Journal of Agricultural Science (2008), **146**, 677–687. © 2008 *Cambridge University Press*
doi:10.1017/S0021859608008071 *Printed in the United Kingdom*

A short-term comparison of organic *v.* conventional agriculture in a silty loam soil using two organic amendments

J. F. HERENCIA[1], J. C. RUIZ[1], S. MELERO[1], P. A. GARCIA GALAVÍS[1] AND C. MAQUEDA[2]*

[1] *Centro de Investigación y Formación Agraria 'Las Torres-Tomejil' (CIFA), P.C. 41200, Alcalá del Río (Sevilla), Spain*
[2] *Instituto de Recursos Naturales y Agrobiología (CSIC), Apdo 1052, P.C. 41080, Sevilla, Spain*

(*Revised MS received 20 June 2008; First published online 30 September 2008*)

SUMMARY

The transition from conventional to organic farming is accompanied by changes in soil chemical properties and processes that could affect soil fertility. The organic system is very complex and the present work carries out a short-term comparison of the effects of organic and conventional agriculture on the chemical properties of a silty loam soil (Xerofluvent) located in the Guadalquivir River Valley, Seville, Spain, through a succession of five crop cycles over a 3-year period. Crop rotation and varieties were compared in a conventional system using inorganic fertilizer and two organic systems using either plant compost or manure. At the end of the study, organic farming management resulted in higher soil organic carbon (OC), N and available P, K, Fe and Zn. The available Mn and especially Cu values did not show significant differences. In general, treatment with manure resulted in more rapid increases in soil nutrient values than did plant compost, which had an effect on several crop cycles later. The present study demonstrated that the use of organic composts results in an increase in OC and the storage of nutrients, which can provide long-term fertility benefits. Nevertheless, at least 2–3 years of organic management are necessary, depending on compost characteristics, to observe significant differences. Average crop yields were 23 % lower in organic crops. Nevertheless, only two crops showed statistically significant differences.

INTRODUCTION

Environmental, economic and social concerns have increased the need for an alternative to conventional agriculture (Pimentel *et al.* 2005). Although reduced cultivation is becoming more popular, conventional farming often involves repeated tillage and reliance on repeated applications of fertilizers and pesticides. These practices can damage the soil structure, leading to soil erosion, organic matter (OM) loss and reduced soil fertility (Bullock 1997; Hollinger *et al.* 1998). In addition to the effects of management, climatic conditions in the Mediterranean area also increase OM oxidation (Garcia *et al.* 2000). Strategies for preserving and increasing soil OM are needed to maintain soil fertility (De Costa & Sangakkara 2006).

Organic farming is an alternative to conventional farming and has been adopted in a wide range of climates and soil types (Altieri 1995). Organic production systems are increasing in the European Union, with an annual growth rate of 0·26 (MAPA 2006). The area of Spain dedicated to organic management increased from 4235 ha in 1991 to 733 182 ha in 2004 (MAPA 2006).

The transition from conventional to organic farming is accompanied by changes in an array of soil chemical properties and processes that affect soil fertility (Clark *et al.* 1998). These changes affect nutrient availability to crops either directly, by contributing to nutrient pools, or indirectly, by influencing the chemical and physical environment of the soil (Bulluck *et al.* 2002). The increase in OM during the

* To whom all correspondence should be addressed. Email: juanf.herencia@juntadeandalucia.es

transition period occurs slowly, generally after several years (Drinkwater *et al.* 1995; Werner 1997), and can have a sizeable effect on long-term productivity (Tiessen *et al.* 1994). The amount of OM accumulated in the soil and the nutrient content depends mainly on OM decomposition rate, the amendment type applied and farm management (Haynes & Naidu 1998; Stockdale *et al.* 2001).

Soil OM is an important source of nutrients for plant growth that needs to be maintained for agricultural sustainability (Whitehead *et al.* 2003). In recent years, the effect of organic amendments on soil properties has received renewed attention. Studies that compare organic and conventional farming practices in soils show higher OM and macronutrient content for organic farming (Clark *et al.* 1998; Edmeades 2003; Herencia *et al.* 2007). However, some studies indicate different trends (Gosling & Shepherd 2005). Although several studies have demonstrated the influence of organic amendment on the availability of micronutrients (Madrid 1999; Kabata-Pendias 2000; Rodríguez-Rubio *et al.* 2003), very little information exists on organic agriculture, especially with respect to the use of plant residue compost (Andrews *et al.* 2002; Herencia *et al.* 2008).

As indicated previously, the incidence of organic farming has increased. This fact, together with the limitations in the amendments that can be applied in organic farming and the limited availability of organic livestock farms, could create a short-term organic fertilizer shortage. In addition, manure can represent a substantial cost to organic producers (Archer *et al.* 2007). For these reasons, plant compost is considered in the present work to be a very promising organic amendment, because farmers could be self-sufficient and produce compost on their own farms. Many studies have shown the influence of different organic amendments on soil fertility, but there is very little information available about the application of compost from plant residues. Both qualitative and quantitative differences can be found in the flow and processing of nutrients from the use of manure and plant compost and the elimination of synthetic fertilizers and pesticides.

Some studies have found that organically managed systems are less productive than conventional systems (Mäder *et al.* 2002), while others have indicated that they can be as productive as conventional ones (Pimentel *et al.* 2005; Posner *et al.* 2008). During the transition from conventional systems to organic systems, crop yield frequently falls, followed by a recovery in production (Altieri 1995). Archer *et al.* (2007) indicated that organic systems could be profitable.

Comparisons of organic with conventional systems are complex and difficult (Watson *et al.* 2008). The literature consists of studies with differences in soil types, crops, edaphic and climatic conditions, type of amendments and the amounts applied, so it is very difficult to compare one study with another. The current study attempted to reduce the number of potential factors affecting nutritional values, by using the same cultivar, planting system, soil and climatic conditions. The aim of the present work was to determine the influence of organic *v.* conventional farming on nutrient availability and crop yields in a calcareous silty loam soil during the first years of organic treatment with two different organic amendments (plant and manure composts).

Table 1. *Soil characteristics at the beginning of the experiment* (*n* = *12*)

Parameter	Units	Values ± S.D.
Sand	(g/kg)	440 ± 45
Silt	(g/kg)	296 ± 23
Clay	(g/kg)	264 ± 22
pH (1:2·5)		8·04 ± 0·06
EC (1:2·5)	(dS/m)	0·19 ± 0·04
$CaCO_3$	(g/kg)	249 ± 21
TOC	(g/kg)	7·56 ± 0·4
Kjeldahl-N	(g/kg)	0·88 ± 0·07
Olsen-P	(mg/kg)	19·5 ± 2·1
AAE-K	(mg/kg)	382 ± 32
Fe	(mg/kg)	6·50 ± 0·8
Cu	(mg/kg)	1·60 ± 0·2
Mn	(mg/kg)	12·1 ± 2·0
Zn	(mg/kg)	0·88 ± 0·1

S.D. = standard deviation; EC = electrical conductivity; TOC = total organic carbon, AAE-K = Ammonium acetate extractable K.
Fe, Cu, Mn and Zn are DTPA-extracted.

