DEPARTMENT for ENVIRONMENT, FOOD and RURAL AFFAIRS **CSG 15**

Research and Development

Final Project Report

(Not to be used for LINK projects)

Project title	Changes to soil quality indicators following conversion to organic vegetable production		
DEFRA project code	**OFO401**		
Contractor organisation and location	Horticulture Research International Wellesbourne		
Total DEFRA project costs	£ 62,706		
Project start date	01/04/01	Project end date	31/03/02

Executive summary (maximum 2 sides A4)

Increasing interest in low input agriculture together with growing environmental awareness, has led to recognition of the need to maintain and enhance soil resources. This has highlighted the requirement for a greater understanding of factors controlling soil 'quality' or 'health' attributes which contribute to sustainability. More reliable methods of assessment need to be be developed, so that soil quality can be enhanced to improve productivity. This is particularly true in organic systems, in which fertility is promoted by the inclusion of fertility building crops within rotations, and by the incorporation of composted waste materials, in the absence of chemical fertilizer and pesticide inputs.

The aim of this 1 year study was to examine how key functional indicators of soil quality are affected by contrasting organic and conventional management regimes. In particular, the project investigated the impact of contrasting fertility building regimes on soil quality, focussing on the initial 5 year period following conversion from conventional to organic production. The study supports DEFRA's policy objectives of assessing and improving the sustainability of organic farming, including the impacts of organic farming on the soil environment, and on sustainability. Additionally, the study contributes to the development of reliable indicators of soil quality for research and monitoring purposes, addressing a need highlighted in the Draft Soil Strategy Document for England

The study site was located on the farm at HRI-Wellesbourne, and is part of a network of organic farms being monitored by HDRA for crop and economic performance as part of projects OF0126T and OF0191. Five 0.8 ha areas were selected for study. These were; two organic vegetable rotations supporting contrasting fertility building regimes, an organic arable rotation, a grass-clover ley and a conventionally managed cereal rotation. The organic areas were located in Hunts Mill field, which had been converted from conventional cereal production 5 years prior to the start of the study. The conventional area was located in Deep Slade field, which is adjacent to Hunts Mill. A range of chemical, biological and physical attributes were determined.

There were differences between the organic and conventional management regimes in most chemical, biological and physical soil quality parameters. Contrasting organic management regimes had different effects on soil quality. Relative to organic vegetable and conventional arable management, the organic arable management rotation enhanced amounts of light fraction organic matter and labile N, with beneficial implications for long term nutrient retention and soil organic matter development. There was little difference in chemical quality between the organic vegetable and the conventional arable areas.

There was evidence that organic management promoted a microbial community that was distinct in composition and functional attributes to that in conventional soil. Relative to conventional management, areas under organic management had greatly increased inoculum of arbuscular mycorrhizal fungi, a larger proportion of 'active' relative to 'resting' biomass within the microbiota, increased metabolic diversity and a distinct microbial community metabolism. However, there was evidence that the productivity of newly converted organic systems could be limited by low inoculum and diversity of arbuscular mycorrhizal fungi inherited following conventional management.

The clearest effect on soil structure was with regard to the detrimental effects of vegetable production rather than to any benefit associated with organic management. Wheeling lines caused compaction that resulted in poor growth of subsequent cereal crops. However, it is likely that increased levels of organic matter may result in a soil better able to cope with damaging operations.

There were differences in the susceptibility of the chemical and biological quality parameters to change. Different susceptibilities of quality parameters to change provides possibilities to use selected parameters as early indicators of the effects of management on soil quality. Furthermore, the results highlight the need to consider a wide variety of 'quality' analyses when investigating soil quality, since limited data sets focussing on traditional measures of soil quality (e.g. total SOM and biomass-N) are too rudimentary to pick up changes to soil functional attributes, and could lead to unsound conclusions regarding the effects of management on soil quality.

There are opportunities to conduct further statistical analysis of our comprehensive data set in order to develop an index suitable for quantifying soil quality in organic systems. Such an index would be of generic value to rate soil quality in diverse agricultural systems. Further work is needed to determine the applicability and conclusions of our study to other soil types and organic management regimes. The work has highlighted fundamental shifts in microbial community structure and functioning following conversion from conventional to organic management. There is a need to characterise and quantify these changes. This will provide new groups of 'indicator' organisms which could be suitable for assessing changes to soil quality, and could also provide opportunities to manage soil microbial communities to improve the sustainability of organic and conventional farming.

Scientific report (maximum 20 sides A4)

1. INTRODUCTION

Increasing interest in low input agriculture, particularly organic systems, together with growing environmental awareness, has led to recognition of the need to maintain and enhance soil resources (Doran et al., 1994). This has highlighted the requirement for a greater understanding of the soil attributes which contribute to sustainability, so that more reliable methods of assessment can be developed, and so that soil quality can be enhanced to improve productivity. There are a great variety of chemical, biological and physical attributes that have been used to describe the 'health' or 'quality' of soil. Many of these attributes have key functional roles in the soil, and their status may have direct implications for crop growth and productivity. However, few of the attributes are likely to have generic importance for sustainability, which will ultimately depend on complex interactions between diverse soil properties.

Organic farming systems have been developed to sustain crop production in the absence of chemical fertiliser and pesticide inputs. Nutrient supply to crops depends on the use of legumes to add nitrogen to the system and limited inputs of supplementary nutrients, added in acceptable forms. Manures and crop residues are carefully managed to recycle nutrients around the farm. The aim is to manage soil organic matter, primarily through the use of short-term leys, to help ensure good soil structure and biological activity. This is important for nutrient supply and the health and productivity of both crops and livestock. Carefully planned diverse rotations help reduce the incidence of pests and diseases and allow for cultural methods of weed control. As a result of the complex interactions between different system components, fertility management in organic farming relies on a long-term integrated approach rather than the more short-term very targeted solutions common in conventional agriculture (Watson et al. 2002).

There is a therefore a need to understand the mechanisms regulating soil fertility in organic systems. This will aid the development of effective organic rotations, and will allow limitations to fertility to be diagnosed and remedied. A number of 'quality' parameters are likely to be central to maintaining fertility in organic systems, including factors contributing to chemical, biological and physical 'health'.

