

1 **Managing soil fertility in organic farming systems**

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11
12 **Abstract.**

13 Complex relationships exist between different components of the organic farm and
14 the quantity and quality of the end products depend on the functioning of the whole
15 system. As such, it is very difficult to isolate soil fertility from production and
16 environmental aspects of the system. Crop rotation is the central tool that integrates
17 the maintenance and development of soil fertility with different aspects of crop and
18 livestock production in organic systems. Nutrient supply to crops depends on the use
19 of legumes to add nitrogen to the system and limited inputs of supplementary
20 nutrients, added in acceptable forms. Manures and crop residues are carefully
21 managed to recycle nutrients around the farm. Management of soil organic matter,
22 primarily through the use of short-term leys, helps ensure good soil structure and
23 biological activity, important for nutrient supply, health and productivity of both
24 crops and livestock. Carefully planned diverse rotations help reduce the incidence of
25 pests and diseases and allow for cultural methods of weed control. As a result of the

1 complex interactions between different system components, fertility management in
2 organic farming relies on a long-term integrated approach rather than the more short-
3 term very targeted solutions common in conventional agriculture.

4

5 Keywords:

6 Organic farming, soil fertility, soil structure, crop nutrition, crop rotation, crop health

7

8

INTRODUCTION

9 Soil fertility is fundamental in determining the productivity of all farming systems.

10 Soil fertility is most commonly defined in terms of the ability of a soil to supply
11 nutrients to crops. Swift & Palm (2000) however suggest that it is more helpful to
12 view soil fertility as an ecosystem concept integrating the diverse soil functions,
13 including nutrient supply, which promote plant production. This broader definition is
14 appropriate to organic farming, as organic farming recognises the complex
15 relationships that exist between different system components and that the
16 sustainability of the system is dependent upon the functioning of a whole integrated
17 and inter-related system (Atkinson & Watson 2000).

18

19 Organic farming systems rely on the management of soil organic matter to enhance
20 the chemical, biological, and physical properties of the soil, in order to optimise crop
21 production. Soil management controls the supply of nutrients to crops, and
22 subsequently to livestock and humans. Furthermore soil processes play a key role in
23 suppressing weeds, pests and diseases. Figure 1 illustrates conceptually the
24 complexity of the relationships between soil fertility and the different components
25 within and outside the system that may influence it. One of the fundamental

1 differences between management of organic and conventional systems is the way in
2 which problems are addressed. Conventional agriculture often relies on targeted short-
3 term solutions e.g. application of a soluble fertiliser or herbicide. Organic systems, in
4 contrast, use a strategically different approach, which relies on longer-term solutions
5 (preventative rather than reactive) at the systems level. An example of this is the
6 importance of rotation design for nutrient cycling and conservation and weed, pest
7 and disease control (Stockdale *et al.* 2001).

8
9 Organic farming is the only sustainable farming system that is legally defined. Within
10 the EU, crop and livestock products sold as organic must be certified as such under
11 EC Regulation 2092/91 and 1804/99. In the UK, it is the role of the UK Register of
12 Organic Food Standards (UKROFS) to implement this legislation. UKROFS licences
13 a number of certification bodies, such as the Soil Association, to certify and inspect
14 organic farms to ensure that organic production practices are followed. Although the
15 regulations of the different bodies differ in detail they all aim to create an
16 economically and environmentally sustainable form of agriculture with the emphasis
17 placed on self-sustaining biological systems rather than on external inputs.

18
19 This paper explores how organic farmers and growers can utilise a range of
20 management practices to maintain and develop soil fertility in order to achieve these
21 wider goals.

22 23 **ORGANIC FARMING SYSTEMS**

24 The total value of UK organic production in 2000/01 was £97 million. Around 81% of
25 certified organic land is rough grazing and permanent pasture, 9% is temporary ley,

1 7.5% is in arable production and 2% is used for horticultural crops. There is an
2 increasing proportion of organic land in pasture, reflecting the relative ease of
3 converting extensive systems and greater benefits from area based support payments
4 (Soil Association 2001). Organic farming systems fall into similar categories as those
5 of conventional agriculture: mixed, livestock, stockless and horticultural. Berry *et al.*
6 (2002) (this volume) describe examples of some of these in more detail. The main
7 characteristics of these systems and their specific soil fertility challenges are
8 summarised below.

9

10 *Mixed systems*

11 Mixed systems are most commonly based on ley/arable rotations (see rotations
12 section). Fertility is built during the ley phase, in which grazing and fodder
13 production provide an economic return. The degree of integration of livestock and
14 cropping will vary, depending on rotation, land type and livestock species. For
15 example, sheep may graze turnips or vegetable residues over winter, while pigs are
16 sometimes used instead of a plough to achieve the transition from ley to arable.

