Soil microbial biomass and organic matter fractions during transition from conventional to organic farming systems

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ABSTRACT

The aim of this study was to investigate the response of soil microbial biomass and organic matter fractions during the transition from conventional to organic farming in a tropical soil. Soil samples were collected from three different plots planted with *Malpighia glabra*: conventional plot with 10 years (CON); transitional plot with 2 years under organic farming system (TRA); organic plot with 5 years under organic farming system (ORG). A plot under native vegetation (NV) was used as a reference. Soil microbial biomass C (MBC) and N (MBN), soil organic carbon (SOC) and total N (TN), soil organic matter fractioning and microbial indices were evaluated in soil samples collected at 0–5, 5–10, 10–20 and 20–40 cm depth. SOC and fulvic acids fraction contents were higher in the ORG system at 0–5 cm and 5–10 cm depths. Soil MBC was highest in the ORG, in all depths, than in others plots. Soil MBN was similar between ORG, TRA and NV in the surface layer. The lowest values for soil MBC and MBN were observed in CON plot. Soil microbial biomass increased gradually from conventional to organic farming, leading to consistent and distinct differences from the conventional control by the end of the second year.

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1. Introduction

Conventional farming has played an important role in the improvement of food and fiber productivity to support human demands but it has been largely dependent of synthetic fertilizers, pesticides and herbicides (Tu et al., 2006). On the other hand, organic farming avoids the use of synthetic fertilizers and pesticides and emphasizes organic inputs for nutrient supply and biological processes for pest management (Araújo et al., 2008). This system increases at an annual rate of 20% accounting approximately 24 million hectares in the entire world (Willer and Yussefi, 2004). Brazil has approximately 850 thousand hectares occupied by organic farming (Willer and Yussefi, 2007) and, specifically, the northeast region produces organic fruits to support international market demands over recent years (Leite et al., 2010).

Organic farming can enhance soil biodiversity, alleviates environmental concerns and improves food safety through exclusion of applications of synthetic chemicals (Araújo et al., 2008). However, during the conversion process from conventional to organic farming system, a transitional period should be necessary to restore and improve soil quality and process. An understanding of the microbial dynamics

during this transitional period is important to provide information about the suitable conversion strategies and to minimize yield losses (Tu et al., 2006).

In organically managed systems where no synthetic fertilizers are allowed, soil microbial biomass is important to supply plant nutrients by mineralization processes and to avoid nutrient leaching (Friedel et al., 2001). Soil microbial biomass, the living part of soil organic matter (SOM), acts as an important ecological indicator and is responsible for organic matter decomposition and nutrients mineralization (Marinari et al., 2006). Any changes in soil microbial biomass may impact these important functions in the soil. In addition, as microbes are living, they respond more quickly to changes in soil conditions than does SOM (Araújo and Melo, 2010). On the other hand, SOM fractions, such as light fraction or humic substance, also can be considered indicators of land use and management effect on the soil environment as reported by several authors (Bayer et al., 2006; Cookson et al., 2008; Leite et al., 2003; Okore et al., 2007; Triberti et al., 2008).

Soil microbial biomass and SOM fractions has been extensively compared between organic and conventional systems (Araújo et al., 2008; Castillo and Joergensen, 2001; Leite et al., 2010; Mäder et al., 2002; Marinari et al., 2006; Sampaio et al., 2008; Tu et al., 2006). However, there is no information how these indicators respond during the transitional period from conventional to organic farming in tropical soils. Previously, Reganold et al. (2001) and Tu et al. (2006) showed the responses of soil microbial biomass during the transition

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from conventional to organic farming in temperate soil. Thus, the objective of our study was to investigate the responses of soil microbial biomass and SOM fractions during the transitional period from conventional to organic farming in a tropical soil.