Soil organic matter (SOM) is crucial for sustaining crop production in agricultural soils. In addition to providing a background turnover of nutrients to drive plant growth (Jenkinson, 1981), SOM also contributes to the maintenance of soil structural properties which are necessary for plant growth and which prevent erosion (Oades, 1984). However, changes in the amounts and characteristics of gross SOM pools occur very slowly, and long-term experiments over decades are needed to determine the impact of management practices or other perturbations on SOM dynamics (Beare et al., 1994; Ladd et al., 1994).

SOM is highly heterogeneous and consists of a variety of different fractions which have various origins and functional roles in the soil (Stevenson, 1994). A number of SOM fractions appear to be more labile than the gross SOM pool, with the result that changes in these fractions have potential to provide early indication of the impacts of management or environmental stress on soil quality. These pools include labile organic nitrogen (N), light fraction organic matter (LFOM) and water soluble carbohydrates. Labile organic N and LFOM are considered to govern patterns of N mineralization in many soils (Bonde and Roswall, 1987; Janzen et al., 1992; Sierra, 1996), while the carbohydrate pool, especially that linked to the heavy fraction OM, plays a role in aggregation of soil particles, which determines soil structural properties (Oades, 1984).

The soil microbial community largely mediates the effect of management on SOM, and the C and N content of the biomass is also viewed as an indicator of soil quality (Rice et al., 1996). A number of techniques including patterns of substrate utilization (Garland and Mills, 1991) and enzyme analysis (Bending et al., 2002) have been used to describe the diversity, structure and functioning of soil microbial populations. Since these techniques measure the profiles and activities of communities directly involved in SOM dynamics, they could have great value for the characterisation of soil quality.

It has long been recognised that soil structure is an important aspect of overall fertility since it affects aeration, and the the infiltration and storage of water in the soil, with consequent effects on mineralisation of organic matter, seed germination, plant establishment and root penetration (Davis et al., 1982). Soil organic matter, together with management are the primary factors which affect soil structure. A difficulty of measuring changes in soil structure is that measurements of single characteristics are too crude to reveal subtle changes which are nevertheless of agronomic significance.

In 1996-1997 analyses were made of soil organic matter and microbial quality indicators immediately after conversion of land at Wellesbourne from conventional to organic production (the wider agronomic and economic implications of conversion at this site were monitored as part of DEFRA Project OF0126T). These measurements provided baseline information regarding the status of soil prior to conversion, and of changes to key soil quality indicators during the initial stages of the fertility-building phase. The study demonstrated that microbial community level physiological profiles (CLPP) and metabolic diversity were sensitive indicators of management, and changed during the fertility-building phase. However, there were no changes to labile soil organic matter pools during the first 18 months of the conversion (Bending et al., 2000).

The aim of this study was to extend earlier studies by comparing how different organic and conventional management strategies affected key chemical, biological and physical components of soil quality after a 5-year period. The results have practical value for the design of organic rotations, for highlighting limitations to fertility in organic systems during the crucial conversion period, and for selecting indicators with generic potential for elucidating management induced changes to soil quality.

2. OBJECTIVES

01 Characterise soil quality indicators in field areas receiving contrasting organic fertility building strategies

02 Determine changes to key indicators of soil quality during the early years after conversion to organic vegetable production

3. MATERIALS AND METHODS

3.1 Study site

The study site was located on the farm at HRI-Wellesbourne. The site is on sandy-loam, the characteristics of which have been described by Whitfield (1974). Five 0.8 ha areas with different management regimes were selected for investigation (Fig 1). Areas 4, 6, 3 and 7 were located in Hunts Mill field, which was converted from conventional cereal production to organic production in 1995/96. Complete descriptions of management activities within Hunts Mill field are given in the final report for Project OF0126T, and annual reports for Project OF0191. Brief details are summarised below;