17

18 *Livestock systems*

19 In situations where it is undesirable or impractical to operate a rotation due to
20 soil/land type, climate constraints or conservation issues, the use of long-term or
21 permanent grassland is acceptable within the organic regulations. Management
22 emphasis is, however, still on the maintenance of soil fertility through nutrient
23 recycling, with minimal external inputs.

24

25 *Stockless systems*

1 The trend towards specialisation in conventional farming has led to large agricultural
2 areas in Europe lacking grazing livestock, e.g. Eastern and South Eastern Denmark,
3 Eastern Germany, and East Anglia in the UK (Høgh-Jensen 1999). The infrastructure
4 costs associated with establishing livestock enterprises on farms wishing to convert
5 from a conventional stockless system to mixed organic agriculture are frequently
6 prohibitive (Lampkin 1990) and so the area of organic land farmed using stockless
7 organic systems is increasing (Mueller & Thorup-Kristensen 2001). The greatest
8 challenge for stockless organic farming is management of the nutrient supply. Forage
9 legumes are of no direct economic benefit in stockless systems (other than for setaside
10 payments), so there is greater emphasis on alternative fertility building strategies,
11 such as the use of green manures, grain legumes and the import of manures, composts
12 and other acceptable fertilisers. These types of organic system are relatively recent
13 and further development of suitable fertility building strategies is required.

14

15 *Horticultural systems*

16 The term horticulture covers a wide range of systems from field vegetable production
17 to fruit and protected cropping (glasshouse/polytunnels). Intensive organic
18 horticultural production systems are often the most dependent on imported nutrients.
19 Many of the fruit and vegetables grown have a high demand for major and minor
20 nutrients and additionally are susceptible to many pests and diseases (Toosey 1983).
21 Combined with the fact that these systems frequently include several crops within one
22 growing season, the maintenance of soil fertility is a major concern in these intensive
23 systems. Organic standards recognize the difficulties of this type of production and
24 permit rotations which, although there are still restrictions, rely on external inputs to
25 maintain crop production (UKROFS 2001). It is difficult to maintain fertility by the

1 use of rotations in perennial crops such as fruit, and in protected cropping where it is
2 uneconomic to grow fertility building crops. Development of organic production in
3 both of these systems is still at an early stage and development of both associated
4 management techniques and standards is ongoing.

5

6 **USING CROP ROTATIONS TO MANAGE SOIL FERTILITY**

7 Crop rotation is a system where different plants are grown in a recurring, defined
8 sequence. Crop rotations, including a mixture of leguminous ‘fertility building’ and
9 cash crops, are the main mechanism for nutrient supply within organic systems.
10 Rotations can also be designed to minimise the spread of weeds, pests and diseases
11 (Altieri 1995). The development and implementation of well-designed crop rotations
12 is central to the success of organic production systems (Lampkin 1990; Stockdale *et*
13 *al.* 2001).

14

15 Organic rotations are divided into phases that increase the level of soil nitrogen and
16 phases that deplete it (Altieri 1995). The nitrogen building and depleting phases must
17 be in balance, or show a slight surplus, if long-term fertility is to be maintained (See
18 Berry *et al.* 2002 and Watson *et al.* 2002 this volume). This type of rotation provides
19 the basis for forward planning of nitrogen supply, necessary in the absence of soluble
20 nitrogen fertiliser. In UK conditions the fertility building phase of the rotation usually
21 takes the form of a ley, from one to five or more years in length, which incorporates a
22 legume usually in combination with grass (Lampkin 1990). Atmospheric nitrogen
23 fixed by the legume-rhizobium symbiosis is made available to subsequent cash crops
24 when the ley is incorporated and the nitrogen mineralised through the action of soil
25 micro organisms.

