DEPARTMENT for ENVIRONMENT, FOOD and RURAL AFFAIRS

Research and Development

Final Project Report

(Not to be used for LINK projects)

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Project title	Organic farming: technology transfer
DEFRA project code	**OF0405**
Contractor organisation and location	ADAS Gleadthorpe Research Centre Meden Vale, Mansfield, Notts NG20 9PF
Total DEFRA project costs	£ 36632
Project start date	01/01/03
Project end date	01/08/03

Executive summary (maximum 2 sides A4)

This project covered two separate activities, but both were examples of technology transfer, relating to organic farming:

1. *Developing a science-based report, which covered an assessment of the environmental impacts of organic farming.* Defra's Action Plan to Develop Organic Food and Farming included as Annexe 3 an assessment of the environmental impacts of organic farming. This paper was prepared by a Subgroup of the Action Plan for Organic Farming. Its purpose was to summarise the Subgroup's views of the likely comparative effects of organic and conventional farming on the environment. However, to be robust and defensible, the assessment needs to be supported by scientific data. Although the report was based on such an assessment, the scientific data were not summarised and this needed to be done. The objective of this part of the project was therefore to collate and publish on the Defra website the evidence that underpinned the overall conclusions.

2. *Preparation of a booklet to provide guidelines for managing soil fertility in organic farming.* Organic farming aims to create an economically and environmentally sustainable agriculture, with the emphasis placed on self-sustaining biological systems, rather than external inputs. Building soil fertility is central to this ethos. 'Soil fertility' can be considered as a measure of the soil's ability to sustain satisfactory crop growth, both in the short- and longer-term, and it is determined by a set of interactions between the soil's physical environment, chemical environment and biological activity. The aim of recent Defra-funded projects has been, therefore, to provide a better scientific understanding of 'soil fertility' under organic farming, in line with Defra's policy objective of greater technical support to organic farming. The aim here was to prepare a booklet based on the findings of Defra-funded project OF0164 'Soil fertility in organically farmed soils'.

The following Table summarises the conclusions from Part 1 of this project:

	Indicator	Assessment of impact Per unit area	Per unit yield	Comments
Ecosystem	Biodiversity	☺	☺	Organic principles encourage a wide variety of habitats.
Soil Quality	Organic matter content	☺/😐	☺/😐	Potential benefits from organic farming, depends on organic matter inputs on individual organic and conventional farms.
	Biology	☺/😐	☺/😐	Literature tends to support a benefit, <u>but not always</u>.
	Structure	☺/😐	☺/😐	Literature tends to support a benefit, <u>but not always</u>.
	Erosion susceptibility	☺	☺	Few direct measurements, but organic practices should decrease risk.
Water Quality	Nitrate leaching	☺	☺/😐	Potentially large losses from ploughed leys, but smaller losses, on average, from other points in the rotation.
	Phosphorus loss	😐	😐	Insufficient information.
	Pesticides	☺	☺	Few pesticides used in organic production.
	Human pathogens	😐	😐	Insufficient information – work ongoing.
Air Quality	Ammonia	☺	😐	No direct studies. Assessed from what is known about processes.
	Nitrous oxide	😐	😐	Insufficient information.
	Methane	☺	☹/😐	Most data relate to dairy systems. Lower emissions on an area basis due to lower livestock densities.
	Carbon dioxide	☺	😐	Main energy input relates to fertiliser manufacture.
Resource use	Energy efficiency	☺	☺	Depends where boundaries are drawn when comparing systems, but main energy input into conventional is fertiliser production.
	Nutrient balance	☺	☺/😐	Smaller surpluses: OK if not over-depleting soil fertility.
	Controlled wastes	☺	☺	Emphasis on recycling. Less packaging and no agrochemical waste.