2. Materials and methods

2.1. Study area

The field study was carried out at Parnaíba (03° 05' S; 41° 47' W; 46 m), Piauí state, Northeast Brazil. The climate is rather dry with a mean precipitation of 1000 mm year⁻¹ and an annual mean temperature of 30 °C. The soil type is a Typic Quartzipsamment in the US soil taxonomy. Soil samples were obtained in March 2010 from the following plots: “acerola” orchard (*Malpighia glabra*) under 10 years of conventional farming (CON); “acerola” orchard (*Malpighia glabra*) under 2 years of transitional period from conventional to organic farming (TRA); “acerola” orchard (*Malpighia glabra*) under 5 years of organic farming (ORG); native vegetation (NV). The size of each experimental plot is 1000 m².

In all plots with “acerola” the plants are distanced 2.0 m long and 3.0 m wide. Conventional plot (CON) is managed since 1999 and the agricultural practices include inputs of synthetic soil fertilizer (Table 1) and pesticides. Annually, lime is applied at a rate of 1 t ha⁻¹. Transitional and organic plots received inputs of green manure (*Crotalaria juncea*, *Vigna unguiculata* and *Cajanus cajan*), 0.5 t ha⁻¹ of rock phosphate and 1.2 t ha⁻¹ of “MB4” (product with lime and micronutrients). Annually, the agricultural practices in these plots are inputs of straw mulch, composted cow manure (20 t ha⁻¹), rock phosphate (0.5 t ha⁻¹), “MB4” (1.2 t ha⁻¹) and “carnauba” straw (10 t ha⁻¹). Table 2 shows the chemical characteristics of composted cow manure and “carnauba” straw used in transitional and organic plots. The organic amendments are applied in the soil surface under the plant canopies.

2.2. Soil sampling and analysis

Soil samples were collected from four independent areas within each plot. In each area, a grid with ten points was selected to collect soil samples in the 0–5, 5–10, 10–20 and 20–40 cm depths. The soil samples (four replicates for each plot) were transported to laboratory on ice in a cooler. Field moist soils were sieved through a 2-mm screen, and immediately stored in sealed plastic bags at 4 °C.

The remaining soil samples were air-dried. Soil samples were ground and passed through a 0.2-mm sieve to evaluate chemical properties. The MBC and MBN were determined by the irradiation-extraction method by microwave (Islam and Weil, 1988) using 0.5 mol L⁻¹ K₂SO₄ as extractant. Soil organic carbon (SOC) in the extracts was measured by wet combustion (Yeomans and Bremner, 1988). Extraction and fractionation of soil humic substances (humic acids, fulvic acids and humin) were carried out using the method recommended by the International Humic Substances Society (IHSS) as described by Swift (1996). The carbon content of humic acid (HAF), fulvic acid (FAF) and humin (HUM) fractions was measured by the dichromate oxidation method (Yeomans and Bremner, 1988). Nitrogen was determined by Kjeldahl method. Soil respiration (CO₂ emission) was determined according to Alef (1995). The qCO₂

Table 1
Annual input of fertilizers on conventional (CON) and organic (TRA and ORG) plots.

Fertilizer	CON (kg ha ⁻¹)	TRA and ORG (t ha ⁻¹)
N	200	Composted cow manure (20)
P	80	Composted cow manure (20) and rock phosphate (0.5)
K	80	Composted cow manure (20)

Table 2
Chemical properties of composted cow manure and “carnauba” straw added to TRA and ORG plots.

Component	Content
<i>Composted cow manure</i>	
Moisture (g kg ⁻¹)	198
pH (1:2.5)	6.9
Organic matter (g kg ⁻¹)	281.6
Total N (g kg ⁻¹)	8.32
C/N ratio	19.1
P available (g kg ⁻¹)	4.1
K available (g kg ⁻¹)	3.5
<i>Carnauba straw (% dry matter)</i>	
Protein	12.3
P	0.41
Fiber	80.3
Lignin	21.5

was calculated as the ratio of basal respiration to microbial biomass C and results were expressed as g CO₂-g⁻¹ MBC day⁻¹.

