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Effect of Organic Farming Practices on Five Orchard Soil Bio-Indicators

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Abstract

The goal of the study was to compare the effects of seven years of conventional and organic fruit production systems on soil biological and mineral properties. The experiment was conducted at Gembloux, Belgium on two adjacent experimental orchards, both planted in 2002 on a flat site with a common cultivation history. The first orchard was managed following organic guidelines and the second one was under conventional management over seven growing seasons. Soil management practices in the organic orchard included additions of composted cattle manure and organic fertilizers and the use of mechanical tillage for weed control. Conventional soil management practices included adding synthetic fertilizers and using herbicides for weed control. Both orchards received different kinds of fungicides. In year 2 (2003), the soil methane oxidation process was measured in order to compare the orchards' soil biological activities. In year 5 (2006), the overall soil microbial activity was assessed by measuring, during five short-term experiments from May to October, the basal respiration (BAS), the substrate-induced respiration (SIR) and the in situ soil CO_2 efflux (CDE). Closed-dynamic-chamber systems were used to analyse the soil CO_2 efflux in situ in the orchards. In year 5 and 7 (2006 and 2008), earthworm abundance was assessed together with chemical soil parameters. No significant difference in the methane oxidation rate was observed between the two orchard management systems in year 2. In year 5, however, the BAS, SIR and CDE values were higher in the organic orchard than in the conventional one on most sampling dates. Total earthworm abundance was strongly improved by organic practices. Soil mineral analysis and soil pH values did not show important differences between the two orchard management systems.

INTRODUCTION

Intensive fruit production in Belgium has increased in recent decades in order to meet market demands, but concerns about the negative effect of these new fruit production practices on environmental factors have also increased. Although studies have found that alternative management practices might improve soil quality compared with conventional management practices, few studies have specifically compared the effects of conventional and organic management on soil quality in orchards (Glover et al., 2000; Mäder et al., 2002). Given the ecological benefits of soil biodiversity (Brussaard et al., 2007), soil organisms are key for estimation of agro-ecosystems sustainability (Cenci and Sena, 2006). It is therefore important to encourage agricultural practices that increase the abundance and diversity of soil organisms by enhancing habitat conditions or resource availability (Altieri, 1999). Sustained agricultural productivity might depend on the selection of management practices that enhance the soil biological activities involved in the fixation of atmospheric N, recycling carbon and nutrients, reducing soil pathogens, decomposing leaf litter, etc. Soil microbial activities lead to the liberation of nutrients available for plants and play an important role in biogeochemical cycling and stabilizing soil structure (Cenci and Sena, 2006; Brussaard et al., 2007). Management techniques such as cover crops and organic fertilizers play an important role in maintaining and enhancing soil productivity and are central to organic practices. These techniques are believed to encourage soil fauna and flora, improve soil formation and structure and create more stable systems. In turn, nutrient and energy cycling is increased and the retentive abilities of the soil for nutrients and water are enhanced, compensating for the non-use of mineral fertilizers (FAO, 2010). The objective of this study was to evaluate the effects of seven years of conventional and organic fruit production systems on several soil biological and chemical properties.

To estimate soil microbial activity, the methods can be divided into those intended for measuring respiration (i) in the field and (ii) in the laboratory (Bloem et al., 2006). Measuring soil respiration in the field is usually accomplished by covering a specific soil surface with a gas-tight chamber. During incubation for a specific time, under ambient climate conditions, changes in gas composition (CO_2 or O_2) are monitored. Field measurements are needed to assess the general microbial activity under natural conditions (Bloem et al., 2006).

Measurement of soil respiration in the laboratory is accomplished by measuring basal respiration (BAS) and substrate-induced respiration (SIR) (ISO 16072, 2002; Bloem et al., 2006; Dilly, 2006). BAS is the steady rate of respiration in soil, which originates from the turnover of organic matter (predominantly native carbon). It can therefore constitute an integrated index of the potential of the soil biota to degrade introduced organic substances under given environmental conditions. The SIR method is based on the principle that, under standardized conditions, the metabolism of glucose added in excess is limited by the amount of active aerobic micro-organisms in the soil. Thus, only glucose-responsive and active organisms are measured. It detects predominantly bacterial biomass, but the method has been calibrated to determine the total soil microbial biomass. BAS and SIR have been used in the laboratory for monitoring soil quality and for ecotoxicological risk assessment of soils contaminated with heavy metals or organic contaminants (Bloem et al., 2006).