Key:
☺ Positive effect
😐 Neutral effect
☹ Negative effect

For Part 2 of the project (soil fertility booklet), the text has been produced and is undergoing review, with a view to publishing a booklet in a similar style to 'Managing manure in organic farming systems'. Contents include the following sections:

- What is 'soil fertility'?
- How organic farms are 'different'
- 'Fertility building'
- Managing nutrient supply
- Managing soil structure

- Managing soil biology
- Assessing soil fertility
- Pitfalls and problems
- Appendices

Scientific report (maximum 20 sides A4)

ORGANIC FARMING: TECHNOLOGY TRANSFER

Introduction

The was two separate parts to this project, both involved with different aspects of technology transfer to the organic farming community:

- Production of a literature review to assess the environmental impacts of organic farming – this helps to support Defra's policy on organic farming by assessing the potential environmental effects of a large-scale move to organic farming.
- Production of a booklet on managing soil fertility in organic farming – this helps to support Defra policy by providing information for organic producers and those considering a move into organic production.

Report

If environmental benefit is a key driver for Government support of organic farming, there needs to be a collation of the scientific evidence to confirm this. This same debate has been held across many countries as they reassess their agricultural policies (e.g. Stolze et al., 2000; Condron et al., 2000; Hansen et al., 2001; Stockdale et al., 2001).

Defra's Action Plan to Develop Organic Food and Farming included, as Annexe 3, an assessment of the environmental impacts of organic farming. This paper was prepared by a Subgroup of the Action Plan for Organic Farming. Its purpose was to summarise the Subgroup's views of the likely comparative effects of organic and conventional farming on the environment. The report covered the following aspects of environmental impact (with the broad conclusions):

- Biodiversity (on average, organic is better than conventional farming)
- Nitrate loss (available information is limited but losses of nitrate from organic systems are similar on an area basis to losses from conventional systems subject to limits on quantity and timing of fertiliser and manure).
- Phosphorus loss (information is limited).
- Pesticide pollution to water and air (organic is better than conventional farming).
- Energy efficiency (organic is usually better).
- Soil protection (on balance, organic has benefits for soil organisms although little difference has been shown for physical effects).
- Carbon dioxide (organic is better because of reduced energy use).
- Ammonia (little difference per unit yield, but probably lower emissions from organic per unit area).
- Nitrous oxide (insufficient information).
- Methane (conventional is probably better per unit of output, but may be similar on an area basis).
- Controlled wastes (organic is usually better).
- Human pathogens (no information – subject to ongoing research).

However, to be robust and defensible, the assessment needs to be supported by scientific data. Although the report was based on such an assessment, the scientific data were not summarised and this needed to be done. The objective of this part of the project was therefore to collate and publish on the Defra website the evidence that underpinned the overall conclusions.

Soil fertility booklet

Organic farming aims to create an economically and environmentally sustainable agriculture, with the emphasis placed on self-sustaining biological systems, rather than external inputs. Building soil fertility is central to this ethos. 'Soil fertility' can be considered as a measure of the soil's ability to sustain satisfactory crop growth, both in the short- and longer-term, and it is determined by a set of interactions between the soil's physical environment, chemical environment and biological activity. The aim of recent Defra-funded projects has been, therefore, to provide a better scientific understanding of 'soil fertility' under organic farming, in line with Defra's policy objective of greater technical support to organic farming. The aim here was to prepare a booklet based on the findings of Defra-funded project OF0164 'Soil fertility in organically farmed soils'.

Objectives

1. To provide a fully referenced and argued paper which collates the evidence used in developing The Organic Farming and the Environment paper published as Annex 3 of the Organic Action Plan.

2. To publish an advisory booklet on managing soil fertility on organic farms.

Environmental impacts of organic farming

There have now been several, independently published, comprehensive assessments of the effects of organic farming on the wider environment. Together, these syntheses of the literature, often encompassing different literature, enable a robust assessment of the effects of organic farming on many environmental parameters. Most of these reviews have been undertaken to inform their respective national debates about the value of organic farming to the wider environment: Stolze *et al*., 2000 (EU); Condron *et al*., 2000 (New Zealand); Hansen *et al*., 2001 (Denmark); Stockdale *et al*., 2001. They have all also generally chosen the same indicators of environmental benefit.