The study was carried out in a completely randomized design with 4 replicates. Analyses of variance (ANOVA) and a *t*-test were used to detect significant differences between the areas studied. When a significant *F* value was detected, the means were compared by the Tukey test (*P*<0.05). All the statistical analyses were performed with the SPSS (version 15.0) software package.

3. Results

3.1. Soil organic carbon and humic substances

SOC contents were higher in the ORG at 0–5 cm and 5–10 cm depths. However, at 10–20 and 20–40 cm depths no differences were observed. ORG also showed higher TN contents in the all evaluated depths (Table 3). TRA and NV showed similar values for SOC and TN in all depths, except for SOC at 5–10 cm depth. Higher differences were observed between ORG and CON, i.e. 74% (0–5 cm) and 69% (5–10 cm) for SOC and 66% (0–5 cm), 63% (5–10 cm), 51% (10–20 cm) and 67% (20–40 cm) for TN contents. In addition, SOC contents were 26% and 42% higher in ORG than NV (reference) at 0–5 cm and 5–10 cm, respectively.

At 0–5 and 5–10 cm depths, FAF contents were higher in ORG, NV and TRA than in CNV (Table 4). Similarly to SOC, no differences were observed at 10–20 and 20–40 cm depths. HAF content showed

Table 3
Soil organic C (SOC) and total N (TN) under conventional (CON), transitional (TRA) and organic (ORG) plots.

Plot	Depth (cm)			
	0–5	5–10	10–20	20–30
SOC (g kg ⁻¹)				
CON	3.63 ± 0.9 ^c	2.10 ± 0.5 ^d	1.98 ± 0.8 ^a	1.35 ± 0.3 ^a
TRA	10.33 ± 2.1 ^b	2.80 ± 0.7 ^c	2.07 ± 0.6 ^a	1.34 ± 0.5 ^a
ORG	14.09 ± 3.3 ^a	6.85 ± 2.4 ^a	2.13 ± 0.5 ^a	1.61 ± 0.3 ^a
NV	8.92 ± 2.7 ^b	3.94 ± 1.2 ^b	2.26 ± 0.9 ^a	1.59 ± 0.7 ^a
TN (g kg ⁻¹)				
CON	0.21 ± 0.04 ^c	0.17 ± 0.07 ^b	0.15 ± 0.03 ^b	0.09 ± 0.02 ^b
TRA	0.36 ± 0.03 ^b	0.24 ± 0.08 ^b	0.18 ± 0.05 ^b	0.11 ± 0.03 ^b
ORG	0.62 ± 0.07 ^a	0.47 ± 0.10 ^a	0.31 ± 0.09 ^a	0.28 ± 0.06 ^a
NV	0.33 ± 0.04 ^b	0.23 ± 0.06 ^b	0.15 ± 0.04 ^b	0.11 ± 0.02 ^b

Mean ± standard error. Means followed by the same letter within each column are not significantly different at 5% level by Tukey's test.

The plots were: conventional plot with 10 years under conventional management system (CON); transitional plot with 2 years under organic farming system (TRA); organic plot with 5 years under organic farming system (ORG); plot under native vegetation (NV).

Table 4

Soil organic fulvic acids (FAF), humic acids (HAF) and humin (HF) under conventional (CON), transitional (TRA) and organic (ORG) plots.