Because of their interaction with soil, earthworm populations are greatly affected by agricultural practices, such as soil tillage, crop residues and the use of fertilizers and pesticides (Edwards and Bohlen, 1996; Paoletti et al., 1998; Peres et al., 2006; Holb et al., 2006; Jamar et al., 2009). So, earthworms may be used as bio-indicators of soil management because they are easy to rear and classify and are very sensitive to both chemical and physical soil parameters (Paolletti et al., 1998).

In summary, soil biological properties such as microbial biomass or activity, as well as earthworm abundance or diversity have been reported to be major soil bio-indicators which can be used for soil quality evaluation (Paolletti et al., 1998; Glover et al., 2000; Bloem et al., 2006; Pompili et al., 2006; Peres et al., 2006; Brussaard et al., 2007).

MATERIAL AND METHODS

The experiment was conducted at Gembloux, Belgium on two adjacent 1 ha orchards. One was an organically-managed apple orchard and the other a conventionally-managed cherry orchard. They were both planted in 2002, on dwarfing rootstocks, on a flat site with a common cultivation history.

Soil management practices in the organic orchard included additions of 20 tons ha^{-1} of composted cattle manure in 2002 and 2005, 800 kg ha^{-1} $year^{-1}$ of organic fertilizers (5.5/2.5/2.5), 1000 kg ha^{-1} $year^{-1}$ of hydrated lime for pH management and the use of mechanical tillage for weed control, involving the 'Swiss-Sandwich-System' the first three years. Conventional soil management practices included applying 850 kg ha^{-1} $year^{-1}$ synthetic fertilizers (7/9/16) and using herbicides for weed control (paraquat and diquat at 2 kg ha^{-1} three times per year, plus propyzamide at 1.5 kg ha^{-1} in years 5 and 6).

Disease control included an annual application of copper (3 kg ha^{-1}) and sulphur (40 kg ha^{-1}) in the organic orchard (Jamar et al., 2010). In the conventional orchard, disease control included an annual mean application of copper (10 kg ha^{-1}) and thiram (6 kg ha^{-1}). In addition, in the conventional orchard, tolylfluanide (1.25 kg ha^{-1}) and fenhexamide (0.5 kg ha^{-1}) were applied in year 5 and captan (1.2 kg ha^{-1}) was applied twice during the study. For pest control, full doses of granulosis virus and *Bacillus thuringensis* were applied twice a year in the organic orchard, and cyclofurine (0.015 L ha^{-1}), pyrimicarb (0.345 L ha^{-1}) and teletox (0.24 L ha^{-1}) were applied 4, 4 and 5 times during the study, respectively, in the conventional orchard.

In year 2 (2003), methane oxidation, an important soil ecological process, was measured in order to compare the orchards' soil biological activities (Seghers et al., 2003). Methanotrophs form a unique group of methyllotrophic bacteria that use methane as their sole source of carbon and energy (Hanson and Hanson, 1996). They can be divided into two distinct physiological groups. The 'Type I' methanotrophs are methylotrophs belonging to the gamma-proteobacteria and using the ribulose monophosphate pathway for formaldehyde assimilation. The 'Type II' methanotrophs belong to the alpha-proteobacteria and use the serine pathway for formaldehyde assimilation (Hanson and Hanson, 1996). The methanotrophic community structure was evaluated by group-specific Denaturing Gradient Gel Electrophoresis (DGGE) analysis and based on methods reported by Peacock et al. (2001). The performance of the methane oxidizing bacteria was evaluated using a methane oxidation test described by Seghers et al. (2003). Each orchard system was sampled nine times.

In year 5 (2006), the overall microbial activity was assessed by measuring the BAS through O_2 consumption rate and the SIR through O_2 consumption rate after a glucose addition (ISO 16072, 2002; Bloem et al., 2006). Five assessments were performed during the growing season, from May to October. Each assessment included six replicates per orchard. For each replicate, 25 individual soil samples (0–15 cm) were taken with an auger in the intra-row parts and then mixed to make one composite soil sample that was analysed. Closed-dynamic-chamber systems were used to analyse in situ carbon dioxide efflux (CDE) due to soil respiration in the orchards (Perrin et al., 2004). The spatial variability of the soil efflux was measured over five short periods between May and October, based on a score of 60 points (30 points per orchard).