Our review drew on these reviews, as well as using other scientific evidence. Much was also drawn from recent MAFF/Defra funded reviews on various aspects of organic farming, most notably biodiversity (Gardner & Brown, 1998), manure (Shepherd *et al*., 1999), soils (Anon., 2002) and organic farming generally (Unwin *et al*., 1995).

Biodiversity

Biodiversity of soil borne organisms has already been considered under soil quality. Here, we have considered effects on flora and fauna at a range of scales. The general conclusion is that organic farming benefits biodiversity. Some of the potential causes for the biodiversity benefits of organic farming include:

- Organic standards require the sympathetic management of wildlife-rich infrastructure features, such as hedges, and ditches. These features also play a role for the organic farmer, providing reservoirs for the predators of crop pests as part of the integrated pest control strategies practised on organic farms.
- A higher proportion of organic lowland farms is in mixed farming.
- Use of synthetic fertilisers, agrochemicals and veterinary medicines is prohibited or much restricted, which removes direct and indirect problems for wildlife.
- Greater variety of crop structure because of more spring cropping in more varied rotations.
- Organic farms often use undersowing, such as with stubble turnips with the land then used for autumn grazing. This can produce attractive over-winter habitat for seed eating birds and helps boost populations of some farmland invertebrates.
- Existing unimproved grassland is protected under organic standards (although legislation on Environmental Impact Assessment gives protection to uncultivated land generally).
- Stocking densities are limited by productive capacity underpinned by the Organic Standards and so tend to be lower in organic systems. The lower density can be an advantage when grazing sensitive habitats. Different species of livestock are more often maintained on organic farms. This helps to control parasite burdens and has advantages in maintaining structurally diverse swards.

Conclusions – Biodiversity: Comparative reviews of the evidence base have been conducted for MAFF, English Nature, The European Commission and the Soil Association. The general conclusion is that on average there is a positive benefit to wildlife conservation on organic farms. In most studies organic agriculture provides a conservation benefit, whereas there are few studies where a disbenefit is shown. While some of these practices are used on some conventional farms it is only generally on organic farms where most of the relevant management is routinely and systematically carried out. Although, the evidence from several studies shows that birds do better on organic farms overall, there are some detrimental actions in organic farming, such as mechanical weeding or mulching operations taking place between April and July. If these practices were to intensify in the future they could reduce the overall benefits for ground-nesting birds. Both organic and conventional farms will perform better when under agri-environmental schemes.

Soil Quality

Soil organic matter benefits many aspects of soil quality. This has long been recognised by both organic and conventional farmers. Within soil textural constraints, soil organic matter levels will increase with greater organic matter inputs to the soil. There is evidence that soil organic matter contents will increase under organic farming. However, many conventional systems also encourage a build-up of organic matter through regular manure applications and returns of large amounts of crop residues etc. Due to the production systems, there may also be fewer differences in organic matter levels between conventional and organic grassland. Stockdale *et al*. (2001) stated that changes in organic matter drive/underpin many of the other changes in soil biological and physical properties. Our review has clearly demonstrated this.

For soil structure, we concluded that there is a large body of evidence to show that organic farms exhibit at least as good and generally better soil physical conditions than conventionally managed soils. Although SOM is often implicated in differences in soil physical properties the soil structure would be the result of all practices (SOM, rotational and tillage practices).

The evidence also tends to support the hypothesis that earthworm populations are more active in organic farming systems than those conventional systems with a great reliance on inorganic fertilisers and pesticides. Small populations of earthworms have been linked to lack of adequate moisture in the soil surface, intensive pesticide use, frequent tillage, and absence of ground cover. Organic management practices try to minimise these effects and are therefore more likely to encourage active earthworm populations.

