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Chemical properties, microbial biomass, and activity differ between soils of organic and conventional horticultural systems under greenhouse and open field management: a case study

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Abstract
Purpose Increasing soil organic matter content is important in improving soil fertility; however, conventional farming practices generally lead to a reduction in such organic material. A comparative study of organic and conventional arable farming systems was conducted in Shanghai, China, to determine the influence of management practices on soil chemistry, microbial activity, and biomass. Soils used in greenhouses and open field cultivation were obtained from plots subjected to organic farming methods for 3 years or from conventionally farmed fields in the same area.
Materials and methods Four combinations of field type and management system were evaluated: (1) organic management in open fields (ORG-OP); (2) conventional management in open fields (CNV-OP); (3) organic management in plastic tunnel fields (ORG-GR); and (4) conventional management in plastic tunnel fields (CNV-GR). Soils obtained at the 0- to 10-cm depth were analyzed using an approach combining traditional soil analysis, microbiological analysis using enzymology and microcalorimetric techniques, and a written survey of management practices among the farmers.
Results and discussion Organic management resulted in significant increases ($p<0.001$) in total organic C and total N, Olsen-P, cation exchange capacity (CEC), soil respiration, microbial biomass C (C_{min}) and N (N_{min}), and alkaline phosphatase and urease activity. Sucrase activity was highest in CNV-GR soil and lowest in ORG-OP and CNV-OP soils. No significant difference was observed between ORG-OP and CNV-OP. The Olsen-P, total organic C, total N, CEC, N_{min}, and sucrase and alkaline phosphatase activities were greater in greenhouse soils than those under open field cultivation, which indicated a higher level of soil management under greenhouse conditions. The microcalorimetry power–time curves for all samples described typical microbial metabolic activity. In soil samples supplemented with glucose and ammonium sulfate, the heat dissipation per cell unit suggested that microorganisms in soils under organic management had more efficient metabolism. In addition, microbial growth in soils under conventional management displayed lower growth rates, lower peak heat, and longer peak heat times, all of which indicated lower activity of soil microorganisms compared with organic management. There was a large positive correlation ($p<0.01$) between the values of P_{max} (the peak value of thermal power), Q_{total} (total heat flux), and k (microbial growth rate constant) and the chemical properties. However, there was a significant negative

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correlation ($p<0.05$) between the value of t_{max} (the time required to reach peak thermal power) and chemical properties other than sucrase activity.
Conclusions Organic production systems significantly improved soil microbial characteristics and increased soil organic C, thus improving soil quality and fertility. Further studies investigating the long-term functional significance of carbon sequestration under organic practices are therefore warranted.

Keywords Conventional farming · Microcalorimetry · Organic farming · Soil enzymes · Soil microbial activity · Sustainability

1 Introduction

Conventional farming has played a significant role in improving food and fiber productivity to meet human consumption demands, but has become excessively dependent on high-yield varieties, intense cropping, increased irrigation, and pesticide and fertilizer use. This in turn places a strain on land resources. Desertification, salinization, soil nutrient depletion, excessive fertilizer use, and biocide residues in food have become prominent issues in China. The problems arising from conventional agricultural management have led to the development and promotion of organic farming practices that address environmental and public health concerns (Melero et al. 2006). Organic farming has been proposed as a valid alternative to conventional practices with regard to the improvement of soil fertility and quality (Stockdale et al. 2006).

Organic farming is gaining worldwide acceptance and has been expanding at an annual rate of 20% in the last decade, accounting for over 32.2 million hectares worldwide (Willer and Lukas 2009). In China, 300,000 ha are currently farmed organically or are in the process of conversion. Significantly, this figure is second in the world. In Eastern China (e.g., Shanghai), organic vegetable production has been intensified over the last few years to meet market demands. Organic vegetable production avoids the application of chemical fertilizers and pesticides, relies on organic input and recycling for nutrient supplies, and emphasizes cropping system designs and biological processes for pest management, as defined by world organic farming regulations. These methods may reduce certain negative effects attributed to conventional farming and provide potential benefits in enhancing soil fertility and quality (Araujo et al. 2008; Mäder et al. 2002).

An understanding of microbial processes is important in the management of farming systems, particularly those that rely on organic materials for nutrient input. Soil organic matter is transformed through the activity of soil microorganisms and enzymes (Melero et al. 2006). Microbial and enzymatic activities are influenced by various factors including physical and chemical conditions, primarily temperature and water content in the case of microorganisms (Griffiths et al. 2006).

Soil microorganisms play an essential role in the environment through their role in cycling mineral compounds and decomposing organic material. Microbial biomass, the living component of soil, functions as a transient nutrient sink responsible for releasing nutrients from organic matter for use by plants. It also acts as a small but labile reservoir of nutrients that contributes to maintaining long-term agricultural sustainability. Microbial biomass, rather than total organic C, has been suggested as a useful and more sensitive measure of change in organic matter status. Changes in microbial biomass C can provide an early indication of short-term trends in total organic C (Bergstrom et al. 1998). Soil respiration (calculated as carbon dioxide evolution or molecular oxygen consumption) is one of the most frequently used parameters for quantifying microbial activity in soil (Anderson and Domsch 1990). Soil enzyme production resulting from microbial metabolism is a sensitive indicator of microbial activity. Extracellular soil enzyme activity is indirectly regulated through increased production and secretion by microbes (Aon and Colaneri 2001) and directly by changes in physicochemical conditions (Sinsabaugh 1994). Long-term studies have demonstrated that soil enzyme activities enable the identification of various soil management practices, such as fertilization by means of animal manure or green manures/crop residues (Martens et al. 1992) and municipal refuse amendment (Perucci 1992), as well as tillage treatments (Gupta and Germida 1988). The response of soil enzyme activities to specific soil practices has been used to compare agricultural systems (combinations of soil practices) such as organic versus conventional farming (Melero et al. 2006). In the present study, we have focused on the activities of three enzymes critical to carbon (C), nitrogen (N), and phosphate (P) cycling in soils: sucrase, urease, and phosphatase. Sucrase is a common soil enzyme important in the degradation of sucrose and is involved in the direct metabolism of soil organic matter as well as playing an important role in the enhancement of soil soluble nutrients; urease is closely linked to N mineralization potential because it is required in converting urea into a form usable by plants. Soil phosphatase plays an important role in the P nutrition of plants by mediating the release of inorganic phosphorus from organically bound phosphorus (Guo et al. 2009).