1

2 The ratio of ley to arable will be determined by both the system (stocked or stockless)
3 and the soil type, being lower on nitrogen retentive soils and higher on un-retentive
4 (sandy) soils. A typical rotation on a mixed organic farm with a three-year grass and
5 clover ley will support two or three years of arable cropping (Lampkin 1990). This
6 may be extended by including a nitrogen-fixing cash crop, such as beans, or by
7 including a short period of nitrogen fixing green manure such as vetch between cash
8 crops (Stockdale *et al.* 2001). In order to make maximum use of the large quantity of
9 nitrogen released following ley incorporation; crops with a high demand for nitrogen,
10 such as winter wheat or potatoes, are usually grown at the start of the cropping phase
11 (Lampkin 1990). The amount of N released decreases with time following
12 incorporation of the ley (Whitmore *et al.* 1992) thus spring sown cereals are often
13 placed later in the arable phase of the rotation due to their lower N demand (Taylor *et*
14 *al.* 2001). As with conventional agriculture, the primary limiting nutrient in organic
15 systems is nitrogen (N) (Stockdale *et al.* 1995; Torstensson 1998). Yields of arable
16 crops under organic management vary from as little as 50% to more than 95% of
17 those in conventional agriculture, depending on the crop (Lampkin & Measures 2001;
18 Nix 2001; SAC 2000). The large shortfall in cereal yields is linked to the difficulty of
19 managing soils to synchronise N mineralization with the period of maximum N
20 demand (Stockdale *et al.* 1992). This is one of the greatest challenges faced by
21 organic farmers (Willson *et al.* 2001).

22

23 Incorporation of leys carries with it a high risk of nitrate loss by leaching. Spring
24 incorporation prior to spring cropping, where possible, has been shown to minimise
25 leaching loss (Watson *et al.* 1993; Djurhuus & Olsen 1997). Other factors such as

1 grazing intensity and sward composition have also been shown to be important in
2 determining the quantity and pattern of N release following ley incorporation (Davies
3 *et al.* 2001).

4

5 Crop rotation also modifies the physical characteristics of the soil both directly and
6 indirectly. The accumulation of organic matter during the ley phase plays a major
7 direct role in soil structure formation (Clement & Williams 1967; Grace *et al.* 1995).
8 This results from the production of organic binding agents, such as polysaccharides,
9 by microorganisms breaking down organic matter, and the enmeshing effects of the
10 clover and grass roots and fungal hyphae (Wild 1988; Breland 1995). Conversely, soil
11 organic matter and aggregate stability decline during the arable phase (Tisdall &
12 Oades 1982). The architectural characteristics of the root systems of different crops
13 included in the rotation also influence soil structure formation (e.g. Chan & Heenan
14 1991). Indirectly, the timing and use of different cultivation techniques and manure
15 application at different points in the rotation influence soil structure.

16

17 Rotation design modifies both the size and activity of the soil microbial biomass.
18 Indicators of biomass activity such as basal respiration and enzymatic activity suggest
19 that there is a more active microbial biomass associated with grass-clover leys than
20 with arable cropping (Watson *et al.* 1996; Haynes 1999), which is in turn linked to the
21 decomposition of organic matter and nutrient mineralization (Haynes 1999). An
22 active soil microbial biomass may also reduce the incidence of organisms deleterious
23 to crop health (Hornby 1983). Currently the possibilities for manipulating individual
24 components of the soil microbial biomass using agricultural practices are limited by
25 our understanding of the functional significance of different organisms or groups of

1 organisms. Knowledge of the impact of management practices on some beneficial
2 organisms e.g. Arbuscular Mycorrhizal (AM) fungi is increasing. The beneficial
3 effects of AM fungi, including improved crop nutrition, reductions in soil borne
4 disease and improved soil structure, are liable to be stimulated in organic systems
5 (Bethlenfalvy & Lindermann 1992; Mäder *et al.* 2000). Fallow periods (Douds *et al.*
6 1997), cultivation (McGonigle & Miller 2000) and the inclusion of non-mycorrhizal
7 crops within the rotation (Karasawa *et al.* 2001) can reduce survival and effectivity of
8 AM fungi.

9

10 Rotations are the primary means of controlling weeds, pests and diseases in organic
11 farming. The use of the term 'appropriate rotation' in the UKROFS Standards
12 (UKROFS 2001) implies that continuous monoculture is unacceptable due to the
13 likely increased pressure from weeds, pests and diseases as well as difficulties of
14 maintaining soil fertility. It has been demonstrated that soil borne pathogens are
15 influenced by rotation length, with reduced disease levels associated with longer gaps
16 between susceptible crops (Clark *et al.* 1998). Several soil fertility-related factors may
17 contribute to the control of soil borne diseases, including increased soil microbial
18 activity, leading to increased competition, parasitism and predation in the rhizosphere
19 (Jawson *et al.* 1993; Workneh & van Bruggen 1994; Knudsen *et al.* 1995). In general,
20 organic systems are characterised by a diversity of crops in the rotation that improves
21 the potential for cultural control of pests and diseases (Altieri 1995). Soil fertility
22 management can also affect the susceptibility of crops to pests and diseases. For
23 example, the relationship between mineral-nutrient content of crops and pest
24 susceptibility is well documented (Dale 1988). Phelan *et al.* (1995) demonstrated for
25 the first time that soil organic matter management history was related to the

1 susceptibility of crops to the above ground pest *Ostrinia nubilalis* (European corn
2 borer).