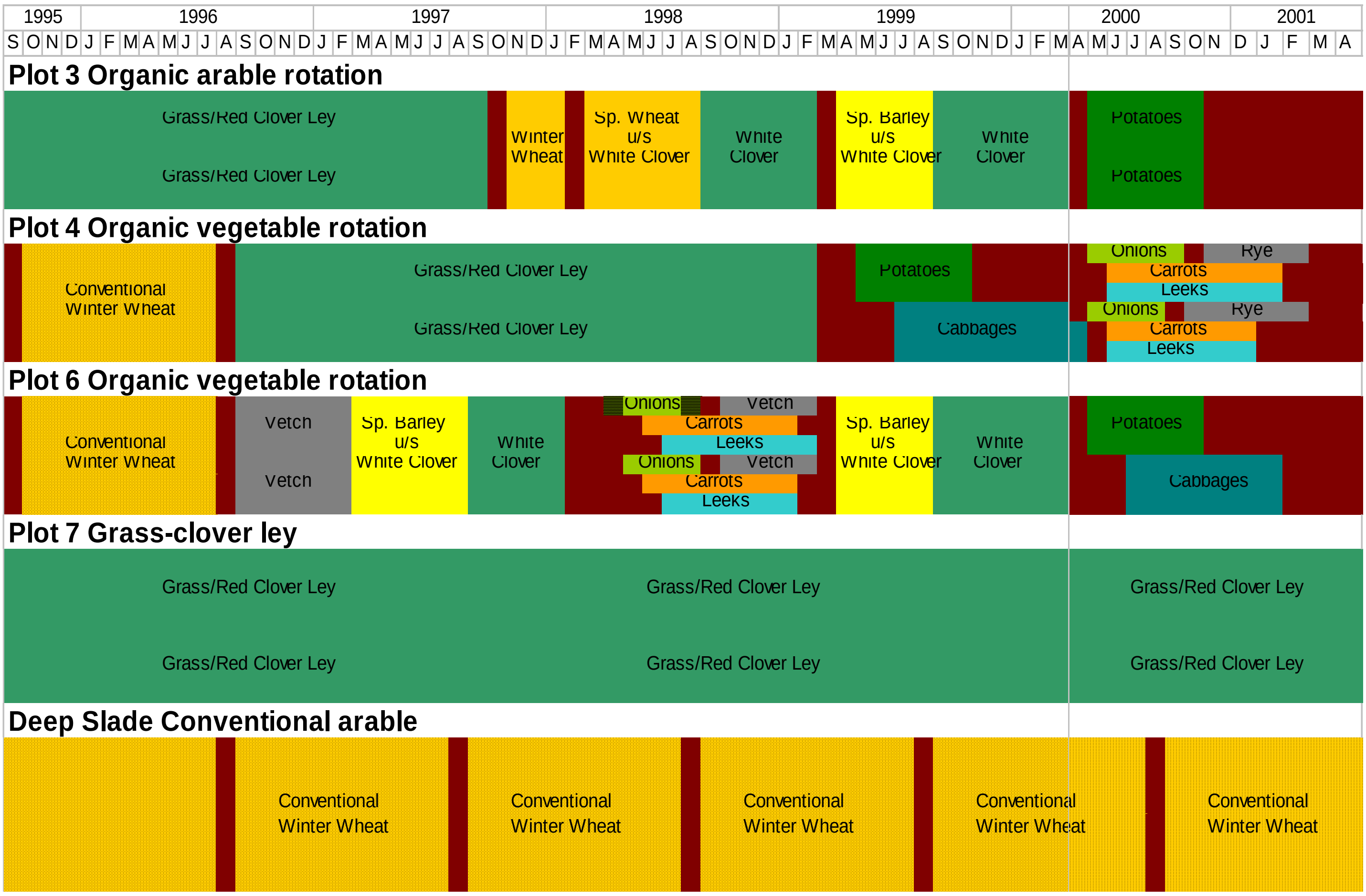
- Area 4 received an organic vegetable-cereal rotation. Following a 30-month grass clover ley, the area was divided into 2, and cropped with potato or cabbage. The area was then further subdivided and onion, carrot and leek grown. At the time of sampling the area had recently been sown with spring barley.
- Area 6 received an organic vegetable-cereal rotation. After a 6 month vetch fertility building crop, a crop of spring barley undersown with white clover was grown. The clover overwintered and the area was split into 6 strips, on which onion, carrot and leek were grown. After a second spring barley crop (again undersown) the area was divided into two and potato and cabbage grown. At the time of sampling the area had been cultivated and formed into beds for more vegetable crops.
- Area 3 had a 23-month grass clover ley on conversion. This was followed by 2 crops of spring barley undersown with clover (the clover being allowed to overwinter after harvest of the cereal. A potato crop

was grown in 2000 but this was harvested late because of the wet autumn. The land was bare at the time of sampling.

- Area 7 was under a mown grass clover ley since conversion began.
- Deep Slade was under conventional management, and had been used for Winter Wheat for the 5 years following conversion in Hunts Mill. Until conversion of Hunts Mill, the two fields had been under the same conventionally managed cereal rotation.

Hunts Mill is registered as organic land with the Soil Association. The site is completely stockless and Green waste compost has been applied to the fertility building phase of the various areas of Hunts Mill in accordance with the Code of Good Agricultural Practice.

Fig 1. Management history of organic and conventional plots 1996-2001



3.2 Sampling strategy

Sampling was done in the first week of May 2001. In the case of areas 4 and 6, each 0.8 ha area was divided into 6 strips which had each received different vegetable crop sequences. For sampling, each strip was divided into 4 equal area sub-strips (16 x 20 m). Across each sub-strip, 20 cores were taken from 0-15 cm depth using a 2.5 cm auger. In areas 3, 7 and Deep Slade, each area had received a uniform management. Each area was divided into 6 sub-areas, from each of which 20 cores were taken from 0-15 cm depth. Cores from each sub-strip or sub-area were pooled and passed through a 3 mm sieve prior to use.

3.3 Soil quality analysis

Soil samples were analysed for a variety of chemical, biological and physical parameters. For chemical quality parameters, soil was analysed without pre-treatment. For the biological analyses, 200 g samples of soil were moistened to 60 % water holding capacity and incubated at 15^{o}C for 14 days in aerated boxes prior to use. The physical quality analyses were made *in situ* or on intact cores removed to the laboratory.

a. Chemical quality

Total organic matter C and N were determined using an automated C/N analyser (CN-2000, Leco Corporation, Michigan, USA). **Light fraction organic matter** (LFOM) was separated using a 1.7 g cm^{-3} solution of NaI according to Strickland and Sollins (1987), and its C and N content determined using the C/N analyser. **Water-soluble carbohydrates** (WS-Carb) were extracted by incubation of soil in a boiling water bath for 16 hours (Brink et al., 1960), and measured using a phenol-H_2SO_4 assay (Dubois et al., 1956). **Soil mineral N** was extracted using 0.5 M K_2SO_4, and NH_4^+-N and NO_3^--N measured using the indolphenol blue assay and by HPLC respectively (Bending et al., 1998). **Labile organic N** was determined by subtracting initial mineral N content from mineral N accumulated following a 2 week incubation of 200 g portions of soil at 15^{o}C in an aerobic incubation chamber (Bending et al., 2000).

b. Biological quality

i) Biomass characteristics

Microbial biomass-N was measured using the chloroform fumigation-extraction technique (Joergensen and Brookes, 1990), followed by an alkaline persulphate oxidation for determination of total N (Cabrera and Beare, 1993). **Microbial biomass-C** was derived from biomass-N using the equation 'biomass C = 21 x N released by fumigation' (Amato and Ladd, 1988). **Microbial basal respiration** was determined by measuring CO_2 evolution from 20 g portions of soil incubated at 25^{o}C for an hour, using an infra red gas analyser (ADC, Hoddesdon, UK). **Microbial ATP** was extracted in 0.1 M Tris-EDTA buffer (pH 7.8) and ATP measured using an Enliten ATP assay kit (Promega). **Metabolic quotient** was determined by dividing microbial biomass C by microbial respiration. The ratio of biomass C/microbial ATP was also determined.