MATERIALS AND METHODS

Location and management of the systems

The field study was carried out on a silty loam soil classified as a Xerofluvent (Soil Survey Staff 1999). The study site (latitude: 37°8′33″N and longitude: 5°16′4″W) was located in the Guadalquivir River Valley (SW Spain), at the Andalusia Research Centre of Agriculture (CIFA Las Torres-Tomejil) farm in Alcalá del Río (Seville). The textural and chemical characteristics of the soil are shown in Table 1.

Three treatments were tested: one inorganic treatment (C) and two organic treatments (PC) and (MC). Treatment PC utilized plant compost (pruning waste and crop residues) while MC utilized manure compost (from stables and cow barns). A completely randomized experimental design (four replicates per treatment) was conducted in 12 subplots each of 10 × 20 m.

Table 2. *Elemental analysis of plant and manure composts* (*dry weight basis*) *used for each crop during the study*

	Potato			Lettuce			Carrot			Spinach			Tomato		
	PC*	MC*	S.E.D.†	PC	MC	S.E.D.	PC	MC	S.E.D.	PC	MC	S.E.D.	PC	MC	S.E.D.
Moisture (g/kg)	248	420	41·0	217	175	20·1	255	248	13·4	229	271	174·2	280	364	21·7
pH	7·8	7·6	0·12	7·3	7·9	0·11	7·7	7·6	0·08	7·6	7·6	0·09	8·0	8·9	0·23
EC (dS/m)	1·3	6·4	1·03	4·8	4·1	0·23	1·5	5·7	0·91	2·2	5·6	0·83	1·5	11·5	1·97
TOC (g/kg)	148	156	7·7	163	124	10·2	228	183	13·2	135	148	6·5	166	266	21·5
TN (g/kg)	9·6	18·7	1·89	11·2	7·6	0·72	11·1	6·4	1·03	7·6	8·2	0·18	5·7	18·5	2·81
C/N	15·4	8·3	1·58	14·6	16·4	0·81	20·6	28·5	2·26	17·8	18·1	1·01	29·1	14·4	3·78
P (g/kg)	3·2	4·3	0·21	4·9	4·0	0·18	5·2	5·0	0·12	2·7	4·3	0·32	2·3	7·8	1·24
Na (g/kg)	1·1	2·8	0·30	1·6	1·3	0·14	0·9	1·6	0·21	1·1	1·9	0·17	0·9	2·7	0·39
Ca (g/kg)	101	41	15·9	123	39	17·4	113	57	12·4	78·1	81·8	4·94	69·1	93·9	6·82
Mg (g/kg)	4·1	7·5	0·84	2·4	7·1	1·02	7·0	5·5	0·42	6·2	6·2	0·20	6·4	5·8	0·19
K (g/kg)	3·8	11·9	1·72	5·4	6·2	0·38	4·1	5·1	0·28	5·3	8·1	0·62	4·7	18·2	2·87
Fe (g/kg)	8·4	9·9	0·43	8·3	9·1	0·23	8·4	8·7	0·13	8·2	8·6	0·14	7·5	7·3	0·11
Cu (mg/kg)	20·1	42·0	4·67	17·8	40·1	4·81	22·3	29·2	1·81	22·7	29·9	1·92	23·1	40·3	3·92
Mn (mg/kg)	305	304	5·6	221	335	23·9	234	285	14·1	350	443	22·6	338	362	11·3
Zn (mg/kg)	54·5	108·7	11·87	47·1	50·5	2·08	46·4	46·6	2·23	53·1	74·4	5·47	43·2	85·8	9·28

* PC = plant compost; MC = manure compost.
† Data are the mean of three samples (by each crop D.F. = 5).
EC = electrical conductivity; TOC = total organic carbon.

The data reported in the present study include the results of five cropping periods from 2001 to 2003. The following crops were grown: potato (*Solanum tuberosum* (L.) cvar. Spunta; February–June 2001), lettuce (*Lactuca sativa* (L.) cvar. Oreja de Mulo; September–December 2001); carrot (*Daucus carota* (L.) cvar. Nantesa; February–July 2002); spinach (*Spinacia oleracea* (L.) cvar. Gigante de Invierno; October 2002–February 2003); tomatoes (*Lycopersicon lycopersicum* (L.) cvar. Plato de Egipto; May–August 2003).

Both organic treatments were applied by superficial tillage in each crop at (30 t/ha). The characteristics of the two composts are shown in Table 2. The inorganic treatment used normal doses of chemical fertilizers for these crops (Maroto Borrego 1995). The organic system was managed organically (European Economic Community 1991). Weed control in organic treatments was performed by mechanical tillage, whereas it was carried out by herbicides in the inorganic treatment. The plots were separated with a 3 m spontaneous grass strip, mechanically controlled, to minimize cross movement of fertilizers and pesticides. The fertilization and pesticides used in the study are shown in Table 3. The doses of nutrients (N, P and K) applied per hectare to the inorganic and organic plots are shown in Table 4. The soil was mouldboard ploughed to a depth of 200–250 mm after each crop harvest. In general, all crops were irrigated by surface irrigation: the water applied from the first to fifth crops was 320, 80, 240, 40, and 880 mm, respectively. Additionally, the crops received a total rainfall of 214, 296, 170, 458, and 2 mm, respectively.

Sampling and soil analysis

At the beginning of each crop period, before fertilization, soil samples from the upper layer (0–150 mm deep) were taken for analysis. Four soil cores were randomly taken in each plot and bulked to make a composite sample. Soil samples were air-dried, sieved to 2 mm, and stored in plastic containers before analysis.

The organic residues were determined by the methods of MAPA (1994). Soil pH and electrical conductivity were determined using a 1:2·5 soil/water extract. Total N content was determined by Kjeldahl digestion and organic carbon (OC) by potassium dichromate oxidation using the Walkley & Black method, as modified by Jackson (1958). Available P was measured using the Olsen *et al.* (1954) method and available K was measured using extraction with ammonium acetate (MAPA 1994). Particle size distribution was measured by the Boyoucos densimeter (MAPA 1994) and total carbonate content by the manometric method (MAPA 1994). The extractable elements (Cu, Zn, Fe and Mn) were determined using 0·05 M diethylene triamine pentaacetic acid (DTPA) + 0·01 M $CaCl_2$ + 0·1 M triethanolamine, adjusted to pH 7·30 (Lindsay & Norvell 1978).