3

4 Growing a range of crops with different physiological attributes, sowing and harvest
5 dates offers opportunities for cultivation and mechanical weed controlling operations
6 to be undertaken at different times helping to prevent particular species from
7 becoming a problem (Liebman & Davis 2000). (See also section on cultivations). The
8 proportion of ley within the rotation has also been shown to affect weed populations
9 and the weed seed bank with weed problems declining as proportion of ley increases
10 (Davies *et al.* 1997). Roots of some plants exude chemicals that deter potential
11 competitors from growing in their vicinity through inhibition of germination and/or
12 growth and the effects can continue after the incorporation of the inhibitive plant.
13 This effect, known as allelopathy, is exhibited by both crop plants such as rye, vetch
14 and triticale and weed species e.g *Stellaria* spp. (Barnes and Putnam, 1986; Teasdale
15 1988; Inderjit & Dakshini 1998). Although there may potentially be negative effects
16 of allelopathy on crop production, e.g. when there is inhibition of the germination of
17 crop seedlings, there is a need to understand allelopathic effects in more detail as they
18 can potentially be manipulated to advantage in organic systems (Olofsdotter 1999).

19

20 *Fertility building crops*

21 Legume based leys are the principle fertility building crops in temperate organic
22 systems. In mixed systems white clover-grass leys are most common. Red clover is
23 also frequently produced, both grown alone or with grass, and used for silage or as a
24 green manure. Other legumes, grown either as fodder or as green manures, may be
25 used in the shorter term or under particular soil or climatic conditions. These include

1 other types of clover, lucerne, vetches, lupins and trefoils. Poutala *et al.* (1994) and
2 Mueller & Thorup-Kristensen (2001) have illustrated the potential of short-term
3 leguminous green manures crops in stockless systems.

4

5 Predicting the actual amount of nitrogen fixed is notoriously difficult as it depends on
6 many factors including legume species and cultivar, proportion of legume in the ley,
7 management, weather conditions and the age of the ley (Ledgard & Steele 1992;
8 Watson *et al.* 2002 (this volume)). White clover-grass leys can fix up to 250 kg N
9 ha⁻¹yr⁻¹ (Kristensen *et al.* 1995), red clover leys up to 240 kg N ha⁻¹yr⁻¹ (Schmidt *et al.*
10 1999) and lucerne up to 500 kg N ha⁻¹yr⁻¹ (Spiertz & Sibma 1986). Field beans have
11 been estimated to fix up to approximately 200 kg N ha⁻¹ yr⁻¹ (van Kessel & Hartley
12 2000). In terms of increasing soil nitrogen, grain legumes are of limited value since
13 only 50% of their N requirement is derived from fixation (compared with >80% in
14 forage legumes) and much of the fixed N is removed in the grain harvest. This can
15 sometimes result in net removal of nitrogen from the soil (van Kessel & Hartley
16 2000).

17

18 *The importance of crop and varietal selection*

19 Crop choice is liable to reflect a number of different factors, such as previous
20 experience of the farmer, soil type and climate constraints, markets and labour
21 availability. The UKROFS standards (UKROFS 2001) require an appropriate multi-
22 annual rotation including legumes (see section Fertility Building Crops) and crops
23 with differing rooting depths. The use of crops with different rooting depths occurs
24 between crops within the rotation and within individual crops, e.g. forage herbs are

1 commonly mixed with several varieties of clover and grass to provide different sward
2 structures both above and below ground.

3

4 The inclusion in a rotation of green manures or cover crops can considerably increase
5 the efficiency with which nitrogen is used. Non leguminous plants that grow
6 vigorously over the winter period, such as grazing rye (*Secale cereale*) immobilize
7 soil nitrogen that would otherwise be leached over winter (Wyland *et al.* 1995). This
8 nitrogen is subsequently made available after incorporation by mineralization. Careful
9 attention to the timing and method of incorporation of the cover crop can synchronize
10 mineralization with periods of high crop demand (Hu *et al.* 1997; Rayns *et al.* 2000).

11 One of the primary difficulties in designing rotations for organic farming is the
12 complexity of managing soil fertility for multiple aims. For example, although the
13 incorporation of green manures/cover crops can have beneficial effects on nitrogen
14 management there may be associated diseases risk, for example, plant pathogens with
15 a saprophytic phase such as *Rhizoctonia solani* can multiply in plant debris (Weinhold
16 1977). In contrast green manures and cover crops have also been shown to have
17 potential for controlling diseases in vegetable crops (Abawi & Widmer 2000).