ii) Microbial community functioning

Arbuscular mycorrhizal fungus (AMF) inoculum potential was measured using an *Allium cepa* (onion) bioassay. Onion seedlings (2 per pot) were grown in 200 g portions of soil (moistened to 60 % WHC) under controlled glasshouse conditions (max / min temperatures 25^{o}C and 15^{o}C respectively) for 14 weeks. Two pots were set up for each soil sample. At harvest, roots were removed, washed and stained in aniline blue according to Grace and Stribley (1991). The % root length of each seedling colonized by AMF was determined by measuring the length of 20 x 1 cm root lengths showing evidence of AMF mycelium, arbuscules or spores. **Microbial community functioning** and **functional diversity** were determined by **enzyme analysis** and by determining metabolism of the **Biolog culturable microbial community**. The activities of 8 key enzymes involved in soil C, N, P and S dynamics were determined using a microplate fluorimetric assay (Marx et al., 2001) in collaboration with Dr M. Wood at the University of Reading. The metabolic profile of microbes culturable in Biolog GN microplates was determined according to Bending et al. (2000). For the enzyme and Biolog analyses, community level physiological profiles were determined using canonical variate analysis. Shannon's diversity index was determined according to Zak et al. (1994). For the enzyme analysis, it was possible to analyse only 38 samples in total. As a result 4 samples were chosen randomly from each of areas 3, 7 and Deep Slade, and 26 samples were chosen randomly from across areas 4 and 6. In the case of the Biolog analysis, within areas 4 and 6, soil from sub-strips from within each strip were pooled, so that a total of 6 samples were analysed from each area, together with 6 from each of areas 3, 7 and Deep Slade.

c. Soil physical quality

Bulk density was measured using the core method (Blake and Hartge, 1986). In the cases of areas 3, 7 and Deep Slade, 4 measurements were made within each sub-area, while for areas 4 and 6, 4 measurements were made within each sub-strip. Cores 10 cm in diameter and 15 cm deep were removed intact, dried and weighed. **Aggregate stability** was determined using a wet sieving method (Kemper and Rosnau, 1986). Carefully rewetted samples from intact cores were sieved underwater through 4 mm, 1.7 mm and 0.5 mm mesh for a period of 10 minutes (12 lifts per minute); the soil remaining on each mesh was then dried and weighed and the mean weight diameter (MWD) calculated. **Water infiltration rate** was determined using cylinder infiltrometers (Bouwer, 1986). A single measurement was made on each subarea for all areas; 45cm diameter metal cylinders were inserted 10 cm into the ground and, after prewetting, the rate of water infiltration was measured every minute over a period of 10 minutes. **Soil hardness** was determined using a penetrometer (Bradford, 1986). Five penetrations were made (to 32 cm depth in 2 cm increments) in each sub area using a Bush Recording Soil Penetrometer (Findlay, Irvine Ltd, Pencuik, Scotland). In area 4, where wheeling marks were clearly visible in the cereal, separate measurements were made in the green and yellowed areas.

3.4 Analytical design and Statistical analysis

Differences between areas receiving contrasting management practices were determined by Analysis of Variance, using the program Genstat (Version 5.3, Lawes Agricultural Trust, Rothamsted Experimental Station).

4. RESULTS AND DISCUSSION

4.1 OBJECTIVE 01

Characterise soil quality indicators in field areas receiving contrasting organic fertility building strategies

a. Chemical quality

Management had a significant effect on all of the chemical quality parameters (Table 1). Area 3 had the highest total and LFOM-C and -N, and labile organic-N contents, and the lowest LFOM-C/N. Total SOM-C and -N and WS-carb were lowest in area 6, while LFOM C and N, mineral-N and labile organic-N were lowest in Area 4.

Each of the soil chemical parameters measured has a known functional role in the soil (see Introduction), and each reflects a 'more is better' attribute (with the exception of mineral-N, excess of which poses a pollution risk at certain periods of the year). These results suggest that the 2 organic vegetable rotations have lower soil chemical quality than the organic arable rotation. This could reflect the relatively high soil disturbance associated with the preparation of seedbeds, the weeding of crops, and the harvest and removal of vegetables. In particular, the organic arable rotation enhanced amounts and quality of LFOM, which is newly formed organic matter derived from plant inputs, and labile organic N, both of which are important for the long term storage of nutrients. There was little or no difference in quality between areas 4, 6, 7 and Deep Slade.

Table 1

Chemical quality in organic and conventional areas[1]

Area	Total soil Organic-C ($\mu g\ g^{-1}$)	Total soil Organic-N ($\mu g\ g^{-1}$)	LFOM-C ($\mu g\ g^{-1}$)	LFOM-N ($\mu g\ g^{-1}$)	LFOM C/N	Mineral-N ($\mu g\ g^{-1}$)	Labile Org-N ($\mu g\ g^{-1}$)	WS-Carb ($\mu g\ g^{-1}$)
4	1097	87.8	581	18.4	32.2	7.56	4.36	4.78
6	985	77.9	680	25.1	27.3	8.60	5.15	4.44
3	1226	99.0	1087	42.8	25.4	7.91	6.71	5.07
7	1074	88.2	710	18.5	37.8	8.36	6.33	5.57
Deep Slade	1147	79.3	684	20.2	33.8	11.57	6.17	5.01
LSD (P=0.05)	228	17.0	185	5.8	4.2	1.52	2.14	1.14
Significance of main effects (***, P<0.001; **, P<0.01; *, P<0.05)	***	***	***	***	***	***	*	***

[1]All parameters reflect amount per g^{-1} dry weight of soil

b. Biological quality

Management had significant effects on biomass N, ATP, metabolic quotient and the Biomass C:ATP ratio, but not microbial respiration (Table 2). Deep Slade had the highest biomass N content, the lowest ATP, and the highest metabolic quotient and biomass C:ATP ratio.

