Soil microbial activity and earthworm abundance in orchards under conventional and organic growth management systems

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Abstract

The study was carried out in Gembloux, Belgium, to compare 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. The orchards had different agricultural inputs (fertilizers, pesticides) and weed control systems. In year 2 (2003) of the study, 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 the basal respiration (BAS), the substrate induced respiration (SIR) and the in situ *soil CO_2 efflux (CDE). Earthworm abundance as useful bio-indicators of agro-ecosystem sustainability 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, important differences were detected for the microbial activity indicators in orchards subjected to different agricultural practices. The BAS, SIR and CDE values were significantly higher in the organic than in the conventional orchard on most sampling dates. Total earthworm abundance was severely reduced by conventional practices. Soil mineral analysis did not show important differences between the two orchard management systems.*

Key words: agro-ecosystems, biomass, microbial respiration, carbon dioxide efflux, soil quality

Introduction

As fruit production in Belgium has intensified to meet market demands in recent decades, concerns about the negative impacts of conventional food production practices on environmental quality have also increased. Although studies have found that alternatives management practices may improve soil quality compared with conventional management practices, a 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, soil organisms are crucial for the sustainability of agro-ecosystems. 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 soil biological activities involved in the fixation of atmospheric N, recycling of carbon and nutrients, reduction of soil pathogens, decomposing leaf litter, etc.

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Several studies have shown that the common earthworm (*Lumbricus terrestris*) decomposes most apple leaves deposited on the orchard floor and thus significantly reduces primary scab inoculum (Glover *et al.,* 2000; MacHardy *et al.*, 2001; Holb, 2006). Soil biological properties such as microbial biomass or activity, as well as earthworm abundance or diversity, were reported to be major soil quality bio-indicators (Paoletti *et al.*, 1998; Glover *et al.,* 2000). The objective of this study was to evaluate the effects of 5 years of conventional and organic fruit production systems on several soil biological properties.

Material and Methods

The experiment was conducted in Gembloux, Belgium, on two adjacent orchards, each 1 ha. 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 composted cattle manure and organic fertilizers (5% N) and the use of mechanical tillage for weed control involving the 'Swiss-Sandwich-System'. Conventional soil management practices included applying 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 year 5 and 6). Disease control included applying, annually, copper (3 kg ha^{-1}) and sulphur (38 kg ha^{-1}) in the organic orchard (Jamar *et al.,* 2008), and copper (10 kg ha^{-1}) and thirame (6 kg ha^{-1}) in the conventional orchard. 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.

During year 2 (2003), the methane oxidation, as an important soil ecological process, was measured in order to compare the orchards' soil biological activities (Seghers *et al.,* 2003). During year 5 (2006), the overall microbial activity was assessed by measuring basal respiration (BAS) through O_2 consumption rate and substrate induced respiration (SIR) through O_2 consumption rate after the addition of glucose addition (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 useful bio-indicators of agro-ecosystem sustainability were assessed together with chemical soil parameters in 2006. Both assessments included four replicates per orchard. An earthworm abundance estimation was performed on 8 September, after a rainy period, using the mustard extract method described by Chan & Munro (2001).

Analysis of variance (ANOVA) was conducted to examine the relationships between individual biological measurements and orchard management systems, using SAS software. For all data sets, significant *F*-tests ($P \leq 0.05$) were used to compare the orchard means.

Results

No significant difference in methane oxidation rate was observed between the two orchard management systems in year 2 (2003) (data not shown). In year 5 (2006), however, important differences were detected for microbial activity in orchards subjected to different agricultural practices. The BAS, SIR and CDE values were significantly higher in the organic than in the conventional orchard on most sampling dates (Table 1 and 2).