Generally, organic farming practices have also 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 and/or biodynamic and conventionally 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 conventional practices 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.

Conclusion – Soil quality: There are few UK studies on the relative benefits of organic or conventional systems for soil quality. However, such studies as have been done and those from other countries tend to show benefits for organic systems. Organic farmers pay particular attention to their soils, and it is a fundamental tenet of organic farming to operate a sound rotational system to 'feed the soil' to maintain organic matter content and to keep it in good condition. However, organic matter additions are also made in conventional agriculture and, in some situations, the return may be similar or greater than in organic systems. Soil structure can benefit from regular returns of organic matter, and the evidence is that soil structure is at least as good and generally better under organic practices. Earthworm numbers tend to be greater in organic systems and studies into the microbial response of soils to organic management indicate there are benefits in many but not all situations and not always in all the attributes measured. The absence of soluble nutrients, most pesticides and reduced use of veterinary medicines such as antibiotics and ivermectins can also be expected to benefit soil organisms.

Water Quality

1. Nitrate

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.

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, the recent study of 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.

Much emphasis is always placed on the ley-ploughing phase. Indeed, nitrate losses can be large after autumn ploughing and further research needs to examine other options. However, because we are discussing a farming system, 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.

Conclusion – Nitrate in water: 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. The body of evidence suggests that leaching losses are generally less from organic systems – though this is not always guaranteed. Losses after ploughing the fertility building leys are one area where losses can be especially large. It might also be argued that this differential will decline as conventional fertiliser practices improve under the increasing regulatory pressure.

2. Phosphorus

The transport processes for P transfer from soil to water are complex. Surface run-off, soil erosion and sub-surface flow are the most common routes. Under UK conditions, downward leaching of P is not a primary route unless the soil P status has been elevated to extreme levels. Because of the complexity of the transport mechanisms, P loss is not necessarily related to P surplus. Factors that encourage infiltration of water and avoid surface run-off and erosion will probably decrease P losses. However, there is no work that has directly compared losses from organic and conventional farming. Information to date is therefore inconclusive.

Conclusion – Phosphorus in water: The main loss pathway for phosphorus is by movement of soil particles. Leaching is a smaller and more site-limited effect. There are some additional “incidental” losses following the application of fertilisers or manure. There is no direct evidence of differences in phosphorus losses between organic and conventional agriculture.

3. Pesticides

An assessment of pesticide pollution risk from organic farming is straightforward because only a few are permitted for use under restricted conditions.

Conclusion – Pesticide pollution to water (and air): Pesticide use in organic farming is very restricted. A small number of pesticides are approved for organic use (principally copper, sulphur, natural pyrethroids, and derris). They have restrictions on their use, and can only be used as a last resort. The pyrethroids, copper and derris are only permitted for use in protected cropping or for a restricted range of horticultural crops. With the exception of sulphur, on certain top fruit crops and pyrethroid sheep dip (which can be used in the same way on both organic and conventional farms), the use of the restricted range of pesticides is very limited by comparison with conventional agriculture. In particular, organic farmers do not use herbicides, some of which (such as isoproturon) have presented particular water pollution problems. Pesticide pollution from organic farming will be far less common than pesticide pollution from conventional agriculture. These differences are likely to hold whether assessed per area, or per unit of food produced.

4. Human Pathogens

The application of organic manure is a potential mechanism for transferring pathogens into the food chain, either by directly contaminating crops or by contaminating water. This is currently an area of intensive research, mainly because data have been lacking to date. There have been no comparisons of the effects of organic and conventional farming. Manure storage methods can influence pathogen survival. Composting will increase kill, but current research projects are not sufficiently advanced to draw firm conclusions.