Table 2

Biomass characteristics in organic and conventional areas[1]

Area	Biomass-N ($\mu g\ g^{-1}$ soil)	Microbial Respiration ($\mu l\ CO_2\ g^{-1}\ h^{-1}$)	Log ATP ($ng\ g^{-1}$ soil)	Log Biomass-C/respiration	Log Biomass-C/ATP
4	16.7	77.8	2.88	0.375	1.81
6	13.0	96.6	3.24	-0.049	1.15
3	21.3	91.6	3.27	0.383	1.60
7	14.8	89.9	3.20	0.185	1.29
Deep Slade	25.4	98.2	2.05	0.537	2.64
LSD (P=0.05)	7.8	48.4	0.88	0.520	1.02
Significance of main effects (***, P<0.001; **, P<0.01; *, P<0.05)	***	NS	*	*	**

[1]Parameters reflect amount per g^{-1} dry weight of soil

Biomass N, respiration and ATP reflect 'more is good' properties, since they reflect the size and activity of the microbiota. The evidence indicates that the organic vegetable rotations and the long-term grass-clover ley have had deleterious effects on biomass relative to the organic arable and conventional cereal rotations. However, while biomass-N measures active and 'resting' microbes, ATP analysis gives an indication of the active portion of the soil microbiota only. ATP analysis showed that while there was no difference in ATP content between areas 3, 4, 6 and 7, ATP content in Deep Slade soil was 30-40 % lower relative to the other areas. This indicates that a far greater proportion of the biomass in Deep Slade was present as 'resting' biomass. This is reflected in the biomass:ATP ratio, which was far higher in Deep Slade relative to the other areas. Similarly, the metabolic quotient, which reflects CO_2 produced per unit of biomass, indicated that less CO_2 was produced per unit of biomass relative to the other treatments. These results could suggest that organic management has had an impact on the structure of the microbial community, favouring 'K' strategists, with more predictable resource inputs, constant population sizes, longer life spans of individuals and keen competition for resources. This contrasts with apparently greater importance of 'R' strategists in the conventional system, possibly reflecting variable resource inputs, populations which vary considerably over time, and short life spans of individuals.

Management had a significant effect on arbuscular mycorrhizal fungus colonization potential (Table 3). Although there was no significant difference in AMF root colonization potential between the organic areas, AMF inoculum potential was very low in Deep Slade, with the % of the onion test crop root length colonized representing less than 1 % of that colonized in area 3.

Table 3

Arbuscular mycorrhiza inoculum potential in organic and conventional areas

Area	% root length colonized by AMF[1]
4	12.9 (19.0)
6	16.7 (22.5)
3	18.9 (25.6)
7	21.4 (26.2)
Deep Slade	0.2 (1.7)
LSD (P=0.05)	(10.4)
Significance of main effects (***, P<0.001; **, P<0.01; *, P<0.05)	***

[1]Figures in brackets represent angular transformed data, to which LSD and ANOVA relate

The results indicate that the AMF community under conventional management was severely depleted. If we assume that AMF inoculum in Hunts Mill prior to conversion was the same as that in Deep Slade, it is apparent that after 5 years under organic management, there had been some recovery of the community. These differences could be the result of fungicide and mineral fertiliser application under conventional management, both of which were absent from the organic areas. The inclusion of long term fertility building phases with rye, clover and vetch, which are all readily susceptible to AMF colonization, could have contributed to the recovery of the AMF population. However, wheat and barley are also susceptible to AMF colonization. Furthermore, the organic vegetable rotation included cabbages, which are not susceptible to AMF infection, and which may actually inhibit AMF populations (Kurle and Pfleger, 1994).

Our results suggest that AMF fungi have a more important role in organic relative to conventional systems. AMF are known to vary considerably in the nature of their functional interactions with plants, and AMF diversity can control the positive impacts of AMF on plant growth and development (van der Heijden et al., 1998). Further, AMF diversity is known to be reduced by conventional agricultural management (Helgason et al., 1998). It was unclear from our study whether there had been an increase in AMF **diversity** under organic management.

Soil enzyme activities are generally considered to be 'more is good' properties, reflecting both amounts of organic matter in the soil and the activities of the soil microbial community. There were management-induced differences in the activities of N-acetyl glucosaminidase, acid phosphatase, and leucine peptidase (Table 4). These enzymes are involved in the processing of chitin, phosphomonoesters and protein, indicating that management had affected some key processes contributing to soil organic N and P cycling. For N-acetyl glucosaminidase, highest activity occurred in area 3, and lowest in area 4. In the case of acid phosphatase, highest activity occurred in area 3, and lowest in Deep Slade. For leucine peptidase highest activity was recorded in area 4, and lowest in area 6. There were no differences in activities of the other 5 enzymes tested.

Table 4

Soil enzyme activities in conventional and organic areas

Enzyme	Activity (nmol MUB/AMC min^{-1} g^{-1} dry weight soil)					
	Area 4	Area 6	3	7	Deep Slade	LSD (P=0.05)
Cellobiohydrolase	3.11	3.11	3.27	2.82	3.23	0.63
Galactosidase	2.29	2.20	2.84	2.40	2.27	0.67
N acetyl-glucosaminidase	3.79	4.11	5.00	4.27	4.02	0.76
b-glucosidase	11.21	10.03	12.75	12.23	10.93	3.00
Acid phosphatase	19.89	21.70	27.20	23.56	15.89	4.51
Sulfatase	1.16	1.22	1.44	1.44	1.19	0.30
Xylosidase	2.07	2.16	2.54	2.53	2.11	0.52
Leucine peptidase	4.09	2.70	3.30	3.64	3.73	0.60

Metabolic diversity reflects the diversity of substrates the soil microbial community is able to metabolise, and is considered to be a 'more is good' parameter, as it reflects the potential of the community to metabolise newly introduced substrates, and to cope with stresses. Both Biolog and enzyme derived metabolic diversity were affected by management (Table 5). In the case of Biolog data, Shannon's diversity index was lowest in Deep Slade soil, and highest in area 4. However, enzyme diversity was highest in Deep Slade.

Table 5

Metabolic diversity in conventional and organic areas

Area	Shannon's diversity index	
	Biolog data	Enzyme data
4	4.27	1.67
6	4.24	1.62
3	4.19	1.60
7	4.20	1.62
Deep Slade	4.06	1.74
LSD (P=0.05)	0.06	0.04

Significance of main effects

(***, P<0.001; **, P<0.01; *, P<0.05)

	***	***

Canonical variate analysis of the Biolog metabolism data showed that community level physiological profile (CLPP) of areas 3, 6 and 7 were similar (Fig 2). However, CLPP in Area 4 and Deep slade were clearly separated from the other areas, and from each other, along CV1. For the enzyme data, CLPP of areas 3, 4, 6 and 7 were clustered together, although there were significant differences between areas 4 and 6 (Fig 3). However, CLPP of Deep Slade soil was clearly separated from the other areas.