Microbial activity can provide an indication of soil fertility and quality (Dumontet et al. 2001), highlighting the importance of soil management in enhancing agricultural use (Kushwaha et al. 2001). Radioisotopes, chemical measurements, and microelectrodes are frequently used to determine microbial activity. Information concerning

changes in microbial biomass is valuable in studies of soil microbial activity because it not only provides a measure of slower, less easily detectable changes in soil organic matter but also provides a description of the important pool of labile plant nutrients (Zheng et al. 2007). Due to the limitations of traditional microbiological methods, the application of microcalorimetric techniques to measuring soil microbial activity has drawn increasing attention (Plante et al. 2009). Microcalorimetry is a highly sensitive method used to assess the overall biomass and activity of soil microorganisms. Power–time curves enable the study of biology at the molecular and cellular levels by providing substantial kinetic information such as microbial growth rate constant, heat evolution process, and heat yield of microbial growth (Zheng et al. 2007). Continuous recording of the signal permits repeated measurements of the same sample, a procedure not possible with other methods (Critter et al. 2004). Microcalorimetry enables the study of soil organism activity and behavior in a nonintrusive environment, providing the following characteristics: (1) It allows growth studies in heterogeneous media; (2) the method is performed under isothermal conditions; (3) the results are independent of the type of organism; (4) the method measures the thermal effect of the total activity in the soil; (5) it permits direct measurements without damaging the samples; and (6) enables a continuous record of the experiment (Wadsö 1999; Silvana et al. 2001).

Understanding microbial changes in organic and conventional farming systems may offer guidance in designing optimal farming system strategies, minimizing yield losses, and protecting the environment (Araujo et al. 2008). Knowledge of microbial processes in arable soils requires a substantial number of measurements under different conditions, a large number of samples, and accurate measurement methods (Turner et al. 2001). Considering the above aspects, the objectives of our work were to investigate the influence of organic horticultural production on soil microbial biomass, activity, and soil enzyme activities as compared to conventional production systems in Shanghai, Eastern China. We also determined various soil chemical and biochemical properties and established whether relationships exist between these parameters.

2 Materials and methods

2.1 Location and management

The study was conducted at two sites belonging to Beigang Horticultural Farms in Fengxian, Shanghai, Eastern China, during March 2009 (Fig. 1). The sites were located approximately 2.5 km from the Yangtze River and the East China Sea, and the elevation was 4 m above sea level. The climate is humid subtropical (Cfa according to the Köppen scheme), with 70% of the annual precipitation (1,255 mm) occurring between May and September. The mean annual air temperature is 17.5°C and the average total annual sunshine is 1,778 h. The soil was a fluvisol developing toward a cambisol (according to FAO 1998) containing approximately 9.3% sand, 70.7% silt, and 20% clay to a soil depth of 40 cm.

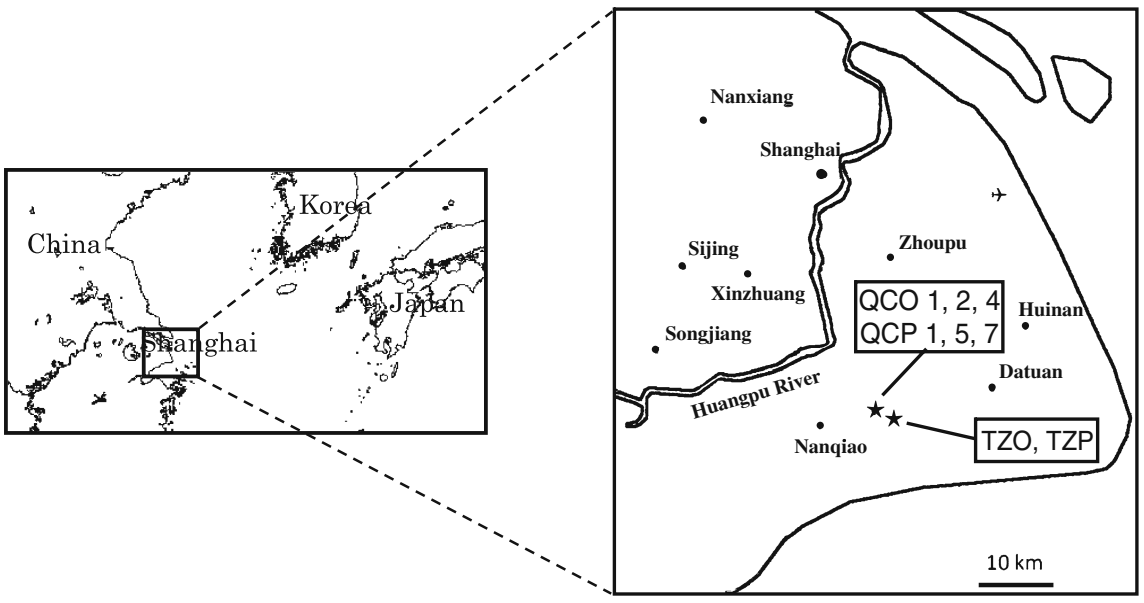

Fig. 1 Location of sampling sites: *QCO* Qingqun Village (open field), *QCP* Qingqun Village (plastic greenhouse, *TZO* Tao-zhai Village (open field), *TZP* Tao-zhai Village (plastic greenhouse). Management systems evaluated were: *1* soil samples from QCO2, QCO1, and QCO4 under ORG-OP, *2* soil samples from TZO under CNV-OP, *3* soil samples from QCP1, QCP5, and QCP7 under ORG-GR, and *4* soil samples from TZP under CNV-GR

Table 1 Characteristics of land management practices investigated in this study

Soil code	Soil	Major crop	Annual input of fertilizers	Farming system	Condition
ORG-GR	QCP1 QCP5	Caraway Cabbage	Pig manure (37.5 $t ha^{-1}$) Organic fertilizer (2.6 $t ha^{-1}$)	Organic farming	Plastic tunnel
	QCP7	Tomato			
CNV-GR	TZP	Cabbage	Complex fertilizer (N–P–K: 14–16–15; 375 $kg\ ha^{-1}$); urea (225 $kg\ ha^{-1}$)	Conventional farming	
ORG-OP	QCO1 QCO2	Soybean Corn	Pig manure (37.5 $t\ ha^{-1}$); Organic fertilizer (2.6 $t\ ha^{-1}$)	Organic farming	Open field
	QCO4	Cowpea			
CNV-OP	TZO	Cabbage	Complex fertilizer (N–P–K: 14–16–15; 375 $kg\ ha^{-1}$); Urea (225 $kg\ ha^{-1}$)	Conventional farming	

The management systems evaluated were (1) soil samples from QCO2, QCO1, QCO4 under organic management in open fields (ORG-OP); (2) soil samples from TZO under conventional management in open fields (CNV-OP); (3) soil samples from QCP1, QCP5, QCP7, under organic management in plastic tunnel fields (ORG-GR); and (2) soil samples from TZP, under conventional management in plastic tunnel fields (CNV-GR). The same as below

The fields QCP1, QCP5, QCP7, QCO2, QCO1, and QCO4 located in Qingcun county (30°56′ N, 121°35′ E) were farmed using an organic approach. All of the fields were near to each other within a continuous area of approximately 4 ha. They had been conventionally cultivated for several years before being converted to organic farming in 2005. The organic horticultural methods used in this study were accredited by the Organic Farming Development Center of China and thus had used no chemical fertilizers, pesticides, or genetically modified organisms for at least 3 years. Reducing conditions were more pronounced in the organic portion of the trial as the irrigation technique of the farm resulted in permanent water table depths between 0.4 and 0.7 m below the soil surface. The fields TZP and TZO located in Taozhai county (30°57′ N, 121°33′ E) were cultivated using a conventional farming approach. These fields had been conventionally cultivated for more than 6 years. The conventional fields were only occasionally irrigated. Farmers completed a questionnaire concerning farm practices for the last 3 years such as (cover) crops, amount and type of animal and green manure and/or fertilizer used, pesticides, disinfectants, mechanical weeding, soil improvements, and plowing depth.