Table 3. *Crops, fertilization and pesticides applied in the three treatments across the study*

Crop (Cycle)	Treatment*	Fertilization (kg/ha)	Pesticide†
Potato	C‡	218-150-150	I: Chlorpyrifos F: Metalaxyl
(spring 2001)	PC	30 000	F: Equisetumm; Biodux; Bordeaux mixture
	MC	30 000	
Lettuce	C	214-150-150	H: Pendimethalin
(autumn 2001)	PC	30 000	–
	MC	30 000	–
Carrot	C	80-150-150	H:Prometryne
(spring 2002)	PC	30 000	–
	MC	30 000	–
Spinach	C	147-150-150	H: Lenacil
(autumn 2002)	PC	30 000	–
	MC	30 000	–
Tomato	C	300-169-400	I: Tefluthrin. H: Metribuzin
(spring 2003)	PC	30 000	–
	MC	30 000	–

* C = conventional; PC = plant compost; MC = manure compost.
† Pesticides applied: I = insecticide; F = fungicide; H = herbicide.
‡ N-P_2O_5-K_2O.

Table 4. *Total organic carbon, N, P, and K (kg/ha) applied via compost or conventional inorganic fertilizers*

	Plant compost				Manure compost				Conventional		
Crop	TOC*	N	P	K	TOC	N	P	K	N	P	K
Potato	3339	216	72	86	2714	325	75	207	218	65·5	124·5
Lettuce	3829	263	115	127	2913	188	99	153	214	65·5	124·5
Carrot	5096	247	115	89	4128	145	110	115	80	65·5	124·5
Spinach	3123	176	62·5	122	3237	179	94	175	147	65·5	124·5
Tomato	3586	123	49·7	101	5075	353	149	347	300	73·8	332
Total	18 972	1025	414·2	525	18 068	1190	527	997	959	335·5	830

* TOC = total organic carbon.

Concentration of the elements was performed using an inductive coupled plasma atomic emission spectrometer (ICP-OES).

Statistical analysis

The results were analysed by analysis of variance (ANOVA), with treatments as the independent variable. All statistical analyses were carried out with the program SPSS 11.0 for Windows. All values are expressed as mean values. The statistical significance of differences between the different treatments were established using Tukey's test at a significance level of $P<0·05$. Results in the Figures and in Table 1 are expressed as means ± standard deviations.

RESULTS

Prior to starting the experiments, the soil homogeneity of the plots was studied, and the results (Table 1) showed a high uniformity among the soil from the different plots under study. The soil was a silty loam soil with high carbonate content and was classified as Xerofluvent.

Organic carbon

The total OC supplied was 5% higher with PC than with MC (Table 4). From the second crop onwards, the soil samples from the organic treatments contained a higher proportion of OC than did the samples from conventional treatment, but the samples were not statistically different until the beginning of the fourth or fifth crop for MC and PC, respectively (Fig. 1).

Nitrogen

The proportion of N applied with MC was about 15% higher than with PC and the N applied as

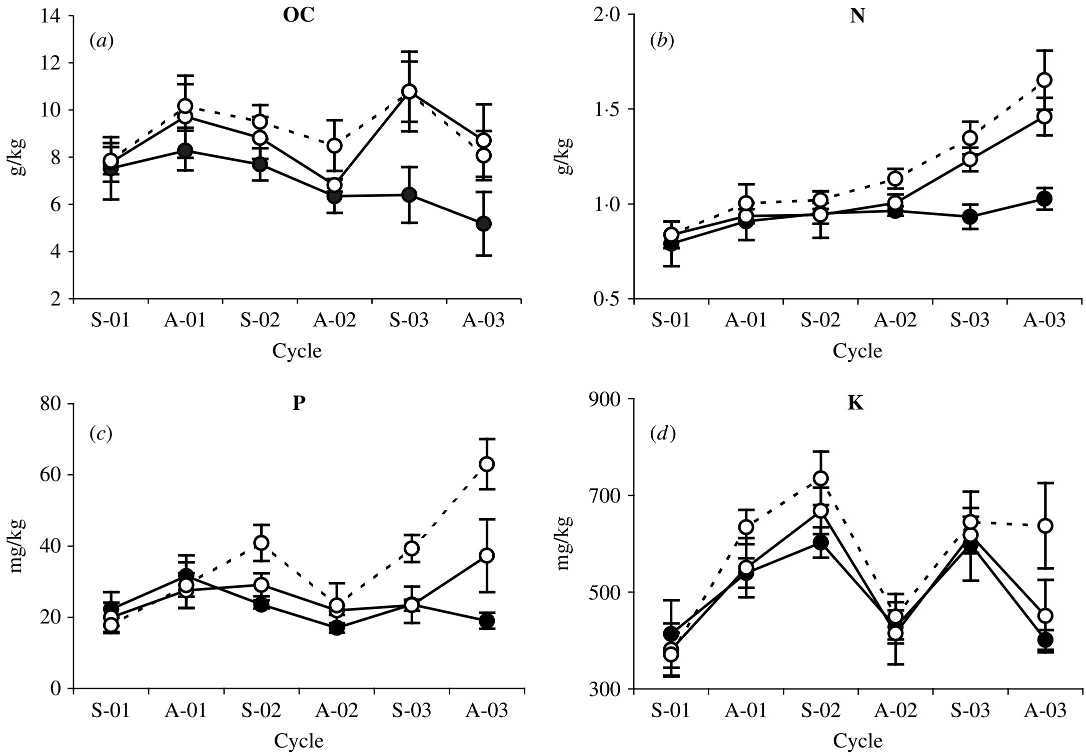

Fig. 1. Values of (*a*) organic carbon (OC), (*b*) Kjeldhal Nitrogen (N), (*c*) available phosphorus (P) and (*d*) available potassium (K) with different management across different cultivation cycles ranging from spring (S) 2001 through autumn (A) 2003. Conventional management plots (—●—); organic management plots fertilized with plant compost (—○—) or manure compost (– –○– –). Error bars indicate standard deviations of means.

mineral fertilizer was about 20 % lower than with the manure (Table 4). Soil nitrogen followed a similar pattern as OC. Soil nitrogen was significantly higher in samples from organic treatments than in samples from conventional treatment from the beginning of the fourth and fifth crop for MC and PC, respectively (Fig. 1).