The results demonstrate that management affected microbial community functioning. In particular, there was evidence that organic vegetable management resulted in a decline in the activities of a number of key nutrient mobilising enzymes, and there was also evidence that organic arable management had stimulated activities of a number of enzymes. Although Shannon's index showed differences in enzyme profiles across the treatments, all 8 enzymes were detected in all treatments, so that the diversity index reflected the relative distribution- or evenness- of enzyme activities only. The Shannon's index therefore indicated that there was greater evenness across the enzyme activities in the Deep Slade soil relative to the other treatments.

Further, there was evidence from the Biolog analysis of lower functional diversity in Deep Slade relative to the other treatments. The soil microbial communities that are able to grow in Biolog plates consist mainly of fast growing bacteria, particularly members of the proteobacteriaceae (Smalla et al., 1998). The Biolog results suggest that organic management has favoured development of such bacteria, relative to the conventional arable site. This could reflect the greater diversity of plant inputs in the organic systems, in particular the incorporation of relatively labile crop residues and fertility building crops.

The CLPP analysis also demonstrated that both the enzyme and Biolog profiles in Deep Slade soil were distinct from those in soils under organic management, indicating that although there were few differences in microbial community functioning between the different organic treatments, there were consistent differences between the organic and conventional treatments. Such differences in community functioning can reflect the amounts and quality of organic matter inputs, and cultivation practices (Bending et al., 2002).

Fig 2 CVA ordination plot of community level physiological profile for Biolog analysis
(Bars represent 95 % confidence limits)

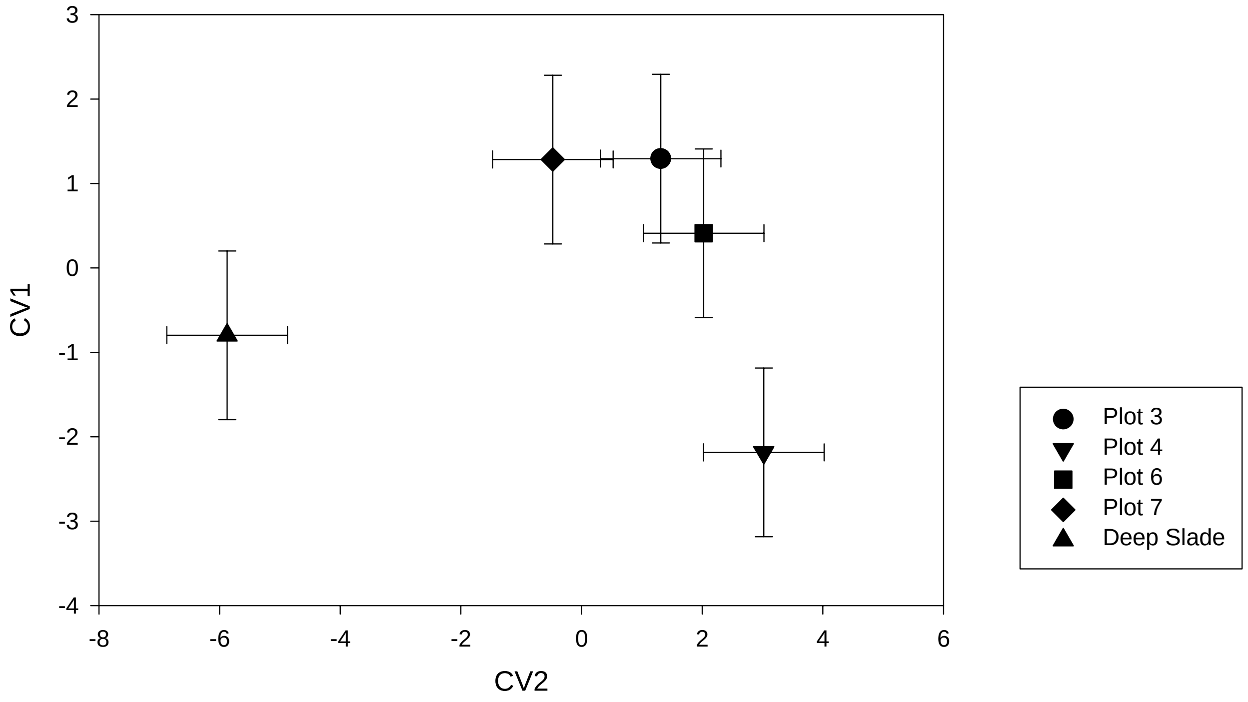
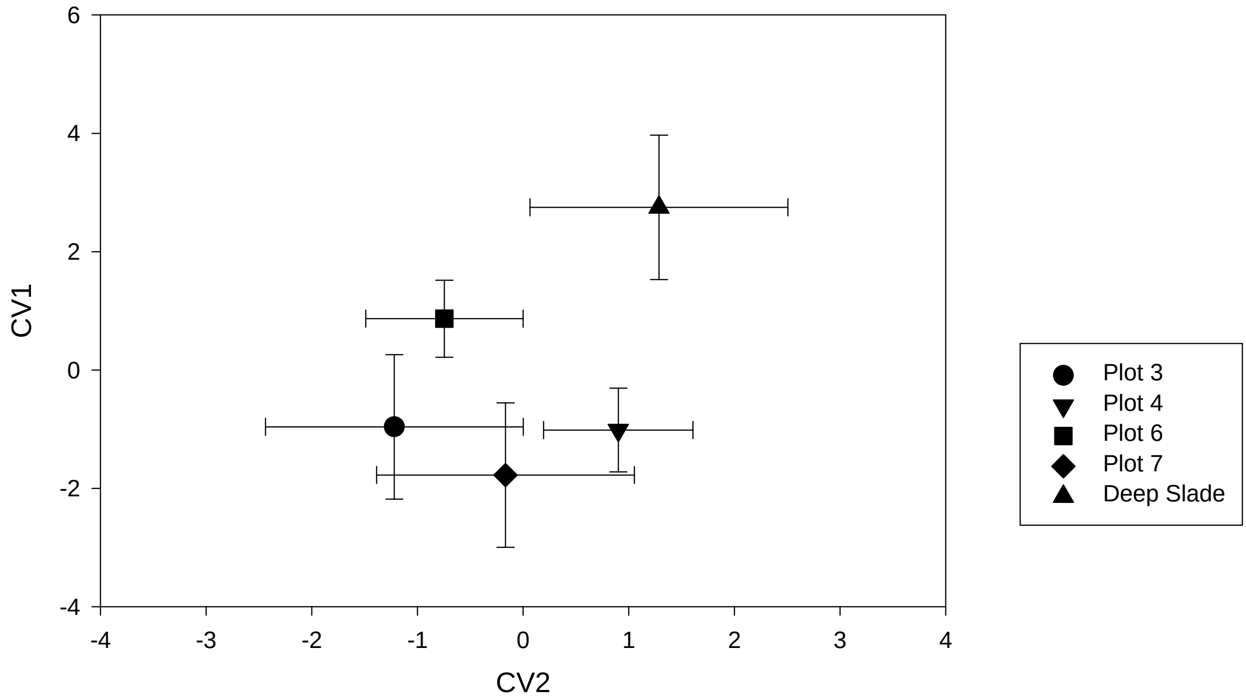