Greenhouse cultivation in plastic tunnels was conducted at QCP1, QCP5, QCP7 (organic management in plastic tunnel fields, ORG-GR), and TZP conventional management in greenhouse fields (CON-GR), and crops were cultivated in open fields at QCO2, QCO1, QCO4 (organic management in open fields, ORG-OP), and TZO conventional management in plastic tunnel fields (CON-OP).

Further details on the major crops grown and fertilizers used in the various fields are summarized in Table 1. The characteristics of the pig manure and organic fertilizer (ProtexPlus®, a commercial product) are described in Table 2.

2.2 Sampling and soil analysis

The soils were sampled during final harvesting to avoid the effects of direct fertilization. Using a stainless steel corer (5.5-cm diameter), soil samples were collected from the surface horizon (0–10 cm) of each field at 10–15 randomly selected positions over an area of 300 m^2 within the vegetable planting rows. The soils were mixed to obtain three composite samples per field. Soil samples were immediately transported in gas-permeable plastic bags

Table 2 Chemical characteristics of pig manure and organic fertilizer (ProtexPlus®) added to organically managed fields

	Composted pig manure	Organic fertilizer (ProtexPlus®)
Moisture ($g\ kg^{-1}$)	186±11	153±9
pH	6.9±0.2	6.2±0.1
EC ($\mu s\ cm^{-1}$)	2317±127	1876±87
Total organic C ($g\ kg^{-1}$)	164.3±9.2	47.2±3.7
Total N ($g\ kg^{-1}$)	9.03±0.23	2.01±0.15
C/N	18.2±1.10	23.5±1.27
Available P ($g\ kg^{-1}$)	4.3±0.2	1.7±0.1
Available K ($g\ kg^{-1}$)	3.8±0.27	2.2±0.16

Table 3 Soil chemical properties (0–10 cm) under different management systems

Management system[a]	pH	EC (μscm^{-1})	Olsen-P (mgkg^{-1})	TOC (gkg^{-1})	Total N (gkg^{-1})	Exchangeable cations (cmolkg^{-1})				CEC (c molkg^{-1})
						Ca^{2+}	Mg^{2+}	K^+	Na^+	
ORG-OP	8.03±0.04b	272.9±22.7c	203.1±13.5b	16.51±0.38b	2.01±0.05b	15.55±0.27b	4.02±0.21b	0.73±0.03c	0.42±0.02b	15.02±0.18b
CNV-OP	8.38±0.05a	265.7±39.8c	31.6±1.21d	7.77±0.04d	1.08±0.02d	15.65±0.55b	3.44±0.08bc	0.39±0.04d	0.20±0.03c	12.66±0.38d
ORG-GR	7.49±0.09c	1971.6±153.7a	330.7±15.0a	25.79±1.01a	3.30±0.14a	17.07±0.32a	6.53±0.31a	1.23±0.07a	2.09±0.07a	20.36±0.36a
CNV-GR	8.15±0.04ab	530.3±22.4b	73.4±7.33c	9.29±0.13c	1.76±0.05c	13.52±0.29c	2.96±0.40c	0.97±0.01b	0.31±0.05bc	14.30±0.34c

Means are followed by the letters indicating significant differences at $p<0.05$ by Duncan's test procedures

EC electrical conductivity, *CEC* cation exchange capacity

[a] The management systems evaluated were listed in Table 1

placed in ice-filled containers. Upon arrival in the laboratory, each sample was thoroughly mixed and sieved through a 2-mm mesh to remove plant matter and earthworms. Half of the fresh samples were stored at 4°C until analysis; the remainder were dried in a thin layer for 2 days at 30°C and stored at room temperature in dark plastic bags.

Soil pH and electrical conductivity (EC) were determined in a 1:2.5 soil/water suspension. Total organic C (TOC) was determined using dichromate oxidation (Nelson and Sommers 1982). Total N was measured using dry combustion in a C/N (Vario MAX C/N, Germany) auto-analyzer. Olsen-P was extracted in a pH 8.5 solution of 0.5 mol dm^{-3} sodium bicarbonate ($NaHCO_3$, Colwell 1963) and determined using ultraviolet spectrophotometry (UV-8500). The exchangeable cation (K^+, Ca^{2+}, Mg^{2+}, and Na^+) concentration and cation exchange capacity (CEC) were measured using titration (Rhoades 1982).

2.3 Laboratory sample preparation

The moisture content of the samples was determined by weighing to 0.1 or 1.0 g using a double-scale balance and heating to constant weight in a natural convection oven at 105°C. The moisture content was obtained from the weight loss of the sample after drying (Lamprecht 1999).

All samples were passed through a 2-mm sieve, thoroughly mixed, placed in hermetically closed polyethylene bags, and stored at 4°C for at least 1 month to ensure calorimetric measurement reproducibility (Liu Xiao-Mei et al. 2009).

2.4 Microcalorimetric measurements

Calorimetric experiments were performed using a thermal activity monitor air multichannel thermal activity microcalorimeter (Thermometric 3114/3236, Sweden; Wadso 2002). Measurements were carried out in 5-cm^3 stainless steel ampoules that had been cleaned and sterilized in an oven at 120°C for 2 h before use. The soil samples were incubated at 28°C for 24 h prior to the experiments. A 1.0-g soil sample at water holding capacity was placed into the ampoule and mixed with 0.4 cm^3 of sterilized solution containing 1.5 mg of glucose and 1.5 mg of ammonium sulfate. The ampoules were hermetically sealed using Teflon discs in order to control evaporation and energy loss. Glucose and ammonium sulfate were provided as C and N sources to stimulate soil microbial activity. The reference ampoule was filled with 1.0 cm^3 of sterilized distilled water. The results obtained using water agreed reasonably well with those obtained using a reference soil (Lisardo et al. 2006).

All experiments were performed in triplicate. The calorimeter and isothermal box were maintained at 300.15 K. The power–time curve was continuously monitored and recorded using a computer.