Plot	Depth (cm)			
	0–5	5–10	10–20	20–30
	FAF (g kg ⁻¹)			
CON	0.66 ± 0.2 ^b	0.31 ± 0.1 ^b	0.29 ± 0.05 ^a	0.23 ± 0.04 ^a
TRA	1.42 ± 0.5 ^a	0.68 ± 0.2 ^a	0.25 ± 0.06 ^a	0.21 ± 0.07 ^a
ORG	1.73 ± 0.4 ^a	0.64 ± 0.3 ^a	0.32 ± 0.05 ^a	0.26 ± 0.03 ^a
NV	1.56 ± 0.5 ^a	0.63 ± 0.2 ^a	0.33 ± 0.08 ^a	0.27 ± 0.05 ^a
	HAF (g kg ⁻¹)			
CON	0.67 ± 0.2 ^c	0.56 ± 0.3 ^c	0.41 ± 0.09 ^a	0.29 ± 0.09 ^a
TRA	2.48 ± 0.5 ^a	1.20 ± 0.2 ^b	0.48 ± 0.10 ^a	0.29 ± 0.10 ^a
ORG	2.57 ± 0.6 ^a	1.77 ± 0.4 ^a	0.45 ± 0.05 ^a	0.36 ± 0.08 ^a
NV	1.41 ± 0.4 ^b	1.47 ± 0.2 ^a	0.47 ± 0.07 ^a	0.38 ± 0.06 ^a
	HF (g kg ⁻¹)			
CON	2.30 ± 0.7 ^d	1.23 ± 0.3 ^c	1.28 ± 0.3 ^a	0.83 ± 0.07 ^a
TRA	6.43 ± 1.1 ^b	1.29 ± 0.4 ^c	1.34 ± 0.2 ^a	0.84 ± 0.05 ^a
ORG	9.79 ± 1.6 ^a	4.44 ± 1.2 ^a	1.36 ± 0.2 ^a	0.98 ± 0.09 ^a
NV	5.95 ± 1.3 ^c	1.84 ± 0.3 ^b	1.46 ± 0.5 ^a	0.95 ± 0.14 ^a

Mean ± standard error. Means followed by the same letter within each column are not significantly different at 5% level by Tukey's test.

The plots were: conventional plot with 10 years under conventional management system (CON); transitional plot with 2 years under organic farming system (TRA); organic plot with 5 years under organic farming system (ORG); plot under native vegetation (NV).

difference only up to 10 cm depth. At 0–5 cm depth, higher values were observed in ORG and TRA, while, that at 5–10 cm depth, higher values were observed in ORG and NV. HF followed same pattern of two others fractions. At 0–5 cm and 5–10 cm depths, higher and lower values for HF were verified in ORG and CON, respectively (Table 4). Differences between highest (ORG) and lowest (CON) for FAF, HAF and HF contents were 61%, 73% and 76% to 0–5 cm and 51%, 68% and 72% to 5–10 cm, respectively.

3.2. Soil microbial biomass

In general form, soil MBC and MBN content fell with depth. In all depths, MBC was highest in ORG than in others plots (Table 5). No significant difference was found in MBC between TRA and NV. However, soil MBN was similar between ORG, TRA and NV in the surface layer, while in the subsurface layer ORG showed highest MBN. The lowest values for soil MBC and MBN were observed in CON. Soil MBC and MBN increased by 10–300% from conventional to transitional plots.

Table 5

Soil microbial biomass C (MBC) and N (MBN) under conventional (CON), transitional (TRA) and organic (ORG) plots.

Plot	Depth (cm)			
	0–5	5–10	10–20	20–30
	MBC (mg kg ⁻¹)			
CON	47.27 ± 4.6 ^c	35.27 ± 5.2 ^c	24.55 ± 3.7 ^c	8.75 ± 1.4 ^c
TRA	151.02 ± 12.1 ^b	76.54 ± 8.1 ^b	60.01 ± 4.9 ^b	31.45 ± 5.8 ^b
ORG	317.45 ± 47.8 ^a	143.45 ± 11.9 ^a	105.45 ± 10.3 ^a	103.09 ± 9.1 ^a
NV	145.23 ± 15.3 ^b	93.09 ± 10.5 ^b	63.84 ± 5.4 ^b	44.18 ± 15.5 ^b
	MBN (mg kg ⁻¹)			
CON	21.10 ± 4.2 ^b	17.52 ± 2.3 ^b	6.67 ± 1.2 ^c	1.70 ± 0.2 ^c
TRA	52.58 ± 8.1 ^a	46.32 ± 7.1 ^a	16.30 ± 4.3 ^b	3.04 ± 0.8 ^b
ORG	69.35 ± 9.4 ^a	48.61 ± 8.4 ^a	29.81 ± 5.1 ^a	11.02 ± 2.3 ^a
NV	50.56 ± 9.0 ^a	40.83 ± 5.8 ^a	16.85 ± 4.9 ^b	3.24 ± 0.9 ^b

Mean ± standard error. Means followed by the same letter within each column are not significantly different at 5% level by Tukey's test.