18

19 Selection of modern crop varieties has generally taken place under high inputs of both
20 fertilisers and pesticides. Conditions of zero N application in conventionally managed
21 soils do not accurately represent soils managed organically, and thus modern
22 conventionally selected breeds are unlikely to have optimal characteristics for organic
23 systems. The yield penalty associated with organic production of crops such as wheat
24 and barley, which have been bred intensively, is greater than for crops such as oats
25 and triticale, which have undergone relatively little selective breeding. Foulkes *et al.*

1 (1998) have found that modern varieties of winter wheat bred and tested with large
2 amounts of fertilizer N were to some extent less efficient at utilising soil N than older
3 varieties. Below ground characteristics such as rooting depth, root architecture and
4 root length are likely to be more important in organic systems, where available soil
5 nutrients may be limited (Atkinson *et al.* 1995). These characteristics have as yet
6 received little attention in breeding programmes. The ability of varieties to form
7 effective associations with AM fungi may also be important for crop nutrition and
8 disease resistance. Hetrick *et al.* (1992) demonstrated that modern cultivars displayed
9 less consistent and smaller growth responses to AM symbionts than old hexaploid
10 wheat landraces and Hetrick *et al.* (1993) showed that cultivars released after 1950
11 have reduced dependance on AM fungal symbiosis.

12

13 Although conventional crop breeding has not produced varieties with nutrient
14 acquisition characteristics that suit organic systems it has, to some degree, addressed
15 resistance to pests and disease. For instance, NIAB recommended lists of cereals
16 include varieties resistance to fungal diseases (NIAB 1996).

17

18 *Intercropping*

19 The growing of two or more crops together (intercropping) has the potential to
20 improve resource use. This results from differences in competitive ability for
21 resources between above and below ground crop components in space and time
22 (Willey 1979). In organic systems, both variety mixtures and species mixtures are
23 potentially useful for optimising nutrient use, controlling weeds pests and diseases
24 (Wolfe 1985; Wolfe 2001) and for reducing soil erosion through increased ground
25 cover. Intercropping is commonly used in forage crops (e.g. grass-clover leys) in

1 organic systems but is less common in arable crops (Lampkin 1990). Several effective
2 intercrop combinations of cereals and legumes have however been developed
3 demonstrating that intercropping offers the opportunity to increase the use of
4 symbiotically fixed nitrogen without compromising grain yield (Jensen 1996; Bulson
5 *et al.* 1997). Undersowing of clover into cereals is a common practice for establishing
6 leys (Taylor *et al.* 2001). Studies of intercropping of vegetables and fertility building
7 crops have indicated that competition between the crop and the legume can be a major
8 problem (Carruthers *et al.* 1997, Lotz *et al.* 1997). The understorey crop must be
9 controlled by mowing and/or cultivation techniques and the cash crop must be more
10 widely spaced than normal. There is a need to develop effective management
11 strategies and crop combinations for all organic systems, but particularly stockless
12 systems, in order to minimise the use of unproductive fertility building phases. Before
13 intercropping is more widely accepted in these systems, the economic viability of
14 intercropping requires more careful analysis (Theunissen 1997).

15

16 *Using cultivations within rotations*

17 Cultivation has a number of purposes, including incorporation of manures and crop
18 residues and weed and disease control, as well as preparation of a seedbed for crops
19 and for remediation of damaged soil structure caused by trafficking (Wild 1988). The
20 choice of cultivation type will depend on both the principle aim and the soil type.
21 Organic systems tend to utilise shallow rather than deep ploughing, as this retains
22 crop residues near the soil surface, where they break down more rapidly and where
23 most rooting occurs, while achieving sufficient aeration (Lampkin 1990, Lampkin &
24 Measures 1999). Cultivation itself leads to an increase in nutrient availability,
25 particularly N, as microbial activity is stimulated and organic matter breakdown

1 occurs (Balloni & Favalli 1987; Torbet *et al.* 1998; Silgram & Shepherd 1999).
2 Mechanical weed control can thus provide a mid-season boost to crops by stimulating
3 mineralization although at other times additional stimulation of mineralization may
4 cause losses by leaching or denitrification. Intensive cultivation to control weeds may
5 also be counterproductive if soil compaction occurs (Liebman & Dyck 1993), or
6 where weeds provide a habitat for beneficial insects or a mycorrhizal bridge between
7 crops (Atkinson *et al.* 2002).