Table 4 Soil microbial biomass C (C_{mic}), microbial biomass N (N_{mic}), and soil respiration under different management systems at the 0- to 10-cm depth

Management system	C_{mic} (mgkg^{-1})	N_{mic} (mgkg^{-1})	Soil respiration (μgCO$_2$–Cg^{-1}day^{-1})
ORG-OP	566.5±52.7ab	102.5±9.2b	12.64±1.29b
CNV-OP	147.4±1.7c	20.1±1.2d	1.64±0.08c
ORG-GR	729.3±43.8a	196.9±23.5a	16.09±2.11a
CNV-GR	144.3±0.8c	91.9±8.2bc	0.31±0.01d

2.5 Microbiological analysis

Microbial biomass C (C_{mic}) and N (N_{mic}) were measured using a fumigation and extraction technique (Brookes et al. 1985). Briefly, samples of moist soil (20 g oven-dried) were fumigated by exposure to alcohol-free $CHCl_3$ vapor for 24 h in a vacuum desiccator. $CHCl_3$ was removed under vacuum and the samples were extracted with 80 cm^3 of 0.5 mol dm^{-3} K_2SO_4 by shaking for 30 min on a reciprocating shaker (Unimax, 2010; Heidolph Elekrto Gmbh, Kelheim, Germany) at a speed of 250 rpm. The suspension was filtered using Whatman no. 42 filter paper. Equivalent portions of non-fumigated soil were directly extracted. Organic C in the extract was analyzed using an automated TOC analyzer (Phoenix-8000). C_{mic} was calculated by subtracting the amount of organic C extracted from the non-fumigated soil from that extracted from the fumigated soil using a conversion coefficient of 0.45 (Wu et al. 1990). Total N in the extracted sample was analyzed using a FIAStar5000 after the addition of 0.19 mol dm^{-3} $CuSO_4$ and oil of vitriol. N_{mic} was calculated by subtracting the total N extracted from the non-fumigated soil from that extracted from the fumigated soil using a conversion coefficient of 0.45 (Brookes et al. 1985; Jenkinson 1988).

Soil respiration was determined from CO_2 evolution according to Alef (1995). Soil samples (50 g) were placed in 100-cm^3 beakers which were in turn placed in 1-dm^3 glass containers closed with rubber stoppers. The soil was moistened to 45% of the maximum water holding capacity and incubated for 7 days at 25°C. Simultaneously, glass vials holding 20 cm^3 of 1 mol dm^{-3} NaOH to trap the evolved CO_2 were placed in each glass container. On day 7 after incubation, the glass vials were removed and the CO_2 trapped in the NaOH was immediately determined using an automated TOC analyzer (Phoenix-8000).

Enzyme activities were assessed using air-dried soil samples. Sucrase activity was measured using the Hoffmann–Seegerer method (Zhou 1988). In a 100-cm^3 flask, 10-g soil was combined with 10 cm^3 20% sucrose solution in pH 5.5 buffer and shaken vigorously at 37°C for 24 h. The sucrose content was measured using a starch indicator following the addition of 0.2 mol dm^{-3} Na_2SO_4. Reagent blanks were produced for each sample by adding toluene to identical samples prior to reagent addition to inhibit sucrase activity. The difference in sucrose content between the reagent blanks and the samples was used to calculate the sucrase activity [cm^3 (10 g soil)$^{-1}$ (24 h)$^{-1}$]. Alkaline phosphatase activity was determined by measuring *p*-nitrophenol released when the soil was incubated with buffered (pH 7.0) sodium *p*-nitrophenyl phosphate solution and toluene at 37°C for 24 h. The procedure was derived from the method proposed by Tabatabai (1982). The urease activity in the soil was determined using a modification of the method proposed by Kandeler and Gerber (1988). In this procedure, 10 cm^3 of urea solution (10%) and 20 cm^3 of citrate buffer (pH 6.7) were added to 2 g of air-dried soil. The mixture was then incubated for 24 h at 37°C. The ammonium content was determined using a modified indophenol blue reaction. Controls were prepared without substrate to determine the ammonium ion production in the absence of added urea.

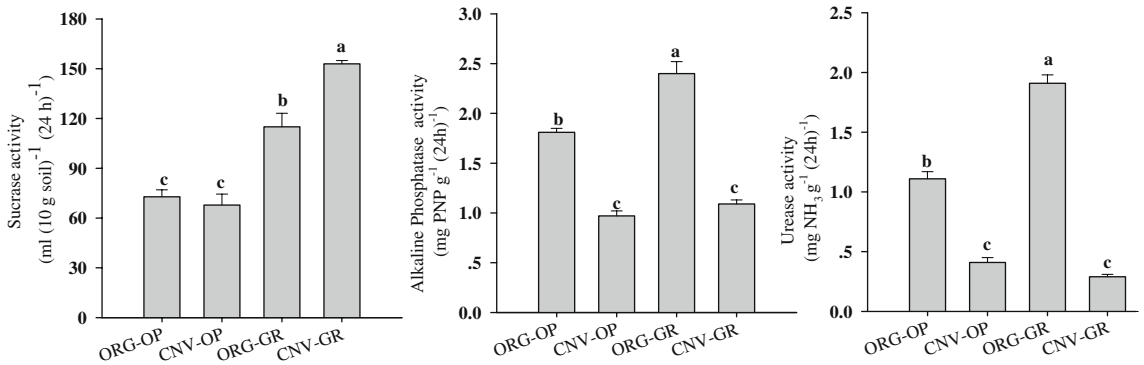

Fig. 2 Soil sucrase, alkaline phosphatase, and urease activities of soils. *Bars* represent standard errors and *letters* indicate significant differences by Duncan's multiple range test at $p < 0.05$

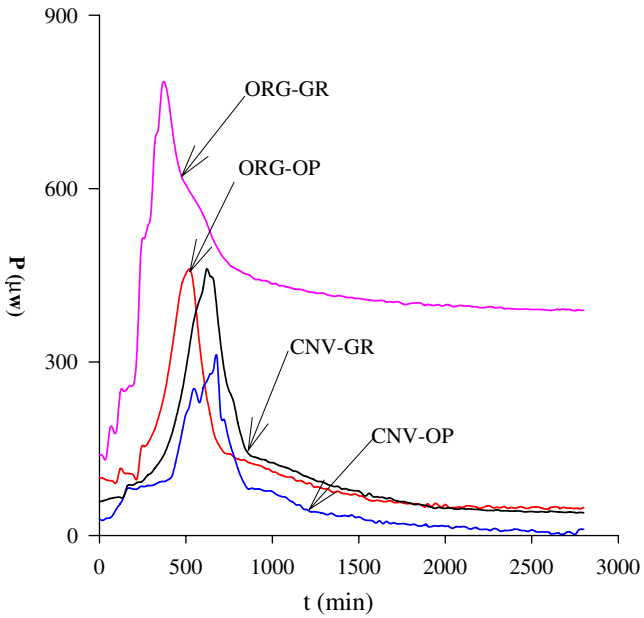

Fig. 3 Power–time curves recorded microcalorimetrically from samples amended with glucose and ammonium sulfate. In these curves, thermal power (µw) is plotted against time (min). Integration of these curves provides values of the total heat evolved by the process. The evolution of peak height (P_{max}) is the power at the maximum of the peak, and peak time (t_{max}) is the time spent to reach the maximum of the peak