Phosphorus

The supply of phosphorus in MC was 21 % higher than in PC, mostly in the last two cycles (Table 4). The content of available phosphorous (P) in the organically managed plots were higher than in conventional plots (Fig. 1), but significant differences were not seen until the beginning and the end of the fifth crop cycle in MC and PC, respectively. At the end of the experiment, the values for amount of available P on organic plots was two to four times higher than on the conventional plots.

Potassium

Available potassium (K) in organically managed plots was generally higher for the MC plots than for the plots using inorganic fertilizer (Fig. 1), but in general the differences were not significant except for MC during autumn 2001, spring 2002 and autumn 2003. The variability affected all treatments in the same manner. It is remarkable that the supply of K was lower with the PC and higher with MC than with C (Table 4); however the availability of this element was equal or higher in the organically managed soil.

Available micronutrients

Copper

The Cu added by MC was higher than that added by PC (Table 5). The available Cu in the soil samples extracted by DTPA (Fig. 2), ranged from 1·0 to 2·3 mg/kg. The content of available Cu in the organic plots was slightly higher than in conventional plots, but the differences were significant only for the autumn 2002 crop (Fig. 2). It is interesting to observe that in the last crops the values were similar among treatments.

Manganese

The available Mn, extracted by DTPA, ranged from 3·5 to 12 mg/kg (Fig. 2). In general, there were no

Table 5. *Micronutrients applied (kg/ha) in plant compost (PC) and manure compost (MC) in each crop*

	Potato		Lettuce		Carrot		Spinach		Tomato			
	PC	MC	PC	MC	PC	MC	PC	MC	PC	MC	TPC*	TMC†
Fe	190	172	195	214	188	197	190	188	163	101	925	872
Cu	0·5	0·7	0·4	0·9	0·5	0·7	0·5	0·7	0·5	0·8	2·4	3·8
Mn	6·9	5·3	5·2	7·9	5·2	6·4	8·1	9·7	7·3	6·9	32·7	36·2
Zn	1·2	1·9	1·1	1·2	1·0	1·1	1·2	1·6	0·9	1·6	5·5	7·4

* TPC = total nutrient applied with plant compost (kg/ha).
† TMC = total nutrient applied with manure compost (kg/ha).

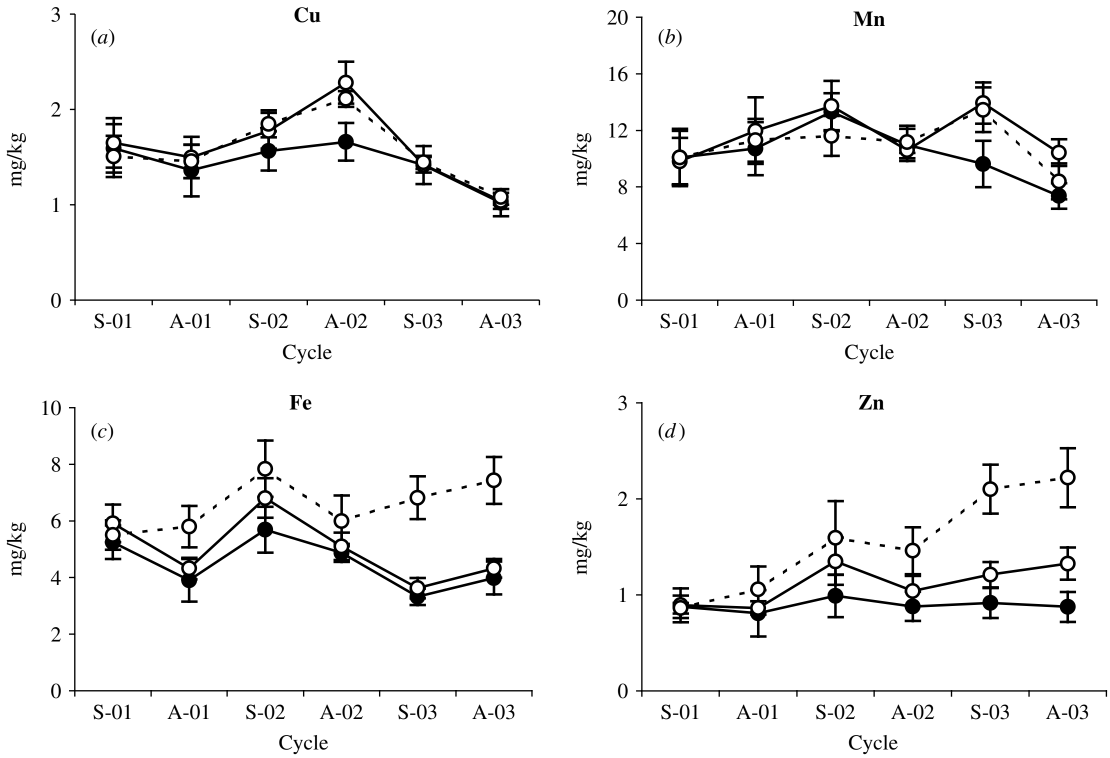

Fig. 2. Values of available (*a*) copper (Cu), (*b*) manganese (Mn), (*c*) iron (Fe) and (*d*) zinc (Zn) with different management across different cultivation cycles ranging from spring (S) 2001 through autumn (A) 2003. Conventional management plots (—●—); organic management plots fertilized with plant compost (—○—) or manure compost (– –○– –). Error bars indicate standard deviations of means.

statistically significant differences among treatments. The organic treatments showed higher values, mainly in the PC plot over the two last cycles.

Iron

The Fe added with both composts was similar (Table 5). The Fe extracted from soil samples ranged from 5·8 to 7·8, 3·6 to 6·8, and 3·3 to 5·7 mg/kg for MC, PC, and C, respectively, and was generally statistically higher in the MC treated plots (Fig. 2). The available Fe for PC was not significantly higher than that for C.

Zinc

The applications to MC had a higher Zn content than either PC or C (Table 5).The available Zn in the organically managed plots was higher, especially in MC, than in the plots with inorganic fertilizer (Fig. 2).