Conclusion – Human Pathogens: Pathogenic organisms from livestock can contaminate surface waters used for drinking, bathing or irrigation. There is no reliable information on any differences in the incidence of zoonoses between organic and conventional farms although there is on-going research. Studies have shown that composting manure and treating slurries as encouraged under organic standards decrease the survival of any pathogenic organisms but stacking or long-term storage can also be beneficial. The methods of handling manure between farming systems may not be sufficiently different to produce a consistent effect and therefore information on the incidence the organisms is needed before any conclusions can be drawn.

Air quality

1. Ammonia

The main source of ammonia from organic farming is manure. An additional source from conventional agriculture may be losses from urea fertiliser, if this is used. However, manure is the major source from agriculture. Many factors affect ammonia loss – diet (amount of N excreted), housing, storage and landspreading. Because ammonia losses occur right through the animal production system, ammonia saved, for example, during housing might be susceptible to loss during manure storage and/or spreading (unless it is immobilised into non-ammoniacal forms). This whole needs to be considered when comparing ammonia losses from different production systems.

Conclusions – Ammonia: Ammonia is mainly lost from the surface of manure, either from animal buildings or hardstandings, which are soiled by manure, or during storage and handling. Manures produced in organic systems often have a lower concentration of nitrogen than do conventionally produced manure. Organic systems encourage the composting of manure, which leads to a relatively high loss of ammonia, although this will reduce the amount emitted when the compost is subsequently spread. Given the constraints on housing and stocking rate it is not possible to have intensive pig and poultry organic units, which are a major source of ammonia from conventional systems. Organic pigs and poultry will have similar losses to conventional outdoor units at the same stocking densities. It seems likely that on balance there is little difference between organic and conventional systems in the amount of ammonia which is lost from the system per unit of yield, but it is likely that emissions are lower per unit area. Given that nitrogen is more valuable to organic systems than it is to conventional systems (which can purchase nitrogen fertiliser at about 30p per kilogram), there should be a greater incentive for organic farmers to control ammonia losses in the future.

2. Nitrous oxide

There are major methodological problems in measuring nitrous oxide emissions from soils, mainly because of the size of the emissions and their intermittent nature. Consequently, there has been no comparative study of emissions from organic and conventional systems. One of the sources – fertiliser N – will not occur from organic systems, so the main organic practices that influence loss will be manure management and soil management.

Conclusions – Nitrous oxide: Nitrous oxide is emitted from manure and from soils. Emission tends to occur intermittently when there is a combination of the appropriate conditions. Within conventional agriculture, the main risks arise from manure and from the waterlogging of soils by heavy rainfall following fertiliser application. Within organic farming the risks are likely to come from manure and from waterlogging of soils where there is a legume crop. In the absence of direct measurement, it is not possible to assess whether there is any difference in risk from organic or conventional production.

3. Methane

Nearly all methane emissions from agriculture are related to ruminant livestock production Comparative data for organic and conventional production systems are limited. We therefore have to draw conclusions on methane emissions from the three main factors that affect emissions: livestock numbers, diet and productivity.

Conclusions – Methane: About 75% of methane on farms is emitted directly from ruminant animals (chiefly cattle and sheep). There have been no direct comparisons of methane generation between organic and conventional production. Different types of fodder will generate different amounts of methane, with higher rates released from diets that are high in roughage relative to diets high in starch. This will tend to result in higher emissions from organic systems, as organic diets tend to be high in roughage and low in concentrates. Methane emission per unit of livestock product decreases as the intensity of animal production increases (two cows producing 5,000l of milk will generate more methane than one cow producing 10,000l of milk). On average, production intensity is lower in organic than conventional systems, so methane generation from organic farms is likely to be greater per unit of food produced. Because of the lower stocking densities, it maybe similar on an area basis.

4. Carbon Dioxide

Although agriculture can be both a sink for and source of CO_2, most of the literature has focused on CO_2 emissions. The likelihood of organic farming increasing carbon sequestration in soils is small, even though organic farming practices encourage an increase in organic matter (manure applications, minimising bare soil, cover crops, etc.). This is because the size of the organic matter increase is small, and is not consistent across farms, depending on the carbon balance of individual farms with widely differing practices.