2.6 Statistical analyses

All measurements were made in triplicate and reported as mean values with standard error. Statistical analyses were carried out using SPSS 10.5 (SPSS Inc., Chicago, IL, USA). For multiple comparisons, it was assumed that the data were from two independent groups (organic and conventional). Normality within each group was tested using residuals (Anscombe and Tukey 1963) according to Shapiro and Wilk (1965). Homogeneity of variance was assessed using Levene's test on squared residuals (Levene 1960). If one of the assumptions was violated, the data were first transformed to conform to the assumptions before multiple comparison tests were performed. Protected Duncan's tests (Fisher 1935) were used for means comparison between any sampling dates (Einot and Gabriel 1975). For comparisons over time within one season, the MIXED procedure was used. According to Akaike's information criterion, the spatial power correlation structure (which accounts for unequal spacing in time) most often provided the best fit to the data (Moser 2004). Paired *t* tests were employed as an exception on comparable treatments (plastic tunnel fields versus (GR) open fields (OP)) within one sampling date as a cautious approach to determining possible differences between systems. A MIXED procedure split-plot model (Steel and Torrie 1980) was used to evaluate comparable treatments between sites. Linear regression analysis was used to identify relationships between soil biological and microbial parameters.

3 Results

3.1 Soil chemical properties

Farm management practice significantly affected soil chemical properties (Tables 3 and 7). The highest pH (8.38) occurred in conventionally managed plots in open fields, followed by conventional management in plastic tunnel fields (CNV-GR, 8.15), organic management in open fields (8.03), and ORG-GR (7.49, see Table 3). The soil salinity in terms of EC and exchangeable K^+ content was significantly influenced by management practice and generally followed the series ORG-GR>CNV-GR>ORG-OP>CNV-OP ($p<0.001$, see Table 7). Similarly, the highest levels of soil exchangeable Ca (17.07 cmol kg^{-1}), Mg (6.53 cmol kg^{-1}), Na (2.09 cmol kg^{-1}), Olsen-P (330.7 ± 6.53 mg kg^{-1}), cation exchange capacity (20.36 cmol kg^{-1}), total organic C (25.79 mg kg^{-1}), and total N (3.30 mg kg^{-1}) were observed in organically managed plots in plastic

Table 5 Microcalorimetric parameters from power–time curves

Management system[a]	P_{max} (µw)	t_{max} (min)	Q_{total} (Jg^{-1})	$k \times 10^{-3}(min^{-1})$	*R*
ORG-OP	461.70±24.07b	522.08±47.65b	7.62±0.13b	4.98±0.17b	0.9936
CNV-OP	308.68±27.05c	681.08±16.48a	4.20±0.02d	3.51±0.14d	0.9984
ORG-GR	781.48±36.42a	379.64±26.04c	13.70±0.47a	7.57±0.31a	0.9980
CNV-GR	461.07±30.17b	599.25±4.61b	6.13±0.13c	4.17±0.21c	0.9957

Data were obtained from power–time curves with 1.0-g soil samples supplemented with 0.4 mL solution containing 1.5 mg of glucose and 1.5 mg of ammonium sulfate. Values represent mean ± SEM ($n=3$)

P_{max} values of thermal power at the maximum of the peak, t_{max} values of peak time or the time taken to reach the maximum of the peak, Q_{total} values of total heat evolution recorded from soil samples, *k* microbial growth rate constant

[a] The management systems evaluated were listed in Table 1

Table 6 Spearman rank correlation coefficients between microcalorimetric parameters (P_{max}, t_{max}, Q_{total}, and k) and soil chemical and microbial properties (TOC, total N, enzyme activity, C_{mic}, N_{mic}, and soil respiration) in soils under different management systems

Index	TOC	Total N	Alkaline phosphatase	Urease	Sucrase	C_{mic}	N_{mic}	Soil respiration
P_{max}	0.920**	0.931**	0.937**	0.897**	0.506	0.843**	0.931**	0.792**
t_{max}	−0.690**	−0.640**	−0.857**	−0.670*	−0.384	−0.705*	−0.685**	−0.598**
Q_{total}	0.893**	0.820**	0.817**	0.936**	0.323	0.810**	0.837**	0.865**
k	0.939**	0.881**	0.863**	0.955**	0.336	0.860**	0.880**	0.887**

n=12; df=10; r=0.576 (p<0.05); r=0.708 (p<0.01)

*p<0.05; **p < 0.01

tunnel fields and generally followed the order ORG-GR> ORG-OP> CNV-GR>CNV-OP (see Tables 3 and 7).

3.2 Soil respiration and microbial biomass

The highest soil respiration and microbial biomass C (C_{min}) and N (N_{mic}) values occurred in organically managed plots in plastic tunnel fields. Significant differences (p<0.001, see Table 7) between the organic and conventional management systems were observed, indicating higher soil microbial activity and greater supply of available C (Table 4). The soil respiration values in open fields were higher than in plastic tunnel fields under conventional management.

3.3 Soil enzyme activities

Sucrase activity was highest in CNV-GR soil and lowest in ORG-OP and conventional management in open fields (CNV-OP) soils. No significant difference was observed between ORG-OP and CNV-OP soils (Fig. 2). The alkaline phosphatase and urease activities were significantly different and followed the series ORG-GR>ORG-OP>CNV-GR>CNV-OP for alkaline phosphatase activity and ORG-GR>ORG-OP>CNV-OP>CNV-GR for urease activity. No significant differences were observed between CNV-GR and CNV-OP (see Fig. 2 and Table 7).

3.4 Microbial activity measurements using microcalorimetry

The results obtained from calorimetric experiments on three soil samples are contained in Fig. 3 and Table 5. The power–time curves indicate that microbial activity evolved over time. The total heat (Q_{total}, J g^{-1}) and the microbial growth rate constant (k, min^{-1}) were calculated from the curves. The correlation coefficients were all larger than 0.9936, indicating good reproducibility and correlation (see Table 5).

Exponential cell growth occurred during the log phase of the curve. If the heat output power was P_1 at time 1 and P_t at time t, then

$$P_t = P_1 \exp(kt) \text{or} \ln P_t = \ln P_1 + kt.$$

The recorded power–time curves described typical microbial metabolic activity. In ORG-GR and CON-GR, the heat flow increased exponentially after a lag phase, which was followed by stationary and decline phases. However, the thermal activity curves of ORG-OP and CNV-OP were markedly different from the other management systems, exhibiting complex curves with two peaks smaller than the single peak of the other soil samples. These samples also displayed faster initial growth (see Fig. 3).