The plots were: conventional plot with 10 years under conventional management system (CON); transitional plot with 2 years under organic farming system (TRA); organic plot with 5 years under organic farming system (ORG); plot under native vegetation (NV).

On the other hand, the MBC and MBN decreased by 50–70% from native vegetation to conventional plots.

3.3. Microbial indices

The qCO_2 was higher in CON than in ORG, TRA and NV in all evaluated plots (Table 6). In the surface layer, the MBC-to-SOC ratio was highest in ORG than in others plots (Table 6). No significant difference was found in the MBC-to-SOC ratio between ORG, TRA and NV plots with depth. However, MBC-to-SOC ratio was different between ORG and CON.

4. Discussion

4.1. Soil organic carbon and humic substances

Conversion from native vegetation to conventional farming decreased SOC and TN contents. However, practices from transitional and organic plots provided a recovery in these contents up to 10 cm. It is particularly important for tropical soils of Northeast Brazil where, naturally, there is low SOM content (Araújo et al., 2008).

Higher SOC and TN contents in organic system compared to conventional system have been verified by several authors (Berner et al., 2008; Lagomarsino et al., 2009; Leite et al., 2010) and it can be attributed to organic inputs from compost and “carnauba” straw which promote greater amounts of C and N. Similarly to SOC and TN, there were reductions in organic matter fractions after change from native vegetation to conventional farming. However, in soils organically managed (2 and 5 years for TRA and ORG, respectively) there were increases in the contents of these fractions. These findings corroborated with Altieri and Sposito (2008) who hypothesized that amended soils present alterations in soil organic matter status in a relatively short-term. The increase in the content of humic fractions is essential for tropical soils since that recalcitrant humic substances, especially humic acids and humin, represent the most persistent pool of SOM, with mean residence times of several hundred years as reported by Marinari et al. (2010).

4.2. Soil microbial biomass

Transitional practices from conventional to organic farming clearly impacted the size of the soil microbial biomass. Our results showed an increasing about 100% to 300% in soil microbial biomass with adoption of organic farming. It occurred due the organic C inputs in organically managed soils. In our organic and transitional plots, the organic C inputs

Table 6

Soil respiratory quotient (qCO_2) and MBC-to-SOC ratio under conventional (CON), transitional (TRA) and organic (ORG) plots.

Plot	Depth (cm)			
	0–5	5–10	10–20	20–30
	qCO_2 (g CO ₂ -C g ⁻¹ C day ⁻¹)			
CON	0.23 ± 0.01 ^a	0.19 ± 0.02 ^a	0.24 ± 0.03 ^a	0.23 ± 0.03 ^a
TRA	0.13 ± 0.01 ^b	0.14 ± 0.01 ^b	0.13 ± 0.01 ^b	0.16 ± 0.04 ^b
ORG	0.13 ± 0.02 ^b	0.13 ± 0.01 ^b	0.14 ± 0.01 ^b	0.12 ± 0.01 ^b
NV	0.12 ± 0.03 ^b	0.15 ± 0.03 ^b	0.15 ± 0.02 ^b	0.17 ± 0.05 ^b
	MBC-to-SOC ratio (%)			
CON	1.30 ± 0.2 ^b	1.68 ± 0.3 ^b	1.24 ± 0.2 ^b	1.59 ± 0.2 ^b
TRA	1.46 ± 0.3 ^b	2.42 ± 0.4 ^a	2.33 ± 0.5 ^a	2.35 ± 0.5 ^a
ORG	2.33 ± 0.5 ^a	2.10 ± 0.2 ^a	2.14 ± 0.6 ^a	1.77 ± 0.2 ^b
NV	1.63 ± 0.4 ^b	2.36 ± 0.5 ^a	1.96 ± 0.3 ^a	1.74 ± 0.3 ^b

Mean ± standard error. Means followed by the same letter within each column are not significantly different at 5% level by Tukey's test.