Fig 3 CVA ordination plot of community level physiological profile for enzyme analysis
(Bars represent 95 % confidence limits)



c. Physical quality

There have been long standing problems with soil structure in Hunts Mill field dating back to before its time of conversion. Although a number of new cultivation techniques have been adopted, including shallow ploughing and regular subsoiling and topsoiling, it is still a challenging site.

Management had significant effects on both bulk density and infiltration rate (Table 6). The highest bulk density was found in Area 4, and the lowest in area 6. Infiltration rate was lowest in area 6 and highest in area 7. Whilst these parameters may be related to long term management effects they will be influenced to a high degree by cropping at the time of sampling and conditions immediately before it – area 6 had been freshly cultivated but area 7 had not been ploughed for over five years.

Table 6

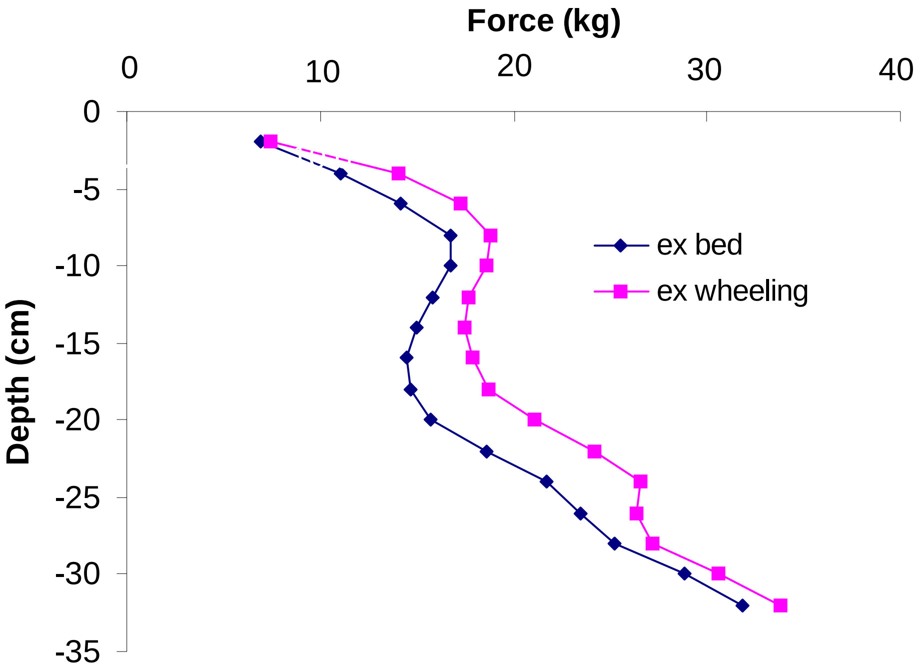
Physical quality parameters in organic and conventional areas

Area	Bulk density (g cm^{3})	Log Infiltration rate (mm min^{-1})
4	1.71	-0.19
6	1.53	-1.54
3	1.68	-0.67
7	1.59	-0.06
Deep Slade	1.64	-1.01
LSD (P=0.05)	0.04	0.78
Significance of main effects (***, P<0.001; **, P<0.01; *, P<0.05)	***	**

Measurements of aggregate stability were not made in all areas but they showed significantly greater (P=0.02) MWD values in soil from Area 3 (1.10) than from Deep Slade (0.84). Higher numbers indicate better soil quality. Area 4 provided an opportunity to investigate the effects of recent soil management on soil quality since it was uniformly cropped with spring barley at the time of sampling but this followed vegetables (onions, carrots and leeks) grown on beds in the previous year. The barley clearly showed lines of poorer, yellowed growth where the wheelings of the previous crop had been. Measurements made with a penetrometer demonstrated that the soil in these areas was indeed more compacted (Fig 3). The detrimental effects of tractor wheelings have been well documented and soil compaction has been identified as a constraint to production on a number of the reference farms within project OF0126T. The problems are most significant in vegetable production systems when the crop may be mechanically weeded throughout the summer and often has to be harvested in wet conditions to satisfy market demands. However, regular mowing of stockless grass/clover leys may also give rise to problems.

Figure 3.

Soil hardness in area 4. Values are the means of 120 penetrations.



4.2 OBJECTIVE 02

Determine changes to key indicators of soil quality during the early years after conversion to organic vegetable production

For a number of parameters, statistical variance was not homogenous across years, so that direct comparison of 1996 and 2001 data was not valid. However, it was possible to compare 1996 and 2001 data for total organic C and N, and soil carbohydrates in areas 4 and 6 (Table 7). Total OM C and N increased over the 5-year period in both areas. In the case of C, there was an increase of 15 and 18 % in areas 4 and 6 respectively. For N, amounts increased by 10 and 12 % in areas 4 and 6 respectively. There were also large changes to soil carbohydrates, with increases of 21 and 24 % respectively in areas 4 and 6.