There were no significant differences in peak heat evolution values P_{max} (μw) between ORG-OP and CNV-

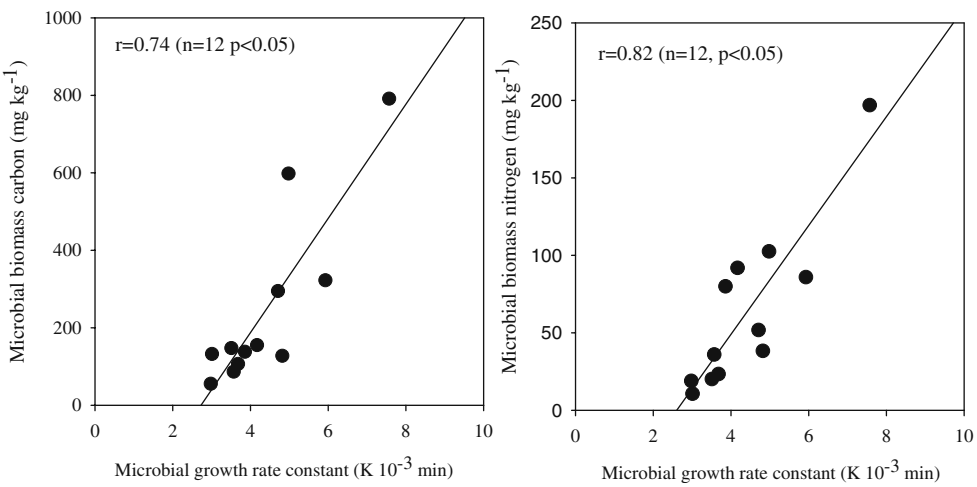

Fig. 4 Correlation between microbial biomass (C_{mic} and N_{mic}) and growth rate (k); in this graph, a higher correlation between k and microbial biomass (C_{mic} and N_{mic}) was observed for the soil samples under different management practices

GR samples, but differences were observed between ORG-GR and CNV-OP (see Table 5). The highest P_{max} value occurred in ORG-GR samples, and the lowest was observed in CNV-GR and ORG-OP samples. The time t_{max} required to reach the peak heat evolution exhibited the opposite trend and generally followed the series ORG-OP> CNV-GR>ORG-OP>ORG-GR (see Table 5 and Fig. 3).

The microbial growth rate constants (k) during the log or exponential phase of microbial activity, Q_{total}, and the total heat released by microorganisms in the soil are presented in Table 5 and Fig. 3. ANOVA revealed that management practice had a significant impact ($p<0.05$) on the values of k and Q_{total} and generally followed the series ORG-GR>ORG-OP>CNV-GR>ORG-OP.

3.5 Correlations between microcalorimetric parameters and soil chemical and microbial properties

Correlation coefficients (with their level of significance) between microcalorimetric parameters and chemical and microbial properties are presented in Table 6 and Fig. 4. There was a strong positive correlation between P_{max}, Q_{total}, and k values ($p<0.01$) and chemical and microbial properties (TOC, total N, alkaline phosphatase and urease activities, C_{mic}, N_{mic}, and soil respiration) other than sucrase activity. However, a significant ($p<0.05$) negative correlation was observed between t_{max} and the chemical and microbial properties (TOC, total N, alkaline phosphatase and urease activities, C_{mic}, N_{mic}, and soil respiration) other than sucrase activity. For all soils, there was a significant positive linear correlation between microbial biomass (C_{mic} and N_{mic}) and k value (see Fig. 4).

4 Discussion

The lower pH values observed in organically farmed soil samples (ORG-OP and ORG-GR) were similar to the findings of Melero et al. (2006). The decrease of soil pH in the organic management system may be due to higher soil microbial activity. The EC was higher when the soil was managed organically (Table 7).

The differences in available P and Ca between the organic (ORG-GR and ORG-OP) and conventional management systems (CNV-GR and CNV-OP) suggest that the addition of organic matter to calcareous soils can increase available P and decrease sparingly soluble phosphates (Braschi et al. 2003). Furthermore, compost addition contributes to the nutrient content of soil (Ca^{2+}, Mg^{2+}), resulting in higher CEC in the organic systems and an increase in soil fertility. A higher TOC content was present in the organic farming samples. Organic management and the use of organic residues have been shown to maintain soil organic matter at higher levels compared with inorganic fertilization (Edmeades 2003). High organic C is important for sustainability because of the influence of organic matter on soil physical, chemical, and biological properties. Soil also benefits from C sequestration due to global environmental changes (Lal 2004).

Organically managed soils exhibited greater biological activity than conventionally managed soils. This agrees with the results of Mäder et al. (2002). The present investigation also provides support to the hypothesis that C_{min} and N_{min} are significantly and rapidly enhanced under organic systems due to their incorporation into organic amendments. C_{min} in organic plots has been reported to be 45–64% higher than in conventional plots with manure amendments (Tu et al. 2006). Microbial biomass (C_{mic} and N_{mic}) is one of the most labile pools of organic matter and serves as an important reservoir of plant nutrients such as N and P (Marumoto et al. 1982). Changes in microbial biomass can therefore have important implications for nutrient bioavailability.

The metabolic efficiency of a microbial community is supposedly reflected in its specific respiration rate (Elsgaard et al. 2010). Higher soil respiration in the organic farming system indicates a higher soil microbial activity caused by permanent and continuous addition of an exogenous source of labile organic matter to the soil and the consequent

Table 7 P values for three-way ANOVA of the effects of organic versus conventional management, plastic field versus open field, and site

	TOC	Total N	CEC	C_{mic}	N_{mic}	Soil respiration	Alkaline phosphatase	Urease	Sucrase
A	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
B	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
C	0.116	0.307	0.085	0.442	0.589	0.217	0.754	0.593	0.445
A×B	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
A×C	0.514	0.658	0.075	0.135	0.014	0.103	0.358	0.601	0.441
B×C	0.012	0.004	0.031	0.127	0.330	0.090	0.051	0.031	0.214
A×B×C	0.317	0.014	0.513	0.306	0.017	0.348	0.059	0.835	0.295

A: organic versus conventional management, *B*: plastic tunnel field versus open field, *C*: site

stimulation of heterotrophic microorganisms (Moeskops et al. 2010). Because diversity of substrate use in organic soils has been found to be higher than in conventional soils (Fliessbach and Mäder 2000), the hypothesis that a more diverse community has higher metabolic efficiency is supported by our data.