The plots were: conventional plot with 10 years under conventional management system (CON); transitional plot with 2 years under organic farming system (TRA); organic plot with 5 years under organic farming system (ORG); plot under native vegetation (NV).

were estimated at $8,100 \text{ kg ha}^{-1}$ per year. The significant differences in MBC and MBN between TRA and CON confirms the benefits of organic C inputs on the size of microbial biomass conform reported by Melero et al. (2005) and Tu et al. (2006). However, these authors observed increasing in soil microbial biomass ranged to 80–100% with C inputs estimated of 10,000 and 4300 kg ha^{-1} per year, respectively. Therefore, we found an increasing in soil microbial biomass three times more those observed by them in soils from temperate regions. Usually, tropical soils show low soil microbial biomass content once that there are high soil microbial activity and the decomposition, influenced of soil temperature. In this way, our results show positive effect of organic farming on microbial biomass in tropical soils, especially those with high content of sand and low fertility. According with Araújo and Melo (2010) soil microbial biomass is extremely important for tropical soils as a pool of nutrients available for plant uptake.

An important observation from our study is that in spite of the soil microbial biomass decrease with depth, we observed higher MBC in the ORG in all depths. This suggests that a great fraction of the soil microbial community is colonizing the soil subsurface. The decline of soil microbial biomass with increasing depth are compatible with others reports (Babujia et al., 2010; Castellazzi et al., 2004; Potthoff et al., 2006). However, for organic farming, the permanent input of organic residues may favor the increasing of microbial biomass in depth (Xavier et al., 2006).

4.3. Microbial indices

Changes in the MBC-to-SOC ratio reflect the input of organic matter to soils, the efficiency of microbial incorporation, C losses from the soils, and the stabilization of organic C by the soil mineral fractions (Sparling, 1992). This higher MBC-to-SOC ratio observed in ORG can be due to the higher soil microbial biomass C content observed in this soil, and indicates high inputs and availability of organic matter to soil microorganisms (Araújo et al., 2008; Leite et al., 2010; Steiner et al., 2008).

The $q\text{CO}_2$ is an index used to measures soil microbial metabolic efficiency and reflect the respiration per biomass unit (Anderson, 2003). Our results showed that CON increased $q\text{CO}_2$, suggesting a decreasing in soil microbial biomass efficiency. On the other hand, the lower $q\text{CO}_2$ observed in ORG and TRA may indicate high efficiency of soil microbial biomass, under organically managed soils, in the incorporation of C and less losses of C through the respiration (Sampaio et al., 2008).

5. Conclusion

Conversion from native vegetation or conventional system to organic farming increases soil organic matter fractions contents and can be an excellent strategy to improve soil quality in areas with fruit production in tropical soils. Organic farming enhanced soil microbial biomass due the high C inputs. However, soil C buildup is needed to sustain microbial biomass over the long term. Our results clearly showed that transitional period is necessary to improve soil microbial biomass content. In addition, the increase in soil microbial biomass occurred 2 years after inclusion of organic practices. In soils from temperate regions, Tu et al. (2006) demonstrated that soil microbial biomass increased with increasing organic inputs after 3 years (Tu et al., 2006). For tropical soils, our current results suggest that 2 years of organic management may be a minimum to significantly and consistently enhance microbial biomass. This observation may suggest a recommendation of 2-year transition requirements for changes in soil biological properties in organic farming.

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