Earthworm abundance as a useful bio-indicator of agro-ecosystem sustainability was assessed together with chemical soil parameters in 2006 and 2008. All species were grouped according to the ecological classes of Bouché reported also by Paoletti et al. (1998): "Endogées", species inhabiting soil horizons, feeding on soil organic matter and "Aneciques", species living in burrows, feeding on surface litter, or "Epigées", species living on surface litter. Both assessments included four and eight samples per orchard in 2006 and 2008, respectively. Earthworm abundance estimations were performed after rainy periods, using the mustard extract method described by Chan and Munro (2001).

Analysis of variance (ANOVA) was conducted to examine the relationships between individual biological measurements and orchard management systems, using SAS software. Unless noted otherwise, only results significant at $p<0.05$ are discussed.

RESULTS

The PCR amplification reaction from bacterial DNA extraction indicated the presence of methane oxidizing bacteria of Type I within all soil samples, but the absence of methane oxidizing bacteria of Type II. No significant difference in methane oxidation rate was observed between the two orchard management systems in year 2 (2003) (data not shown). However, the DGGE image and the cluster analysis of the soil samples showed a distinguishable methanotrophic community structure in the organic soil samples compared with the conventional soil samples. This effect could be traced by molecular fingerprinting of the methanotrophic community. Various bands (phylotypes) were present from the organic samples, but were not visible from the conventional samples.

In year 5 (2006), however, apparent differences were detected for microbial activity in orchards subjected to different agricultural practices. The BAS, SIR and CDE values tended to be higher in the organic than in the conventional orchard on most sampling dates (Fig. 1). The CDE values were generally higher in the organic orchard than in the conventional orchard on all sampling dates (Fig. 1). The variability of CDE values was high in spite of similar measures of soil temperature and relative soil water content for both orchard samples (Jamar et al., 2008).

Total earthworm abundance was generally lower in the orchard managed with conventional practices (Fig. 2). The earthworm populations within soil varied between the two management systems, with the mean numbers in the organic plots always higher, whatever the ecological classes. Soil mineral analysis and soil pH values were similar within the two orchard management systems, except for the nitrogen, boron and copper elements in 2006 and 2008, as well as phosphorus and potassium elements in 2008 (Tables 1 and 2). In both systems, soil analysis showed zinc deficiencies.

DISCUSSION

The organic management system applied over 2 years influenced the community structure of the methanotrophic bacteria. It seems, however, that the differences observed in the methanotrophic community structure were not reflected in the mean methane oxidation after 2 years of organic management.

The soil biological properties analysed in this study showed that the conventional management system applied over 5 years could affect non-target soil microbial activity compared with an organic management system in orchards. On the base of the present trials, the organically-managed soils exhibited greater microbiological activity than the conventionally-managed soils.

Being a very complex concept, a global evaluation of soil fertility is almost impossible, and this is why fertility factors are generally reported in three distinct categories: physical, chemical and biological. The complex interaction of these three aspects makes up agronomic or integral fertility of soil, from which productivity depends (Pompili et al., 2006). The microbial fraction represents a really important component in soil fertility whose absence could make soil a simple mechanical support for plants. Measurements of microbial activity are actually included as indicators in many national and international monitoring programs on soil quality (Pompili et al., 2006). Soil is a living medium hosting an extensive biodiversity which can consist of more than 1000 species within one gram of soil. Respiration is probably the process that is most closely associated with life (Bloem et al., 2006). Soil respiration is attributed to a wide range of micro-organisms, such as fungi, bacteria, protozoa and algae. The soil fauna also make a significant contribution. Generally, the microbial contribution to the total release of CO_2 (excluding root respiration) is thought to be about 90%, compared with 10% released by the fauna. Although fungal biomass often dominates microbial biomass, the fungi:bacteria relationship with regard to respiration can vary considerably due to, for example, type of ecosystem or soil management (Bloem et al., 2006). But plant roots also contribute between 12% and 30% to the total release of CO_2 through respiration in the field (Bloem et al., 2006). Hence, field-based methods (measuring CDE) give the sum of respiration of all organisms (including roots), whereas laboratory methods (assessing BAS and SIR) give only the microbial respiration. Field methods are implemented under uncontrolled conditions and therefore often result in large spatial and temporal variations in gas fluxes.

Organic management greatly increased earthworm abundance in the present study, although soil tillage operations for weed control in orchards can reduce earthworm abundance (Paoletti et al., 1998). Earthworms are particularly sensitive to copper and zinc (Paoletti et al., 1998). Several studies reported negative effects on earthworm abundance following long term copper applications in perennial crops (Edwards and Bohlen, 1996; Paoletti et al., 1998). Van Rhee (1976) found that earthworms are almost completely eradicated from orchards if the soil copper concentration is >80 µg/g. According to Paoletti et al. (1998), 'Endogées' are more sensitive to copper than 'Anecique' and 'Epigées' species and disappear when the copper concentration is higher than 175 ppm. Although soil copper content, in our experiment, was significantly higher in the conventional orchard, under both systems soil copper and zinc content seemed to be kept below the estimated harmful level for earthworms.