A number of long-term studies have suggested that soil enzyme activities are capable of discriminating among soil management practices (García-Ruiz et al. 2009). Despite the relatively low variability of the soil enzyme activities in this investigation, differences between the organic and conventional farming techniques were significant. Urease and alkaline phosphatase activities were higher under organic management. However, this was not always true when paired values for sucrase activity in organic and conventional management were compared (Kremer and Li 2003). Both intracellular and extracellular forms of urease are present in soil. Extracellular urease activity has been associated with clay–organic matter complexes (Kandeler et al. 1999). In addition, because enzymatic action plays a role in nutrient cycling, the correlation between soil chemical properties and enzyme activities (see Table 6) could be the result of improved soil chemical and physical properties after treatment with organic amendments.

An important limitation of this study is that we obtained samples only at the end of the crop growing season and consequently could not identify possible seasonal trends (March 2009). Previous studies examining organic and conventional olive oil farming soils reported that soil enzymes, nematode population, and other physicochemical properties display distinct seasonal variations (Roberto et al. 2009).

Based on our results, microbial biomass, activity, and chemical parameters were affected by the choice of agricultural management system. Organic farming supports soil quality because (1) microorganisms use available resources more economically (for growth rather than maintenance) and (2) higher microbial biomass indicates better conditions within the soil organic matter, which may contribute to nutrient mineralization and temporary storage of potentially leachable elements (Fliessbach and Mäder 2000).

All metabolic processes occurring within living cells produce heat; thus, metabolic processes can be studied by monitoring changes in heat flux with a sufficiently sensitive microcalorimeter. Microcalorimetry can directly measure the biological activity of a living system and provides continuous information concerning heat production, thereby providing considerable qualitative and quantitative information (Critter et al. 2004; Yao et al. 2003). Power–time curves were recorded for samples representing different management practices in which great variability in microbial activity can be observed (see Fig. 3). The calorimetric information provides considerable assistance in understanding features related to the effects of management practices on soil. The calorimetric curves resulting from soil microbial activity can display a single large thermal effect, various minor initial thermal effects, or a rapid increase followed by a slow decrease. The area under the curve (Q_{total}) describing the thermal power as a function of time (s) reveals the intensity and time necessary for the development of microbial activity within a specific soil system. As a result, the area under the heat flux peak is a good indicator of microbial activity.

In general, a positive correlation exists between TOC, microbial biomass and activity, and P_{max}, Q_{total}, and k values (see Table 6 and Fig. 4). Diversity of microorganisms is a key parameter of soil structure, fertility, and microbial metabolism. The metabolic activity of soil microorganisms depends on the quality and nature of the organic matter rather than the quantity (Diaz-Ravina and Carballas 1988). The diversity and structure of soil microbe populations was not investigated in our present study. However, in the future, the relationship between microcalorimetric parameters and diversity should be studied in soils farmed using organic and conventional management practices.

5 Conclusions

Very few studies have examined the impact of farming management on the microbial properties of tropical soils. The extreme differences between organic and conventional management practices were reflected in strong differences in microbial biomass and enzyme activities. Organic residues added to the soil (organic production systems) promoted increased microbial biomass and enzyme activities, which led to improved chemical properties, higher nutrient availability, and enhanced fertility. Further work is clearly required to characterize the significant long-term ecological effects (such as carbon sequestration, microbial structure and functional diversity, productivity, etc.) of organic agricultural systems.

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References

Alef K (1995) Estimation of soil respiration. In: Alef K, Nannipieri P (eds) Methods in soil microbiology and biochemistry. Academic, New York, pp 464–470

Anderson TH, Domsch KH (1990) Application of eco-physiological quotients (qCO2 and qD) on microbial biomasses from soils of different cropping histories. Soil Biol Biochem 22:251–255

Anscombe FJ, Tukey JW (1963) The examination and analysis of residuals. Technometrics 5:141–160

Aon MA, Colaneri AC (2001) Temporal and spatial evolution of enzymatic activities and physico-chemical properties in an agricultural soil. Appl Soil Ecol 18:255–270

Araujo ASF, Santos VB, Monteiro RTR (2008) Responses of soil microbial biomass and activity for practices of organic and conventional farming systems in Piauí state, Brazil. Eur J Soil Biol 44:225–230

Bergstrom DW, Monreal CM, King DJ (1998) Sensitivity of soil enzyme activities to conservation practices. Soil Sci Soc Am J 62:1286

Braschi IC, Giovannini C, Gessa C (2003) Combined effect of water and organic matter on phosphorus availability in calcareous soils. Nutr Cycl Agroecosyst 67:67–74

Brookes PC, Landman A, Pruden G, Jenkinson DS (1985) Chloroform fumigation and the release of soil nitrogen: a rapid direct extraction method to measure microbial biomass nitrogen in soil. Soil Biol Biochem 17:837–842

Colwell JD (1963) The estimation of the phosphorus fertilizer requirements of wheat in southern New South Wales by soil analysis. Aust J Exp Agric Anim Husb 3:7

Critter SAM, Freitas SS, Airoldi C (2004) Comparison of microbial activity in some Brazilian soils by microcalorimetric and respirometric methods. Thermochim Acta 410:35–46

Diaz-Ravina MT, Carballas T (1988) Microbial biomass and metabolic activity in four acid soils. Soil Biol Biochem 20:817–823

Dumontet SA, Casucci C, Perucci P (2001) Effectiveness of microbial indexes in discriminating interactive effects of tillage and crop rotations in a Vertic Ustorthens. Biol Fertil Soils 34:411–416

Edmeades DC (2003) The long-term effects of manures and fertilisers on soil productivity and quality: a review. Nutr Cycl Agroecosyst 66:165–180

Einot I, Gabriel KR (1975) A study of the powers of several methods of multiple comparisons. J Am Stat Assoc 70:574–583

Elsgaard L, Jørgensen MH, Elmholt S (2010) Effects of band-steaming on microbial activity and abundance in organic farming soil. Agri Ecos Envi 137:223–230

Fisher RA (1935) The design of experiments. Oliver & Boyd, Edinburgh

Fliessbach A, Mäder P (2000) Microbial biomass and size-density fractions differ between soils of organic and conventional agricultural systems. Soil Biol Biochem 32:757–768

García-Ruiz R, Ochoa V, Viegla B, Hinojosa MB, Pena-Santiago R, Liebanas G, Linares JC, Carreira JA (2009) Soil enzymes, nematode community and selected physico-chemical properties as soil quality indicators in organic and conventional olive oil farming: influence of seasonality and site features. Appl Soil Ecol 41:305–314

Griffiths RI, Bailey MJ, McNamara NP, Whiteley AS (2006) The functions and components of the Sourhope soil microbiota. Appl Soil Ecol 33:114–126

Guo LJ, Wei Z, Bin LY, Yan SY, Min BX (2009) Effects of long-term continuous cropping system of cotton on soil physical-chemical properties and activities of soil enzyme in oasis in Xinjiang. Agricultural Science in China 42:725–733

Gupta VVSR, Germida JJ (1988) Distribution of microbial biomass and its activity in different soil aggregate size classes as affected by cultivation. Soil Biol Biochem 20:777–786