8

9

MANAGING CROP RESIDUES

10 Crop residues can be an important source of nutrients to subsequent crops. It is well
11 documented that different quantities of N, P, K and minor nutrients are removed from,
12 and returned to, the soil depending on the crop species concerned (Wild 1988;
13 Sylvester-Bradley 1993). The quantity and quality of crop residues will clearly
14 influence the build up of soil organic matter (Jenkinson & Ladd 1981) and the
15 subsequent availability and timing of release of nutrients to following crops (Jarvis *et*
16 *al.* 1996). Cereal straw, for example, contains only around 35 kg N ha⁻¹ compared
17 with more than 150 kg N ha⁻¹ for some vegetables residues (Rahn *et al.* 1992, Jarvis *et*
18 *al.* 1996). Most available values for nutrient contents of crop residues are from
19 conventional agriculture and N limitation in organic systems means that crop residues
20 are likely to be lower in N (Berry *et al.* 2002 this volume) and other nutrients (Watson
21 *et al.* 2002 this volume). Residues also contain variable amounts of lignin and
22 polyphenols, which influence decomposition and mineralization rates (Jarvis *et al.*
23 1996; Vanlauwe *et al.* 1997). Incorporation of N rich, low C:N ratio residues leads to
24 rapid mineralization and a large rise in soil mineral N (Rahn *et al.* 1992), while
25 residues low in N such as cereal straw can lead to net immobilization of N in the short

1 to medium term (Jenkinson 1985; Aulakh *et al.* 1991). The latter can be advantageous
2 in preventing N leaching between crops (Jenkinson 1985; Nicholson *et al.* 1997). The
3 inclusion of crops with a diverse range of C:N ratios can help to conserve N within
4 the system and, compared with monocropping, has the potential to increase the
5 capacity of the soil to supply N in synchrony with crop demand (Drinkwater *et al.*
6 1998; Sanchez *et al.* 2001). Mixing residues of differing quality also has potential to
7 synchronize mineralization with crop demands (Handayanto *et al.* 1997) though the
8 practicalities of this on a farm scale are questionable.

9

10 **MANAGING MANURES AND SUPPLEMENTARY NUTRIENTS**

11 In addition to symbiotic N fixation and atmospheric deposition, nutrients may be
12 brought in to the organic system in imported animal feeds, manures, composts and
13 permitted fertilisers, such as rock phosphate (UKROFS 2001). The nature and
14 quantity of imported nutrients will depend on the system and the soil type. Watson *et al.*
15 (2002) (this volume) highlight the reliance on bought-in feed and bedding on
16 organic dairy farms and purchased manure in organic horticultural systems.

17

18 Animal manures are the most common amendments applied to the soil. On mixed and
19 livestock farms they are an important currency for re-distributing nutrients as it is
20 important to ensure that fertility is not built in some fields at the expense of others.
21 Manure use should be planned with regard to both farm system and field nutrient
22 budgets (see Berry *et al.* 2002, this volume). Organic manures are traditionally
23 applied to silage and root crops although it may be more beneficial to apply them to
24 cash crops. Manure management within the rotation has been shown to have large
25 effects on both yield and product quality, including protein levels in cereals (Stein-

1 Bachinger 1996; Frederiksson *et al.* 1997). The possibility of using manures more
2 profitably on cash crops is discussed in more detail by Berry *et al.* (2002) (this
3 volume). Manures from non-organic livestock production may be brought onto the
4 holding but there are restrictions (e.g. it must originate from an 'ethical' source and
5 the animals producing it must not have been fed on a diet containing Genetically
6 Modified Organisms (GMO's)).

7

8 The quantity of nutrients in manures varies with type of animal, feed composition,
9 quality and quantity of bedding material, length of storage and storage conditions
10 (Dewes & Hunsche 1998; Shepherd *et al.* 1999). A typical application of 25 t ha⁻¹ of
11 farmyard manure from housed organic cattle will contain 150 kg of N, 35 kg of P and
12 140 kg of K (Shepherd *et al.* 1999). In organic systems it is particularly important to
13 conserve manure nutrients for both economic and environmental reasons. Manure
14 handling, storage and composting has been widely studied in organic systems (e.g.
15 Hansen 1995). Composting is recommended in organic farming as a management tool
16 for controlling weeds, pests and diseases. True composting of manures, i.e. aerobic
17 decomposition at temperatures of around 60°C, results in fundamental physical and
18 chemical changes, causing a significant reduction in nutrient availability, particularly
19 of nitrogen. Composted manure thus has a more long-term role in building soil
20 fertility, and has been shown to be more effective in building soil microbial biomass
21 and increasing activity than uncomposted manure (Fließbach & Mäder 2000).
22 Composts have been show to reduce disease severity (Kim *et al.* 1997; Abawi &
23 Widmer 2000). In addition to composts made from on-farm materials, composts may
24 originate from commercial sources and include materials from parks and gardens
25 (green waste compost), pack house wastes and food industry wastes. Although such

1 material fits well with the ethical basis of organic farming there may be increasing
2 problems with contamination with residues from GMO's.