These results indicate that organic management had beneficial effects on organic matter C and N and carbohydrates, with implications for soil structure and long-term supply of nutrients. However, comparison of changes to control areas under conventional management over the 5-year period was not possible. These results should be treated with caution, since comparison of organic matter C and N, and carbohydrates in the 2001 analysis revealed no significant differences in the organic, relative to conventional areas (Table 1).

Table 7

Changes to soil quality parameters over the period 1996-2001 in areas 4 and 6

	Total soil Organic-C (μg g^{-1} soil)	Total soil Organic-N (μg g^{-1} soil)	WS-Carb (μg g^{-1} soil)
Area 4 1996	857	583	4.2
Area 4 2001	987	643	5.1
Area 6 1996	772	499	3.8
Area 6 2001	912	560	4.7
LSD (P=0.05)	67.5	55.4	0.4
Significance of main effects (***, P<0.001; **, P<0.01; *, P<0.05)	***	*	***

5. CONCLUSIONS

- There were differences between the organic and conventional areas in key chemical and biological soil quality parameters.
- Contrasting organic management regimes had different effects on soil quality. While there were indications that organic vegetable rotations had no effect on soil chemical quality relative to conventional arable management, an organic arable rotation appeared to improve soil chemical quality.
- Relative to organic vegetable and conventional arable management, an organic arable management rotation enhanced amounts of light fraction organic matter and labile N, with beneficial implications for long term nutrient retention and soil organic matter development.
- There was evidence that organic management changed microbial community structure and functioning. Relative to conventional management, areas under organic management had greatly increased inoculum of arbuscular mycorrhizal fungi, a larger proportion of 'active' relative to 'resting' biomass within the microbiota, increased metabolic diversity and a distinct microbial community level physiological profile.
- The clearest effect on soil structure was with regard to the detrimental effects of vegetable production rather than to any benefit associated with organic management. However, it is likely that increased levels of organic matter may result in a soil better able to cope with damaging operations.
- There were differences in the susceptibility of the chemical and biological quality parameters to change. Different susceptibilities of quality parameters to change provides possibilities to use selected parameters as early indicators of the effects of management on soil quality.
- The results highlight the need to consider a wide variety of analyses when investigating soil quality, since limited data sets focussing on traditional measures of soil quality (e.g. total SOM and biomass-N) are too rudimentary to pick up changes to soil functional attributes, and could lead to unsound conclusions regarding the effects of management on soil quality. For example, in our study, analysis of biomass-N alone would have suggested that there were limited differences between the microbial community of conventional and organic areas. However, further analysis revealed that there were major differences in community diversity, structure and functioning in organic and conventional areas.

- The evidence indicates that productivity of newly converted organic vegetable systems could be limited by low inoculum and diversity of arbuscular mycorrhizal fungi inherited following conventional management.

6. FUTURE WORK

The project has highlighted a number of key areas in which further research is needed to understand 'soil quality' in organic and other agricultural systems.

- Further statistical analysis of this comprehensive data set would enable the development of a soil quality index suitable for rating the organic and conventional areas. This could be based on a soil quality index that has been developed to assess the quality of orchard soil in the US (Glover et al., 2000; Reganold et al., 2001). Such an index would be a valuable tool to quantify and compare soil quality in diverse agricultural management systems in the UK, and to measure the effects of management on soil quality.
- It would be valuable to build on the current data set with continued monitoring of the Wellesbourne conversion as it becomes a mature organic system, so that rates of change of the quality parameters can be determined.
- Further work is needed to determine the applicability of the conclusions of our study to other soil types and organic management regimes. This could be done using the existing organic reference farms which are being monitored by HDRA as part of project OF0191. Additionally, further experimental work is required to determine the relative contribution and interactions of different organic and conventional management practices on soil quality. This information would be valuable for formulating management regimes for the improvement of defined soil quality parameters in agricultural soil. This could include countering the apparent limited impacts of organic vegetable production on soil chemical quality.
- The results indicate that there was a fundamental shift in the structure and functioning of the soil microbial community on conversion to organic management. Research is needed to quantify and characterise these changes, and determine the long term implications for soil quality (e.g. amounts and functionality of OM generated and stabilised). Molecular methodologies (e.g. 16/18S rDNA-DGGE) to characterise bacterial and fungal populations would be valuable tools in such studies, providing information on 'indicator' groups within the microbiota which change with management.
- The study has demonstrated that AMF have a functional role in organic systems, but that this role is limited in conventional systems. Conventional agricultural management results in drastic changes to AMF diversity (Helgason et al., 1998). Further, AMF fungi vary widely in their functional attributes, and the degree to which they can contribute to plant growth and disease suppression (van der Heijden et al., 1998). Work is needed to quantify the benefits of AMF in organic systems, and to assess the time required, and management necessary, for AMF diversity to reach optimum levels following conversion. This will facilitate the best use of AMF communities in organic systems.
- More work is needed on the effect of management on soil structure, particularly with regard to the potential benefits of minimising cultivations. Such effects would need to be evaluated in conjunction with other agronomic implications

7. ACTION RESULTING FROM THE RESEARCH

(IP, Technology Transfer, Publications)

- The project was highlighted in an interactive display on 'soil quality' at the HDRA ‘Farming for Fertility’ Open day, HRI-Wellesbourne, 26 September 2001.
- An outline of the main project findings will appear in the HRI annual report for 2002;

Bending, G.D. (2002) Soil microbial communities under organic and conventional management. Horticulture Research International Report for 2002 (in press).

- A poster presentation of some key project findings was made at the Colloquium of Organic Researchers;

Rayns, F.W., Jackson, L.R., Bending, G.D., Turner, M.K., Wood, M. & Marx, M.C. (2002) Effect of organic management on soil quality indicators. Proceedings of the UK Organic Researchers Conference, Aberystwyth, 26-28 March 2002.

- A paper outlining the results is in preparation;

Bending, G.D., Turner, M.K., Raynes, R., and Wood, M. Effects of organic management practices on chemical, biological and physical soil quality after 5 years (For submission to *Soil Biology and Biochemistry*)

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