Jenkinson DS (1988) Determination of microbial biomass carbon and nitrogen in soil. In: Wilson JR (ed) Advances in nitrogen cycling in agricultural ecosystem. CAB International, Wallingford, pp 368–385

Kandeler E, Gerber H (1988) Short-term assay of soil urease activity using colorimetric determination of ammonium. Biol Fertil Soils 6:68–72

Kandeler E, Stemmer M, Klimanek EM (1999) Response of soil microbial biomass, urease and xylanase within particle size fractions to long-term soil management. Soil Biol Biochem 31:261–273

Kremer RJ, Li J (2003) Developing weed-suppressive soils through improved soil quality management. Soil Tillage Res 72:193–202

Kushwaha CP, Tripathi SK, Singh KP (2001) Soil organic matter and water-stable aggregates under different tillage and residue conditions in a tropical dry land agroecosystem. Appl Soil Ecol 16:229–241

Lal R (2004) Soil carbon sequestration impacts on global climate change and food security. Science 304:1623–1627

Lamprecht I (1999) Combustion calorimetry. In: Kemp RB (ed) Handbook of thermal analysis and calorimetry. Elsevier, Amsterdam, pp 175–218

Levene H (1960) Robust tests for equality of variances. In: Olkin I, Ghurye SG, Hoefding W, Madow WG, Mann HB (eds) Contributions to probability and statistics: essays in honor of Harold Hotelling. Stanford University Press, California, pp 278–292

Lisardo Núñez-Regueira José A, Rodríguez-Añón J, Proupín-Castiñeiras O, Núñez-Fernández (2006) Microcalorimetric study of changes in the microbial activity in a humic Cambisol after reforestation with eucalyptus in Galicia (NW Spain). Soil Biol Biochem 38:115–124

Liu Xiao-Mei, Fang Jian, Zhang Jing, Lin Wu-Ying, Fan Ting-Lu, Hu-Yuan F (2009) Effects of long-term fertilization on vertical distribution of microorganisms in wheat field soil. Chinese J Plant Ecol 33:397–404

Mäder P, Fliebbach A, Dubois D, Gunst L, Fried P, Niggli U (2002) Soil fertility and biodiversity in organic farming. Science 296:1694–1697

Martens DA, Johanson JB, Frankenberger WT (1992) Production and persistence of soil enzymes with repeated additions of organic residues. Soil Sci 153:53–61

Marumoto T, Anderson JPE, Domsch KH (1982) Mineralization of nutrients from soil microbial biomass. Soil Biol Biochem 14:469–475

Melero S, Porras JCR, Herencia JF, Madejon E (2006) Chemical and biochemical properties in a silty loam soil under conventional and organic management. Soil Tillage Res 90:162–170

Moeskops B, Sukristiyonubowo D, Buchan S, Sleutel L, Herawaty E, Husen R, Saraswati D, De Neve S (2010) Soil microbial communities and activities under intensive organic and conventional vegetable farming in West Java, Indonesia. Appl Soil Ecol 45:112–120

Moser EB (2004) Repeated measures modelling with proc mixed. Paper 188-29. SAS Users Group International Conference 29 (SUGI 29), May 9–12, 2004, Montréal, Québec, Canada

Nelson DW, Sommers LE (1982) Total carbon, organic carbon, and organic matter. In: Page Miller AL, Keeney RH (eds) Methods of soil analysis. Part 2, 2nd edn. American Society of Agronomy–Soil Science Society of America, Madison, pp 539–580

Perucci P (1992) Enzyme activity and microbial biomass in a field soil amended with municipal refuse. Biol Fertil Soils 14:54–60

Plante AF, Fernández JM, Leifeld J (2009) Application of thermal analysis techniques in soil science. Geoderma 153:1–10

Rhoades JD (1982) Cation exchangeable capacity. In: Pace AL, Miller RH, Keeney DR (eds) Methods of soil analysis: part 2—chemical and microbiological properties, 2nd edn. American Society of Agronomy, Soil Science Society of American, Madison, pp 149–165

Roberto GR, Ochoa V, Vinegla B, Hinojosa BM, Pena-Santiago R, Liebanas G, Linares JC, Carreira JA (2009) Soil enzymes, nematode community and selected physico-chemical properties as soil quality indicators in organic and conventional olive oil

farming: influence of seasonality and site features. Appl Soil Ecol 41:305–314

Shapiro SS, Wilk MB (1965) An analysis of variance test for normality (complete samples). Biometrika 52:591–611

Silvana AMC, Sueli SF, Claudio A (2001) Calorimetry versus respirometry for the monitoring of microbial activity in a tropical soil. Appl Soil Ecol 18:217–227

Sinsabaugh RS (1994) Enzymic analysis of microbial pattern and process. Biol Fertil Soils 17:69–74

Steel RGD, Torrie JH (1980) Principles and procedures of statistics—a biometrical approach, 2nd edn. McGraw-Hill, New York

Stockdale EA, Shepherd MA, Fortune S, Cuttle SP (2006) Soil fertility in organic farming systems—fundamentally different? Soil Use Manage 18:301–308

Tabatabai MA (1982) Soil enzymes. In: Page AL, Miller RH, Keeney DR (eds) Methods of soil analyses, part 2, chemical and microbiological properties, 2nd edn. American Society of Agronomy, Madison, pp 903–947

Tu C, Ristaino JB, Hu S (2006) Soil microbial biomass and activity in organic tomato farming systems: effects of organic inputs and straw mulching. Soil Biol Biochem 38:247–255

Turner BL, Bristow AW, Haygarth PM (2001) Rapid estimation of microbial biomass in grassland soils by ultra-violet absorbance. Soil Biol Biochem 33:913–919

Wadso I (2002) Isothermal microcalorimetry in applied biology. Thermochim Acta 394:305–311

Wadsö I (1999) On the accuracy of results from microcalorimetric measurements on cellular systems. Thermochim Acta 219:1–15

Willer H, Lukas K (2009) The world of organic agriculture: statistics and emerging trends. International Federation of Organic Agriculture Movements, Bonn

Wu J, Joergensen RG, Pommerening B, Chaussod R, Brookes PC (1990) Measurement of soil microbial biomass C by fumigation–extraction—an automated procedure. Soil Biol Biochem 22:1167–1169

Yao J, Liu Y, Liu P, Gao Z, Sun M, Qu S, Yu Z, Shen Y (2003) Microcalorimetric investigation of the effect of manganese(II) on the growth of *Tetrahymena shanghaiensis* S 1 99. Biol Trace Elem Res 92:71–82

Zheng SJ, Zhao B, Yu Z (2007) Influence of agricultural practices on soil microbial activity measured by microcalorimetry. Euro J Soil Biol 43:151–157

Zhou LK (1988) Soil enzymology. Science, Beijing, pp 23–28