Table 6. *Crop yields in the three treatments across the study*

Crop (Cycle)	Treatment*	Yields (t/ha)	Reference Yields†
Potato	C	21·69	22–28
(spring 2001)	PC	15·65	
	MC	19·34	
S.E.D. (D.F. = 11)		1·17	
Lettuce	C	17·61	36–39
(autumn 2001)	PC	14·56	(17·5‡)
	MC	15·37	
S.E.D. (D.F. = 11)		0·85	
Carrot	C	24·36	37–41
(spring 2002)	PC	24·54	
	MC	17·80	
S.E.D. (D.F. = 11)		2·34	
Spinach	C	34·72	15–18
(autumn 2002)	PC	20·82	
	MC	24·41	
S.E.D. (D.F. = 11)		2·62	
Tomato	C	68·12	64–68
(spring 2003)	PC	46·97	
	MC	43·66	
S.E.D. (D.F. = 11)		3·60	

* C = conventional; PC = plant compost; MC = manure compost.
† Reference values of agronomic yields in the Guadalquivir River Valley (CAP 2000–04).
‡ In 2001, yields were specially lower in the agronomics zone (17·5 t/ha).

The values in the last crop ranged from 0·8 in C to 1·3 and 2·2 mg/kg in PC and MC, respectively (Fig. 2), and the organic plots showed a continuous increase over the study. The differences in Zn content were statistically different starting with the fourth crop in MC and the last crop in PC.

Crop yields

Table 6 shows the crop yields obtained in conventional and organic plots from 2001 to 2003. Across all the experiments, the crop yields were higher in the conventional system than in the two organic systems. However, the differences were significant only for two spinach and tomato yields (Table 6). The potato yield was significantly lower for the PC as compared with the C. The variability for carrot yield among the plots was large and so the differences between treatments were not significantly different. The average crop yield for the organically amended plots was about 23 % lower than for the conventional one.

In agreement with the reference values of agronomic production in the Guadalquivir River Valley (CAP 2000–2004), the crop yields in conventional plots were acceptable, while the organic crops yields were lower than referenced values, except for lettuce and spinach.

DISCUSSION

The soil was initially very uniform in physical and chemical characteristics (Table 1), implying that any crop or soil differences identified during the experiments were due to the treatment and not to soil heterogeneity.

The samples from organic treatments showed higher OC than did the samples from conventional treatment. Andrews *et al.* (2002) reported that the application of 11·2–22·5 t/ha per year of different composts increased OC by 16 % in organic soil as compared with mineral-fertilized soil for the third year. However, after 15 years, Gosling & Shepherd (2005) did not observe differences in OM with different types of fertilization; this is not surprising because the composition of soil, climate condition and the doses and composition of organic amendments were quite different.

The increase in OC of the samples receiving organic treatments was higher than those reported in previous experiments, but the dose of organic amendment applied in the experiment was 30 t/ha and the original OC of the soil was very low (Table 1). Consequently, a small increase represents a high proportion as compared with the original soil. In addition, the continuous application of OM to the soils studied in the present work was very important because the oxidant conditions in the Mediterranean climate rapidly reduce soil OM content (Fernández 1998). It is very important to control the type and amount of OM added to the soil, and fundamentally, it is important to maintain an adequate level of soil OM because a rich and equilibrated soil can supply the nutrients necessary for crops. The higher soil OM content and microbial biomass in the organic plots (Melero *et al.* 2006) may provide important fertility benefits.

Similarly, at the end of the present experiment, soil nitrogen was higher in the organic than in the conventional plots. A strong relationship between the behaviour of N and OM was found for the organic amended soils, in agreement with other studies (Reganold *et al.* 1993; Drinkwater *et al.* 1995). Knudsen *et al.* (2006) indicated that in general, organic arable farms increased their soil N pool through management practices. Other authors have also reported a higher N content in soil amended with organic residues (Scheller & Raupp 2005; Warman 2005).

The percentage increase of soil N was much higher in the present experiment than previously shown in the literature, for the same reason as for OC (low OM of the original soil). The higher values for MC amendment are correlated with a higher content in N.

It should be noted that the N applied with the organic amendment is not immediately available to the plant because it must first be mineralized. The mineralization rate is variable and depends on several factors such as soil properties, type of compost and environmental conditions (Sims 1995) and it is largely mediated by soil micro-organisms (Stockdale & Brookes 2006). Hadas & Portnoy (1994) indicated that mineralization rates of composted manure were only 11–29 mg/g in the first year, because part of the decomposed N is immobilized in OM (Van Delden *et al.* 2003).

The content of available phosphorous (P) in the organically managed plots was higher than in conventional plots for the later crops. Andrews *et al.* (2002) indicated that organic management increased the available P content by 14% in the third to fourth years. That increase was less than that found in the present study mainly due to a lower application of organic amendment. In a 3-year study, Gliessman *et al.* (1996) found significant differences after the second year with annual compost application of 18·5 and 37 t/ha/year.

Most of the P in soil exists in strongly adsorbed or insoluble inorganic forms (Sharpley 2000). In calcareous soils (as in the present study), the majority of P added with mineral fertilizers is mainly precipitated as calcium phosphate. There is considerable evidence in the literature to suggest that the application of organic material to soil may increase P solubility (Sanyal & De Datta 1991). There are various mechanisms to explain the increase of available P in the present study. Composts rich in P were supplied to the organic plots, in order to have an appropriate N source for crops. Consequently, the great availability P in the organic plots, (primarily in MC) was due in part to the use of organic amendments. In addition, manure increases the availability of P in calcareous soils because of the increase in the organic forms (Meek *et al.* 1982). The decomposition of organic amendment resulted in concentrations of organic acids that effectively reduced P adsorption to the soil and increased P availability (Laboski & Lamb 2003). Nevertheless, the application of mineral fertilizer to calcareous soil results in a high retention of P; consequently, the addition of OM is recommended for improved availability of P.

The P uptake by crops from the different treatments (data not shown) is very similar and hence nutrient availability in the later crops is not affected by the crop yields.

The results indicate that improvements in available K come either from K released from organic inputs (mainly observed in MC) or from increased availability of native K following the addition of organic fertilizer (observed in PC) (Table 4). Either way, the higher content of available K is related to the OM content. Most of the simple cationic forms of nutrients present in the soil at any time are in exchangeable forms associated with clay minerals and the organic fraction of the soil; these can be rapidly exchanged with the cations in the soil solution. In temperate soils, the organic fraction of soils normally is responsible for 0·30–0·65 of the total cation exchange capacity (Stockdale *et al.* 2002).

The OM exchange sites do not fix K as do illite-type clay minerals which are dominant in the soil of the present study (data not shown); similar conclusions have been reported by Reganold (1988). Andrews *et al.* (2002) found higher K in organic systems. They attributed this result to high K content of the compost and the increased exchange sites due to OM.

The K uptake by the crops from the two organic treatments (data not shown) is similar; however, the K uptake from conventional plots was higher from the fourth crop cycle and hence could have affected nutrient availability in these plots.