3

4 In order to balance the offtake of specific nutrients there are a number of mineral
5 nutrient sources acceptable in organic systems although their use is permitted only
6 where the need can be demonstrated to the certifying body (for example by soil
7 analysis or by presentation of a nutrient budget). Amendments include rock
8 phosphate, rock potassium, magnesium rock and gypsum. Products such as rock
9 phosphate release nutrients over a period of years rather than weeks (Rajan *et al.*
10 1996) and thus their use is planned to build fertility in the longer-term. Trace elements
11 may also be applied, with approval, if they are necessary. The use of lime to maintain
12 pH levels is also acceptable (UKROFS 2001).

13

14 **SOIL FERTILITY AND LIVESTOCK IN ORGANIC FARMING**

15 Within organic systems both the influence of livestock on soil fertility and the
16 influence of soil fertility on livestock nutrition and health are important management
17 considerations (See Figure 1). Livestock influences soil fertility by two major routes,
18 through physical effects associated with trampling and also through the removal and
19 return of nutrients in dung and urine. Stocking rate in organic systems is limited by a
20 maximum application rate of 170 kg N ha⁻¹ yr⁻¹ (UKROFS 2001) over the farm as a
21 whole. Compared with conventional systems the lower stocking rates and mixed
22 grazing systems common in organic farming (Lampkin & Measures 1999) may help
23 to minimise the effects of grazing on soil compaction. Bannerjee *et al.* (2000)
24 suggested that pasture management could also influence soil microbial biomass, with
25 lower stocking rates promoting both higher biomass C and N mineralization potential.

1 In forage based organic systems on soils naturally low in trace elements, livestock
2 health can be adversely affected by trace element deficiencies. Under known
3 deficiency conditions trace element supplementation is allowed within the organic
4 standards (UKROFS 2001). An alternative solution is the inclusion of forage herbs
5 such as chicory within organic swards; these are known to contain higher
6 concentrations of trace elements than many grasses (Belesky *et al.* 2001).

7

8 It is becoming increasingly clear that both livestock and manures can act as a conduit
9 for environmental pathogens that survive in soils. Management practices can help to
10 minimise the spread of pathogens via manure. Both composting of farmyard manure
11 (Jones 1982) and anaerobic digestion of slurry (Kearney *et al.* 1993) have been shown
12 to decrease pathogen viability. It has also been shown that earthworms can be
13 beneficial in parasite control as they ingest eggs and larvae and carry them far enough
14 below ground to prevent them maturing (Wells 1999). The effect of organic
15 management practices on earthworms is discussed in Scullion (2002) (this volume).

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DECISION SUPPORT TOOLS

18 Improving soil fertility in organic farming relies on improved understanding of the
19 effects of management practices on soil fertility and also on improved technology
20 transfer of research results into practice. This requires the provision of good on-farm
21 advice by advisors who fully understand the complexity of managing soil fertility in
22 organic farming systems. The development and widespread accessibility of
23 appropriate tools to support decision-making is also important (Wander & Drinkwater
24 2000).

25

1 *Soil analysis*

2 As soil fertility management in organic systems is a longer term, more strategic
3 process than in conventional systems, soil analysis and interpretation must be adapted
4 to reflect this. Trends in soil nutrient and organic matter status are likely to be more
5 important than snapshot analysis. There has been considerable discussion over
6 whether different methods of soil analysis are required for organic farming.
7 Conventional soil analysis for advisory purposes relies on the interpretation of the
8 chemical extraction of different nutrient pools from the soil to predict nutrient release
9 to crops (Edwards *et al.* 1997). This type of analysis is likely to be more difficult to
10 interpret in organic than conventional systems where there is a much stronger reliance
11 on biological processes for nutrient supply. There is much interest in the development
12 of indicators of soil health and quality although little agreement over what these
13 should be (Doran & Zeiss 2000). Simple indicators of soil health would help organic
14 farmers to solve problems on farm. Wander & Drinkwater (2000) suggest that organic
15 matter and organic matter dependent properties show most promise for supporting
16 management decisions.