For CO_2 emissions, the number of comparative studies is few. The limited evidence is in favour of decreased emissions of CO_2 when comparing organic with conventional systems on an area basis, but the evidence is less convincing when comparing on a unit production basis. Much also depends where the boundary of the study is drawn.

Conclusions – Carbon dioxide: Net emissions of carbon dioxide from agriculture depend upon use of fossil fuel and the amount of carbon sequestration in soil organic matter. Emission from fossil fuel use will be lower on a per area and a per yield basis, reflecting the greater energy efficiency of organic agriculture noted below. There is insufficient evidence on whether there is a significant difference in the amounts of carbon sequestered in soils.

Resource Use

1. Energy efficiency

The review of the current literature showed that organic lowland livestock systems tend to have lower energy use than conventional lowland livestock systems. For extensive upland livestock systems, the energy uses are more similar although, on average, organic production uses somewhat less. Some of the differences in energy ratio were large. Organic arable production used 35% and organic dairy 74% less energy than conventional per unit of product.

Conclusions – Energy efficiency: The literature supports the statement that organic methods generally use less energy per unit area and per unit of output, both for individual crops and livestock types, and overall on a whole-farm basis. However, the setting of system boundaries, methods of calculating the energy values of inputs and methods of calculating energy use efficiencies vary substantially between studies. The intensity of production in the conventional comparison, particularly in relation to the level of use of mineral nitrogen fertiliser, also had a large impact on the relative performance of organic methods in comparative studies. This makes comparisons across studies difficult; there is a need for an agreed standard methodology. Information is lacking for non-ruminant livestock

2. Nutrient use and balance

Calculation of farm gate and soil surface balances is becoming an increasingly popular tool for judging the sustainability of a farming system. There are no hard and fast guidelines for the optimum size of any surplus to judge sustainability, but they provide an indication of whether a system will deplete soil reserves in the long-term (and therefore be deemed unsustainable). A large surplus may also indicate the potential for large losses, though the relationship between surplus and loss to the wider environment is not straightforward, nor proven.

Conclusions – Nutrient balance and use: Comparisons of nutrient budgets suggests that the balances can vary widely within a farming system. However, the general conclusion is that organic systems operate smaller nutrient surpluses. This is taken as an advantage, providing that nutrient reserves are not being depleted. Prohibition of various fertiliser additions is on the basis of encouraging self-sufficiency in a system, but there is a need to continually review the lists of allowed and disallowed products to ensure that choices are environmentally sound.

3. Controlled wastes

Organic farming focuses on recycling and on minimising external inputs. Thus the likelihood of needing to deal with controlled wastes when practising organic principles is small.

Conclusions – Controlled wastes: Waste is generally lower in organic farming since the system relies less on external inputs. Packaging materials for agrochemicals, veterinary medicine, animal feed, and fertilisers should all be lower on organic holdings. There is also little need for disposal of pesticide washings on organic systems.

Overall Conclusions

The general conclusion from our review concurs with that from other reviews, i.e. organic farming can deliver positive environmental benefits. However, this statement needs to be covered by several caveats:

- Organic farming does not automatically deliver all of these benefits. Clearly, where regulations control the management activities (e.g. no herbicide applications), environmental benefits are delivered. However, for other aspects, benefit will depend very much on the individual farmer, as does the impact of conventional farming. Here, soil quality improvement is a good example. Organic matter build-up can occur on a conventional farm if the farmer has access to animal manure and they are applied regularly (in accordance with codes of practice). The benefit here may be greater than on an organic stockless farm with limited or no access to manure. It is therefore important to bear in mind that there is a continuum of farming systems even within ‘organic’ and ‘conventional’ classifications.
- The outcome of any comparison depends on the type of farms being compared. We have already stated that ‘organic’ is legally defined, whereas ‘conventional’ is not. The tendency with some of the reported research is also to compare organic systems with conventional systems at similar levels of production. However, it is the higher intensity of some conventional systems that can lead to most problems. It would be more appropriate to compare organic with ‘typical’ intensive systems if this is what a switch to organic would replace. This is most likely to be the case in lowland agriculture. There are likely to be fewer differences between conventional and organic extensive upland livestock production systems.
- For some impacts (e.g. gaseous emissions), the potential benefit depends on the basis of comparison, i.e. on area or unit of production. This is important, and not easy to interpret.