The slightly higher levels of Cu and Mn extracted in the organically managed plots could be due to the formation of Cu and Mn organic complexes with the organic amendments. According to Kabata-Pendias (2000), in high pH soils (e.g in calcareous soils as in the present study) complexation promotes maintenance of Cu and Mn in dissolved forms, increasing the availability in soil. However, this increase is slight because Cu can also form stable complexes with humic acids and peat and the metal becomes immobilized. Rodríguez-Rubio *et al.* (2003) concluded that carbonate was the main component responsible for Cu retention in calcareous soil and availability was enhanced by application of organic wastes. The results in the present study suggest that by yielding soluble complexes, the supply of organic composts could give rise to a more available element after the first crops, but in the last crops the OM primarily promotes the most stable complexes. In soils with low amounts of OM, including normal mineral soils, available Cu increases as OM increases. In a previous experiment at the present location, an increase was found in available Cu with the application of PC over 6 years (Herencia *et al.* 2008). It may therefore be necessary to study more than 3 years in order to show differences in Cu availability with organic fertilization. The role of OM in complexing Mn is important because OM can affect the redox status of soils. The microbial decomposition of added OM in continuous crops creates reducing conditions, which favour Mn solubilization (Mandal & Mitra 1982). Microbial soil activity is known to be largely responsible for the oxidation and reduction of manganese compounds (Bromfield 1978). In the present study, the microbial activity was greater in the organic plots than in the conventional plots (Melero *et al.* 2006).

The higher values of DTPA-extracted Fe and Zn in MC treatment are in agreement with other authors who indicate that OM exerts a significant and direct effect on micronutrient availability (e.g. Wei *et al.* 2006). A highly significant difference between Fe and Zn extracted by DTPA and the OM content of soils has been found by several authors (Katyal & Sharma 1991; Sharma *et al.* 2000). The Fe can be in oxidized or reduced forms. Therefore, due to its acidic and reducing characteristics, an increase in soil OM could increase the more available reduced form of iron-Fe^{2+}. Soil Fe has a strong tendency to form mobile organic complexes and chelates (Kabata-Pendias 2000). These compounds are responsible for the supply of Fe to plant roots, especially in neutral and calcareous soil. The amount of Fe added with either compost (Table 4) was similar; nevertheless the available Fe was higher in the MC treatment (Fig. 2), indicating the importance of the composition of the compost.

The higher amount of available Zn in MC could be due to the higher Zn concentration in MC (Table 5). The addition of exogenous OM containing functional groups with the ability to form complexes promotes Zn availability in soils with a high pH range. In the present results, the highest values of Zn were noted in the organically managed plots as comparison with the conventional ones (Fig. 2). In a previous study conducted over 6 years, it was found that the addition of organic amendments influenced the distribution of Zn in the different fractions by moving Zn from the less soluble fractions to more plant-available forms (Herencia *et al.* 2008).

The average crop yields over the experimental period were lower for the organic treatments than for the conventional treatment. Mäder *et al.* (2002) reported that lower yields for organic systems as compared with conventional systems appear to be caused by lower nitrogen nutrient inputs in the organic systems. According to Pimentel *et al.* (2005), organic systems may create nitrogen shortages over the short term, which temporarily reduce crop yields. It is necessary to note that the N applied in the organic amendment is not immediately available to the plant because it must first be mineralized.

In addition to nitrogen deficiency, the weed competition in organic plots is another problem related to lower yields (Pimentel *et al.* 2005; Taylor *et al.* 2006). The difficulty of weed management in organic crops is seen as a limitation to the wider adoption of organic cropping systems (Beveridge & Naylor 1999). The present authors had problems with the establishment of carrot and spinach crops from seeds because of weed competition.

Vogtmann *et al.* (1993) reported that organic treatments lowered vegetable yields during first 2 years of treatment, but yields did not differ after the third year. Recovery of productivity may be associated with beneficial changes in soil OM and OM-dependent soil properties (De Costa & Sangakkara 2006). In a 3-year study, Gliessman *et al.* (1996) indicated that strawberry production was initially lower in organic systems, but this difference decreased progressively in such a way that, considering the superior prices of the organic fruit, the final result was economically favourable for the organic systems. Taylor *et al.* (2006) reported that organic farming with an appropriate crop rotation system can be agronomically and financially sustainable.

The main conclusions from the present work are that the use of two different composts (plant and manure) in the amounts used in this study increased soil fertility. Organic farming management resulted in higher soil OM, N, and available P and K, but at least 2 or 3 years are necessary to realize significant effects. The use of organic amendments also resulted in higher available Fe and Zn. The MC generally showed greater values. Nevertheless, plant compost is a very interesting organic amendment because it does not depend on external farm inputs. The availability of Mn, and especially Cu, did not increase significantly, possibly due to the great stability of the organic complex formed.

A decline in crop yield was found throughout the present experiment for the plots with organic amendments. This was due to the longer times necessary for the changes in chemical, physical, and biological properties of soil to occur, which enhance nutrient cycling and plant growth. Soil fertility and weed management could be the most important factors limiting yields in the organic systems. More research is needed on the aspect of profitability. If, during the first years of organic soil amendments, an appropriate crop rotation system is applied (i.e. planting legume crops or crops with a low nitrogen demand) and this is coupled with a higher price for organic crops, a system that is both agronomically and financially sustainable can be achieved.

The authors wish to thank Mr J. M. Molina and J. Aragon for assistance in soil determinations and systems management. The financial support of the Spanish Commission of Science and Technology (CICYT) under project no. AGL-2000-0493 and the Government of Andalusia through Projects PAI RMN 166, and exp. 92162/1 are acknowledged.

REFERENCES

Altieri, M. A. (1995). *Agroecology: the Science of Sustainable Agriculture.* London: Intermediate Technology Development Group Publications.

Andrews, S. S., Mitchell, J. P., Mancinelli, R., Karlen, D. L., Hartz, T. K., Horwarth, W. R., Pettygrove, G. S., Scow, K. M. & Munk, D. S. (2002). On-farm assessment of soil quality in California's Central Valley. *Agronomy Journal* **94**, 12–23.

ARCHER, D. W., JARADAT, A. A., JOHNSON, J. M., WEYERS, S. L., GESCH, R. W., FORCELLA, F. & KLUDZE, H. K. (2007). Crop productivity and economics during the transition to alternative cropping systems. *Agronomy Journal* **99**, 1538–1547.

BEVERIDGE, L. E. & NAYLOR, R. E. L. (1999). Options for organic weed control – what farmers do. In *Brighton Crop Protection Conference – Weeds*, vol. 3 (Ed. G. Marshall), pp. 939–944. Farnham, Surrey, UK: British Crop Protection Council

BROMFIELD, S. M. (1978). The effect of manganese-oxidizing bacteria and pH on the availability of manganous ions and manganese oxides to oats in nutrients solutions. *Plant and Soil* **49**, 23–31.