In temperate regions, the earthworms, in terms of biomass, constitute the principal component of the total faunal biomass. They have a large influence on soil physical, chemical and biological properties and thus are considered as important agent for promoting soil fertility in agro-ecosystems (Peres et al., 2006). In particular, the common earthworm (*Lumbricus terrestris*) plays an important role in the leaf litter decomposition deposited on the orchard floor and can consume fruiting bodies of different fungi including *V. inaequalis* and thus significantly reducing primary scab inoculum (Niklas and Kennel, 1981; MacHardy, 1996; Paoletti et al., 1998; Glover et al., 2000).

Even if the orchard management system did not greatly influence soil chemical parameters in our study, positive effects on microbial and earthworm communities were observed in the organic orchard. These positive effects on soil bio-indicators might favourably shape the performance of important soil functions (Brussaard et al., 2007). But further studies are needed to better understand the effects of individual soil management practices on soil biodiversity functions. Only additional experiments will help to clarify this issue and to assess the real effect of the two types of farming practices on soil fertility and sustainable crop production. On the base of the present findings, organic management system seems the best farming approach to maintain soil quality with regard to biological indicators.

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Tables

Table 1. Major element contents of conventional and organic orchard soils at Gembloux, Belgium in 2006 and 2008.

Year	Orch.	pH (KCl)	C (%)	N (%)	P[z]	K	Mg	Ca	CEC (meq/ 100 g)
2006	conv.	6.3 (0.2)[y]	1.15 (0.1)	0.13 (0.01)	26 (9)	33 (2)	17 (2)	174 (15)	10.6 (0.5)
	org.	6.5 (0.1)	1.05 (0.1)	0.11 (0.02)	23 (2)	31 (4)	26 (9)	151 (36)	9.8 (0.4)
2008	conv.	6.7 (0.2)	1.34 (0.1)	0.13 (0.02)	8 (1)	34 (2)	17 (1)	199 (9)	10.5 (0.6)
	org.	6.0 (0.2)	1.04 (0.1)	0.10 (0.01)	3 (1)	10 (2)	15 (1)	153 (8)	9.8 (0.5)
Norm. range[x]		6.5-7.0	1.0-1.5	–	7-10	13-20	9-16	175-385	–

[z]P, K, Mg, Ca, values are expressed in mg 100 g^{-1}.
[y]Values in brackets are the standard deviations of the means ($n = 4$ and 8 in 2006 and 2008, respectively).
[x]Normal range in this kind of soil (heavy loam) in Belgium.

Table 2. Minor element contents of conventional and organic orchard soils at Gembloux, Belgium in 2006 and 2008.

Year	Orch.	Fe[z]	Mn	Cu	Zn	Na	B	S
2006	conv.	260 (33)[y]	229 (20)	39.9 (4)	6.2 (1.1)	18 (4)	0.42 (0.2)	163 (5)
	org.	242 (28)	209 (18)	26.8 (5)	5.3 (0.6)	15 (3)	0.47 (0.1)	163 (7)
2008	conv.	265 (31)	235 (9)	24.0 (3)	6.0 (0.9)	30 (7)	0.40 (0.2)	160 (6)
	org.	245 (21)	215 (16)	15.5 (1)	5.3 (0.4)	26 (5)	0.43 (0.1)	166 (5)
Normal range[x]		120-180	80-110	7-11	9-13	31-61	0.5-0.9	100-500

[z]All elements are expressed in mg kg^{-1}.
[y]Values in brackets are the standard deviations of the means ($n = 4$ and 8 in 2006 and 2008, respectively).
[x]Normal range in this kind of soil (heavy loam) in Belgium.