Table 1: Basal respiration and substrate-induced respiration in conventional (conv) and organic (org) soil samples (mg O_2 kg^{-1} dry weight h^{-1}) from Gembloux's orchards in 2006

Date	Basal respiration (BAS)			Substrate-induced respiration (SIR)		
	Conv	Org	*F*-test[b]	Conv.	Org.	*F*-test
06 June	1.26 (0.19)[a]	1.61 (0.23)	*	13.24 (4.35)	14.62 (2.27)	*n.s.*
26 June	0.73 (0.11)	1.15 (0.12)	***	12.38 (2.33)	20.83 (2.33)	***
01 August	1.61 (0.11)	1.71 (0.16)	*n.s.*	14.36 (2.18)	18.66 (2.08)	**
05 September	1.36 (0.26)	1.31 (0.13)	*n.s.*	11.65 (2.08)	13.02 (0.74)	*n.s.*
11 October	1.31 (0.22)	1.60 (0.24)	*	13.20 (2.80)	18.71 (2.51)	***
Overall season	1.25 (0.34)	1.48 (0.27)	**	12.96 (2.83)	17.16 (3.52)	***

[a] Values in brackets are the standard error of the mean (n = 6, for overall mean n = 30).
[b] *F*-test refers to comparisons between the orchards, *n.s.* = non significant, *, **, *** = significant at $P \leq 0.05$, 0.01, 0.001, respectively.

Table 2: *In situ* soil temperature (°C), relative soil water content (m^3 $m^{3\,-1}$) and soil CO_2 efflux (ppm/s) in two adjacent conventional and organic orchards at Gembloux in 2006

Date	Conventional orchard			Organic orchard			
	T °C	Hum	CO_2 efflux[a]	T °C	Hum	CO_2 efflux	*F*-test[b]
12 May	22.5	0.34	0.37 (0.13)	20.5	0.34	0.42 (0.15)	*n.s.*
08 June	19.9	0.37	0.49 (0.17)	21.1	0.33	0.64 (0.21)	*
29 June	21.1	0.19	0.39 (0.12)	21.0	0.18	0.47 (0.12)	*
09 August	18.4	0.31	0.39 (0.09)	18.8	0.29	0.50 (0.12)	**
08 September	18.4	0.37	0.43 (0.11)	18.6	0.35	0.45 (0.13)	*n.s.*
Overall season	20.1	0.32	0.41 (0.13)	20.5	0.30	0.50 (0.17)	**

[a] Values in brackets are the standard error of the mean (n = 30, for overall season n = 150).
[b] *F*-test refers to comparisons between the orchards for CO_2 efflux, *n.s.* = non significant, *, **, *** = significant at $P \leq 0.05$, 0.01, respectively.

Table 3: Mean number of earthworms per m^2 orchard floor in conventional and organic management systems at Gembloux in 2006

Earthworm classes	Conventional orchard	Organic orchard	*F*-test[b]
Epigées + Anéciques	109.2 (41.4)[a]	173.5 (23.3)	*
Endigées	7.3 (1.7)	13.0 (10.6)	*n.s.*

[a] Values in brackets are the standard error of the means (n = 4).
[b] *n.s.* = non significant, * = significantly different from the conventional mean at $P \leq 0.05$.

Table 4: Chemical properties of conventional and organic orchard soils at Gembloux in 2006

	pH_KCl	C%	P[a]	K	Mg	Ca	Na	B	Cu	S
Conventional	6.3[b]	1.1	26	33	17	174	1.8	0.42	39.9	16.3
Organic	6.5	1.0	23	31	26	151	1.5	0.47	26.8	16.3
F-test	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	**	**	*n.s.*

[a] For P, K, Mg, Ca, Na: mg 100 g^{-1} dry weight, B : ppm, Cu and S : mg kg^{-1} dry weight.
[b] Values are the means of four samplings from four replicates per orchard and *F*-test refers to comparisons between the orchards, *n.s.* = non significant, ** = significant at $P \leq 0.01$.

Total earthworm abundance was severely reduced by conventional practices (Table 3). Soil mineral analysis and soil pH values did not show any significant differences between the two orchard management systems in 2006, except for the boron and copper elements (Table 4).

Discussion

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. Soil fauna also makes a significant contribution (about 10%). 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 total 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. The soil biological properties analysed in this study clearly demonstrated that the conventional management system applied over 5 years could affect negatively non-target soil microbial activity compared with an organic management system in orchards. Also, organic management increased earthworm abundance by about 60% although soil tillage operations for weed control in orchards could reduce earthworm abundance (Paoletti *et al.*, 1998). These non-target effects on microbial and earthworm communities might adversely affect the performance of important soil functions (Altierri, 1999). The orchard management systems, however, did not greatly influence soil mineral composition. Under both systems, copper soil content was kept below the estimated harmful level for earthworms (Paolleti *et al.*, 1998).

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