BULLOCK, K. P. (1997). Sustainable development of soils in western Europe. An overview. In *Ponencias Edafología: Conferences in the 50th Commemorative Meeting of the Spanish Soil Science Society, Madrid, Spain*. pp. 109–123. Madrid: Consejo Superior de Investigaciones Científicas.

BULLUCK, L. R., BROSIUS, M., EVANYLO, G. K. & RISTAINO, J. B. (2002). Organic and synthetic amendments influence soil microbial, physical and chemical properties on organic and conventional farms. *Applied Soil Ecology* **19**, 147–160.

CLARK, M. S., HORWATH, W. R., SHENNAN, C. & SCOW, K. M. (1998). Changes in soil chemical properties resulting from organic and low input farming practices. *Agronomy Journal* **90**, 662–671.

CAP (2000–04). *Anuario de Estadísticas Agrarias y Pesqueras de Andalucía*. Junta de Andalucía: Consejería de Agricultura y Pesca.

DE COSTA, W. A. J. M. & SANGAKKARA, U. R. (2006). Agronomic regeneration of soil fertility in tropical Asian smallholder uplands for sustainable food production. *Journal of Agricultural Science, Cambridge* **144**, 111–133.

DRINKWATER, L. E., LETURNEAU, D. K., WORKNEH, F., VAN BRUGGEN, A. H. C. & SHENNAN, C. (1995). Fundamental difference between conventional and organic tomato agroecosystems in California. *Ecological Applications* **5**, 1098–1112.

EDMEADES, D. C. (2003). The long-term effects of manures and fertilisers on soil productivity and quality: a review. *Nutrient Cycling in Agroecosystems* **66**, 165–180.

EUROPEAN ECONOMIC COMMUNITY (1991). *Regulation No. 2092/91 on Organic Production of Agricultural Products and Indications Referring thereto on Agricultural Products and Foodstuffs*. Brussels: Office for the Official Publications of the European Union.

FERNÁNDEZ, M. C. (1998). *Utilización como fertilizante del compost urbano procedente de la planta de compostaje de Villarasa* (*Huelva*). Proyecto Fin de Carrera E.U.I.T.A. Cortijo del Cuarto, Sevilla.

GARCIA, C., HERNÁNDEZ, M. T., PASCUAL, J. A., MORENO, J. L. & ROS, M. (2000). Microbial activity in soils of SE Spain exposed to degradation and desertification processes. Strategies for their rehabilitation. In *Research and Perspectives of Soil Enzymology in Spain* (Eds C. García & M. T. Hernández), pp. 93–143. Madrid: Consejo Superior de Investigaciones Científicas.

GLIESSMAN, S. R., WERNER, M. R., SWEZEY, S. L., CASWELL, E., COCHRAN, J. & ROSADO-MAY, F. (1996). Conversion to organic strawberry management changes ecological processes. *California Agriculture* **50**, 24–31.

GOSLING, P. & SHEPHERD, M. (2005). Long-term changes in soil fertility in organic arable farming systems in England, with particular reference to phosphorus and potassium. *Agriculture, Ecosystems & Environment* **105**, 425–432.

HADAS, A. & PORTNOY, R. (1994). Nitrogen and carbon mineralization rates of composted manures incubated in soil. *Journal of Environmental Quality* **23**, 1184–1189.

HAYNES, R. J. & NAIDU, R. (1998). Influence of lime, fertilizer and manure application on soil organic matter (SOM) content and soil physical conditions: a review. *Nutrient Cycling in Agroecosystems* **51**, 123–137.

HERENCIA, J. F., RUIZ-PORRAS, J. C., MELERO, S., GARCIA-GALAVIS, P. A., MORILLO, E. & MAQUEDA, C. (2007). Comparison between organic and mineral fertilization for soil fertility levels, crop macronutrient concentrations, and yield. *Agronomy Journal* **99**, 973–983.

HERENCIA, J. F., RUIZ-PORRAS, J. C., MORILLO, E., MELERO, S., VILLAVERDE, J. & MAQUEDA, C. (2008). The effect of organic and mineral fertilization on micronutrient availability in soil. *Soil Science* **173**, 69–80.

HOLLINGER, E., BAGINSKA, B. & CORNISH, P. S. (1998). Factors influencing soils and nutrients loss in storm water from a market garden. In *Proceedings of the 9th Australian Agronomy Conference* (Ed. Australian Society), pp. 741–744. Wagga Wagga, Australia: Australian Society of Agronomy.

JACKSON, M. L. (1958). *Soil Chemical Analysis*. London: Prentice Hall.

KABATA-PENDIAS, A. (2000). *Trace Elements in Soils and Plants*, 3rd edn. New York: CRC Press LLC.

KATYAL, J. C. & SHARMA, B. D. (1991). DTPA-extractable and total Zn, Cu, Mn and Fe in Indian soils and their association with some soil properties. *Geoderma* **49**, 165–179.

KNUDSEN, M. T., KRISTENSEN, I. S., BERNTSEN, J., PETERSEN, B. M. & KRISTENSEN, E. S. (2006) Estimated N leaching losses for organic and conventional farming in Denmark. *Journal of Agricultural Science, Cambridge* **144**, 135–149.

LABOSKI, C. A. M. & LAMB, J. A. (2003). Changes in soil test phosphorus concentration after application of manure or fertilizer. *Soil Science Society of America Journal* **67**, 544–554.

LINDSAY, W. L. & NORWELL, W. L. (1978). Development of DTPA soil test for zinc, iron, manganese and copper. *Soil Science Society of America Journal* **42**, 421–428.

MÄDER, P., FLIESSBACH, A., DUBOIS, D., GUNST, L., FRIED, P. & NIGGLI, U. (2002). Soil fertility and biodiversity in organic farming. *Science* **296**, 1694–1697.

MADRID, L. (1999). Metal retention and mobility as influenced by some organic residues added to soils: a case study. In *Fate and Transport of Heavy Metals in the Vadose Zone* (Eds H. M. Selim & I. K. Iskandar), pp. 201–223. Boca Raton, FL: CRC Press.

MANDAL, L. N. & MITRA, R. R. (1982). Transformation of iron and manganese in rice soils under different moisture regimes and organic matter applications. *Plant and Soil* **69**, 45–56.

MAPA (1994). *Métodos Oficiales de Análisis. Tomo III*. Madrid: Ministerio de Agricultura, Pesca y Alimentación.