The assessments are summarised in Table 1, assuming lowland agriculture and comparing organic with moderately intensive conventional systems.

Table 1. Summary of environmental effects of organic farming.

	Indicator	Assessment of impact: Per unit area	Assessment of impact: Per unit yield	Comments
Ecosystem	Biodiversity	☺	☺	Organic principles encourage a wide variety of habitats.
Soil Quality	Organic matter content	☺/😐	☺/😐	Potential benefits from organic farming, depends on organic matter inputs on individual organic and conventional farms.
	Biology	☺/😐	☺/😐	Literature tends to support a benefit, <u>but not always</u>.
	Structure	☺/😐	☺/😐	Literature tends to support a benefit, <u>but not always</u>.
	Erosion susceptibility	☺	☺	Few direct measurements, but organic practices should decrease risk.
Water Quality	Nitrate leaching	☺	☺/😐	Potentially large losses from ploughed leys, but smaller losses, on average, from other points in the rotation.
	Phosphorus loss	😐	😐	Insufficient information.
	Pesticides	☺	☺	Few pesticides used in organic production.
	Human pathogens	😐	😐	Insufficient information – work ongoing.
Air Quality	Ammonia	☺	😐	No direct studies. Assessed from what is known about processes.
	Nitrous oxide	😐	😐	Insufficient information.
	Methane	☺	☹/😐	Most data relate to dairy systems. Lower emissions on an area basis due to lower livestock densities.
	Carbon dioxide	☺	😐	Main energy input relates to fertiliser manufacture.
Resource use	Energy efficiency	☺	☺	Depends where boundaries are drawn when comparing systems, but main energy input into conventional is fertiliser production.
	Nutrient balance	☺	☺/😐	Smaller surpluses: OK if not over-depleting soil fertility.
	Controlled wastes	☺	☺	Emphasis on recycling. Less packaging and no agrochemical waste.

Key:
☺ Positive effect
😐 Neutral effect
☹ Negative effect

Finally, there are some other considerations that need to be borne in mind for this exercise:

- The effects of scale of converted areas are unknown. Larger areas of contiguous organically farmed land could result in greater or, possibly, lesser environmental benefits than the conversion of individual farms.
- The implications at the macro-scale if a large proportion of agricultural land was converted to organic are uncertain. Organic systems tend to produce lower yields than conventional systems, and have a higher proportion of land occupied by animals, whereas many conventional livestock systems have a greater reliance on feed produced off-farm. This could lead to differences in food imports and in the balance of land-use within the country. It is not clear what the implication of these macro changes would be for the environment.

The project has generated the following outputs:

- Full report, published on the Defra website.
- A paper has been written, based on the complete report. This has been submitted to the Journal of Science of Food and Agriculture.
- Summary article in 'Organic Farming'.
- Abstract submitted to the Colloquium of Organic Researchers Conference.