17

18 *Computer modelling*

19 Simple nutrient budgets are becoming widely used in organic farming by advisors and
20 certification organisations to assist in the planning of organic crop rotations.
21 Computer models for calculation of nutrient budgets are currently being developed in
22 association with organic farming research programmes being funded by DEFRA and
23 SEERAD. The use of nutrient budgets in organic systems is discussed more fully in
24 Berry *et al.* (2002) and Watson *et al.* (2002) (this volume). One of the limitations of
25 both nutrient budgets and more detailed nutrient cycling models such as WELL_N

1 (Rahn *et al.* 2001) is the difficulty of predicting the soil processes which drive organic
2 systems, particularly mineralization and N fixation. Some of the more detailed models
3 of nutrient cycling and crop growth may however be useful in developing new and
4 efficient cropping systems for organic farming. For example, Baumann *et al.* (2001)
5 suggest that ecophysiological crop growth models could be used to maximise crop
6 complementarity and thus design more effective intercropping systems.

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CONCLUSIONS

9 Organic farming systems utilise highly complex and integrated biological systems to
10 achieve their goal of sustainable crop and livestock production. Most, if not all,
11 management practices used in organic systems affect more than one component of the
12 system, for example, cultivation may be beneficial for weed control but may stimulate
13 mineralization of nitrogen when the crop does not require it. Some soil management
14 decisions, such as the choice between winter and spring incorporation of a ley, are
15 likely to have important economic consequences as well as environmental ones. Thus
16 the interaction between soil management practices and different aspects of production
17 and environmental impact will continue to challenge the nature and development of
18 organic farming in the future.

19

20 Large-scale organic production is still a relatively recent development and further
21 development of fertility building strategies is warranted in all systems. This is
22 particularly true with regard to the most efficient use of manures and the most
23 appropriate types of ley and green manures. Fertility management in stockless arable,
24 field vegetables, fruit and protected cropping is particularly challenging and requires
25 development, both in terms of techniques and of organic standards.

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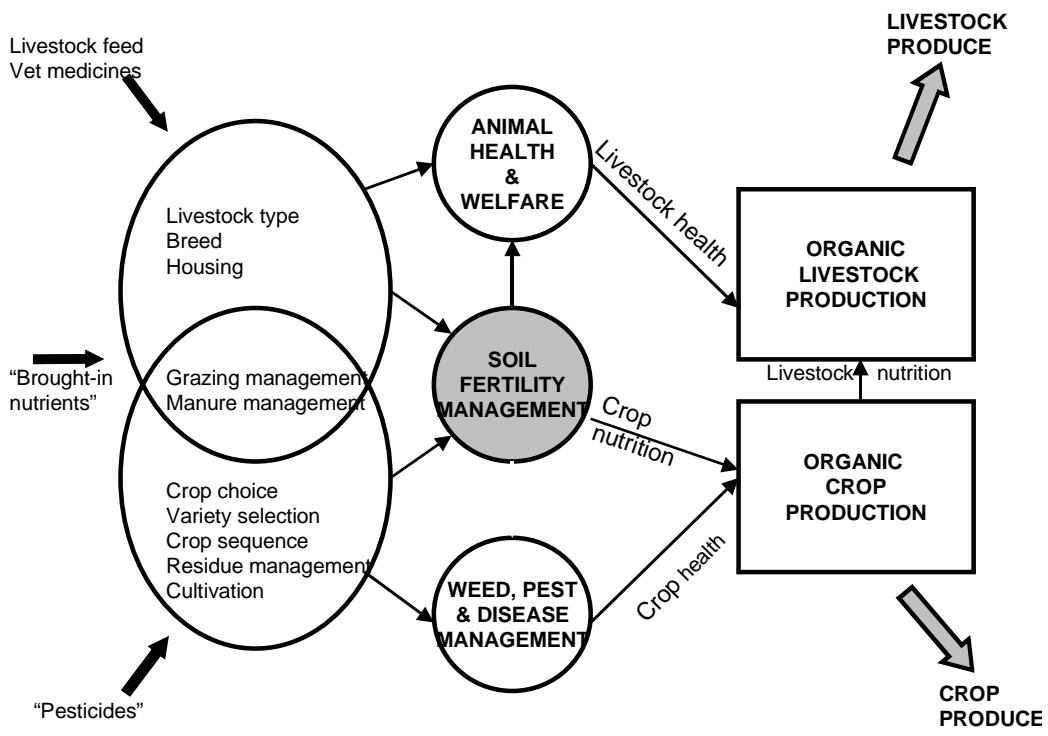
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- 1 Figure 1. The interactions between soil fertility and crop and animal productivity in
- 2 organic farming systems.

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