MAPA (2006). *Estadísticas 2006 de Agricultura Ecológica en España*. Madrid: Ministerio de Agricultura; Pesca y

Alimentación. http://www.mapa.es/alimentación/pags/ecologica/pdf/2006.pdf (verified 11 July 2008)

MAROTO BORREGO, J. V. (1995). *Horticultura Herbácea Especial*. Madrid: Mundi-Prensa.

MEEK, B., GRAHAM, L. & DONOVAN, T. (1982). Long-term effects of manure on soil nitrogen, phosphorus, potassium, sodium, organic matter and water infiltration rate. *Soil Science Society of America Journal* **46**, 1014–1019.

MELERO, S., RUIZ PORRAS, J. C., HERENCIA, J. F. & MADEJON, E. (2006). Chemical and biochemical properties in a silty loam soil under conventional and organic management. *Soil & Tillage Research* **90**, 162–170.

OLSEN, S. R., COLE, C. V., WATANABE, F. S. & DEAN, L. A. (1954). *Estimation of Available Phosphorus in Soils by Extraction with Sodium Bicarbonate*. US Department of Agriculture Circular No. 939. Washington, DC: USDA.

PIMENTEL, D., HEPPERLY, P., HANSON, J., DOUDS, D. & SEIDEL, R. (2005). Environmental, energetic, and economic comparisons of organic and conventional farming systems. *Bioscience* **55**, 573–582.

POSNER, J. L., BALDOCK, J. O. & HEDTCKE, J. L. (2008). Organic and conventional production systems in the Wisconsin integrated cropping systems trials: I. Productivity 1990–2002. *Agronomy Journal* **100**, 253–260.

REGANOLD, J. P. (1988). Comparison of soil properties as influenced by organic and conventional farming systems. *American Journal of Alternative Agriculture* **3**, 144–155.

REGANOLD, J. P., PALMER, A. S., LOCKHART, J. C. & MACGREGOR, A. N. (1993). Soil quality and financial performance of biodynamic and conventional farms in New Zealand. *Science* **260**, 344–349.

RODRÍGUEZ-RUBIO, P., MORILLO, E., MADRID, L., UNDABEYTIA, T. & MAQUEDA, C. (2003). Retention of copper by a calcareous soil and their textural fractions: influence of amendment with two agroindustrial residues. *European Journal of Soil Science* **54**, 401–409.

SANYAL, S. K. & DE DATTA, S. K. (1991). Chemistry of phosphorus transformations in soil. *Advances in Soil Sciences* **16**, 1–120.

SCHELLER, E. & RAUPP, J. (2005). Amino acid and soil organic matter content of topsoil in a long term trial with farmyard manure and mineral fertilizer. *Biological Agriculture & Horticulture* **22**, 379–397.

SHARMA, B. D., MUKHOPADHYAY, S. S., SIDHU, P. S. & KATYAL, J. C. (2000). Pedospheric attributes in distribution of total and DTPA-extractable Zn, Cu, Mn and Fe in Indo-Gangetic plains. *Geoderma* **96**, 131–151.

SHARPLEY, A. N. (2000). Bioavailable phosphorus in soil. In *Methods for Phosphorus Analysis for Soils, Sediments, Residuals and Waters* (Ed. G. M. Pierzynski), pp. 38–43. Southern Cooperative Series Bulletin No. 396. Raleigh, NC: North Carolina State University.

SIMS, J. T. (1995). Organic wastes as alternative nitrogen sources. In *Nitrogen Fertilization in the Environment* (Ed. P. E. Bacon), pp. 487–490. New York: CRC Press.

SOIL SURVEY STAFF (1999). *A Basic System of Soil Classification for Making and Interpreting Soil Survey*. Agriculture Handbook 436. Washington, DC: US Government Printing Office.

STOCKDALE, E. A. & BROOKES, P. C. (2006). Detection and quantification of the soil microbial biomass – impacts on the management of agricultural soils. *Journal of Agricultural Science, Cambridge* **144**, 285–302.

STOCKDALE, E. A., LAMPKIN, N. H., HOVI, M., KEATINGE, R., LENNARTSSON, E. K. M., MACDONALD, D. W., PADEL, S., TATTERSALL, F. H., WOLFE, M. S. & WATSON, C. A. (2001). Agronomic and environmental implications of organic farming systems. *Advances in Agronomy* **70**, 261–327.

STOCKDALE, E. A., SHEPHERD, M. A., FORTUNE, S. & CUTTLE, S. P. (2002). Soil fertility in organic farming systems – fundamentally different? *Soil Use and Management* **18**, 301–308.

TAYLOR, B. R., YOUNIE, D., MATHESON, S., COUTTS, M., MAYER, C., WATSON, C. A. & WALKER, R. L. (2006). Output and sustainability of organic ley/arable crop rotations at two sites in northern Scotland. *Journal of Agricultural Science, Cambridge* **144**, 435–447.

TIESSEN, H., CUEVAS, E. & CHACON, P. (1994). The role of soil organic matter in sustaining soil Fertility. *Nature* **371**, 783–785.

VAN DELDEN, A., SCHRÖDER, J. J., KROPFF, M. J., GRASHOFF, C. & BOOIJ, R. (2003). Simulated potatoes yield, and crop and soil nitrogen management strategies in the Netherlands. *Agriculture, Ecosystems & Environment* **96**, 77–95.

VOGTMANN, H., MATTHIES, K., KEHRES, B. & MEIER-PLOEGER, A. (1993). Enhanced food quality: effects of compost on the quality of plant foods. *Compost Science & Utilization* **1**, 82–100.

WARMAN, P. R. (2005). Soil fertility, yield and nutrient contents of vegetable crops after 12 years of compost or fertilizer amendments. *Biological Agriculture & Horticulture* **23**, 85–96.

WATSON, C. A., WALKER, R. L. & STOCKDALE, E. A. (2008). Research in organic production systems – past, present and future. *Journal of Agricultural Science, Cambridge* **146**, 1–19.

WEI, X., HAO, M., SHAO, M. & GALE, W. J. (2006). Changes in soil properties and the availability of soil micronutrients after 18 years of cropping and fertilization. *Soil & Tillage Research* **91**, 120–130.

WERNER, M. W. (1997). Soil quality characteristics during conversion to organic orchard management. *Applied Soil Ecology* **5**, 151–167.

WHITEHEAD, C. C., FLEMING, R. H. & JULIAN, R. J. (2003). Skeletal problems associated with selection for increased production. In *Poultry Genetics, Breeding and Biotechnology* (Eds W. M. Muir & S. E. Aggrey), pp. 29–52. Wallingford, UK: CABI Publishing.