Soil fertility booklet

Much of the Defra-funded research that has taken place on aspects of soil fertility in organic farming was summarised in Soil Use and Management (Anon., 2002):

- Organic matter is linked intrinsically to soil fertility, because it is important in maintaining good soil physical conditions (e.g. soil structure, aeration and water holding capacity), which contribute to soil fertility. Organic matter also contains most of the soil reserve of N and large proportions of other nutrients such as P and sulphur. Field management data gathered from farmers showed, however, that organic matter returns are not necessarily larger in organic systems. Many non-organically farmed soils receive regular manure applications and the generally higher yielding crops on conventional farms may return larger crop residues. Conversely, many organic fields receive little or no manure, relying on the fertility building ley phase for organic matter input. This observation is important. Management practices within organic and non-organic systems are diverse and, sometimes, overlapping with consequences for soil fertility.
- *Soil Structure* - Whilst addition of SOM generally promotes an increase in soil aggregate stability, only a part of the total SOM (generally the younger SOM with a larger content of polysaccharides, roots and fungal hyphae) stabilises aggregates: fungal hyphae (the biological agent) and extracellular polysaccharides (major cementing agents, deriving from plants and soil bacteria) are capable of linking together mineral particles and stabilising aggregates. Thus, the most significant SOM components in agronomic systems are transient materials that exert their effect for one year at most. 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.
- *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.

- *Nutrient cycling* - Organic farming seeks to build up the reserves of nutrients in the soil while at the same time reducing inputs. This apparent conflict can only be resolved by increasing the efficiency of nutrient use and moving away from a definition of fertility based on the production of maximum yields. 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. Differences are more apparent with arable than with grassland soils because the latter usually have higher organic matter contents, irrespective of whether they are managed non-organically or organically.

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.

An advisory booklet has been drafted and is undergoing editing with a view to publishing in a similar format to the previous Defra-funded booklet ‘Managing manures on organic farms’. Table 2 indicates the main headings and the points summarised within the text.

Table 2. Summary of soil fertility booklet.

Section	Summary points
What is this booklet about?	Nutrient management is one of THE major challenges facing the organic farmer. Organic farming aims to build up soil nutrient reserves whilst at the same time reducing external inputs. Skilful management can only resolve this apparent conflict. Efficient management of nutrients should ensure good yields of crops and healthy animals. Poor management can result in poor yields, poor animal health and environmental pollution. This booklet provides: • Information on the underlying scientific principles behind soil fertility in organic farming systems. • Practical advice on managing soils in organic systems to maintain soil fertility. This booklet draws on scientific research undertaken in the last 10 years, much of it in the UK, and most of it funded by Defra.
What is ‘soil fertility’?	• The interaction of biological, chemical and physical attributes: not just how much nutrient is in a soil. • The key word is ‘interaction’: enhanced biological activity impacts on nutrient recycling and soil structure; good structure benefits biological activity. • Organic matter is central to good soil fertility
How are organic farms different?	• Organic farming aims to create an economically and environmentally sustainable agriculture. • The emphasis is placed upon self-sustaining biological systems, rather than

	reliance on external inputs. • Organic farming is much more than simply replacing synthetic inputs with natural ones, though it is often described as this
Building soil fertility	• Rotations rely on fertility building and depleting phases. • Legumes are the main source of nitrogen. • Manures/composts are valuable sources of nutrients. • It is essential to minimise losses of nutrients to the wider environment.
Managing nutrient supply	Nutrient management is one of the main challenges facing the organic farmer. In the short term, the problem is supplying sufficient nutrients to the crop at the correct point in its development to achieve economically viable yields. In the long-term, the challenge is to balance inputs and off takes of nutrients to avoid nutrient rundown or environmental pollution. Both of these goals must be achieved in the most part through the tricky management of organic matter.

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

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

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

Pitfalls and problems	• Meeting all production and environmental objectives not always straightforward, especially when contrasting requirements. • Holding on to nutrients, particularly N: at risk of loss upwards and downwards: P and K less mobile (K at risk in manure heaps); grow cover crops, timing of manure applications etc. • Green manures good in theory, not always easy to accommodate in rotations; difficult to manage on heavier soils. • Trace elements for animals? • Maintaining N for the rotation on less retentive soils (probably same as a point above) [some soils are more suitable for organic farming than others]
Appendices	• Certification bodies

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