally easier to manage organic or inorganic nutrient sources? Where is the greatest risk?

Organic farming systems have the potential to deliver significant environmental benefits, but so do other more extensive systems. The effect of changing to organic farming will depend on specific cropping and management practices on each farm. It is important that we study and improve nutrient management on *all* farm systems and in the context of plant, animal and human health in order to develop more sustainable farming systems.

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