Figures

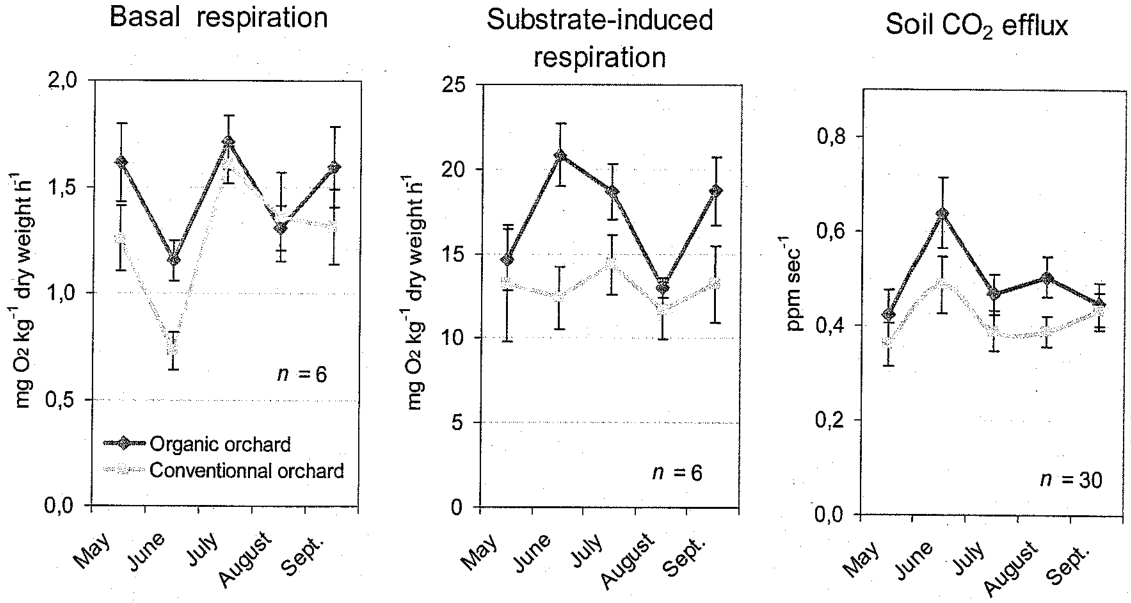
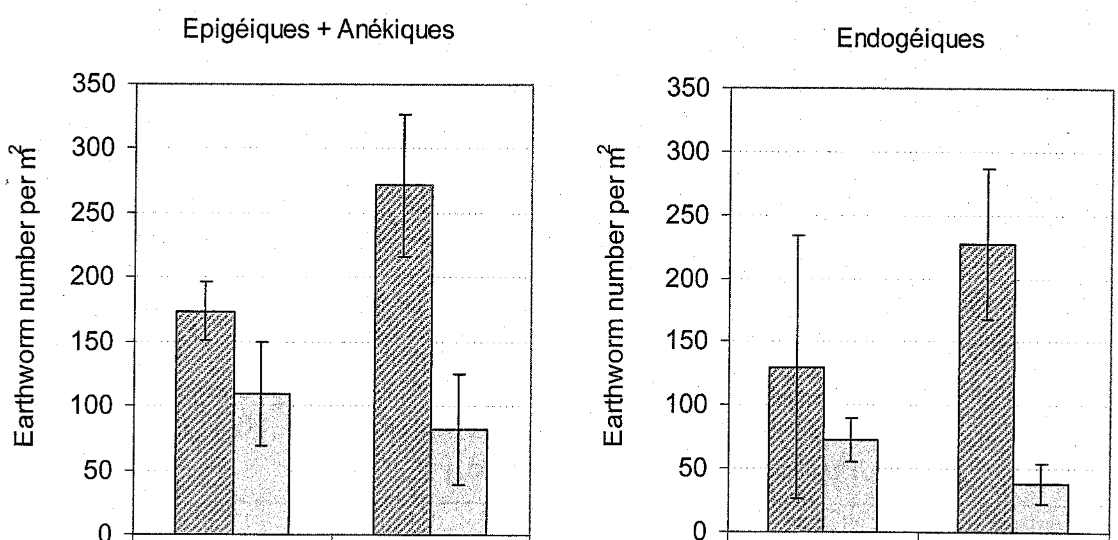


Fig. 1. Basal respiration and substrate-induced respiration in soil samples and in situ soil CO_2 efflux, from two adjacent conventional and organic orchard soils in Gembloux, Belgium in 2006. Error bars indicate confidence interval of the mean (α= 0.05).



	2006	2008
▨ Organic	174	272
□ Conv.	109	82

	2006	2008
▨ Organic	130	228
□ Conv.	73	39

Fig. 2. Mean number of earthworms per m^2 of orchard floor in conventional and organic management systems at Gembloux, Belgium in 2006 and 2008. Error bars indicate confidence interval of the mean (α= 0.05 and n = 4 and 8 in 2006 and 2008 respectively).