Earthworm communities in organic and conventional coffee cultivation

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Abstract – The objective of this work was to evaluate the effect of organic and conventional coffee crops on biomass, population density and diversity of earthworms, in Lerroville, district of Londrina County, Paraná state, Brazil. Earthworm communities were sampled in three areas with organic coffee cultivation (CO1, CO2 and CO3), two with conventional coffee (CC1 and CC2), and a native forest fragment (MT). The soil of the areas CO1, CC1, and MT was classified as Nitossolo Vermelho (Rhodic Kandiudox), while CO2, CO3, and CC2 were on Latossolo Vermelho (Rhodic Hapludox). Eight samples were taken in each area on two occasions, winter and summer, using the Tropical Soil Biology and Fertility (TSBF) method in the 0–20 cm soil layer. The earthworms were handsorted and preserved in 4% formaldehyde, and were later weighed, counted and identified. The highest earthworm biomass, both in winter and summer, occurred in the CO3 area. For population density, the higher numbers of individuals were found in CO1 and CO3. The highest number of species was identified in the organic cultivation. The adoption of organic practices in coffee cultivation favored the diversity, density and biomass of earthworm communities.

Index terms: biomass, conventional cultivation, diversity, Oligochaeta, organic cultivation, population density.

Comunidades de minhocas em cultivo de café orgânico e convencional

Resumo – O objetivo deste trabalho foi avaliar o efeito do cultivo de café orgânico e convencional sobre a biomassa, densidade populacional e diversidade de minhocas em Lerroville, distrito de Londrina, Paraná. A comunidade de minhocas foi avaliada em três áreas de cultivo orgânico (CO1, CO2, CO3), duas áreas em cultivo convencional (CC1 e CC2) e um fragmento de mata nativa (MT). O solo das áreas CO1, CC1 e MT foi classificado como Nitossolo Vermelho e o solo das áreas CO2, CO3 e CC2 como Latossolo Vermelho. Oito amostras foram coletadas em cada área, em dois períodos, inverno e verão, pelo método do Tropical Soil Biology and Fertility (TSBF), na camada 0–20 cm. As minhocas foram separadas manualmente e preservadas em formol 4%, e, depois, foram pesadas, contadas e identificadas. A biomassa das minhocas, nas amostragens de inverno e de verão, foi maior na área CO3. A densidade populacional foi maior nas áreas CO1 e CO3. O maior número de espécies foi identificado nos cultivos orgânicos. A adoção de práticas orgânicas, no cultivo do café, favoreceu a diversidade, densidade populacional e biomassa das comunidades de minhocas.

Termos para indexação: biomassa, cultivo convencional, diversidade, Oligochaeta, cultivo orgânico, densidade populacional.

Introduction

Organic production is based on agroecological and natural resource conservation principles, in which biodiversity is a key component. This type of soil management should guarantee continuous supply of organic matter, stimulating the living fractions and favoring fundamental biological processes that maintain and enhance soil fertility (Ricci & Neves, 2006).

Invertebrate fauna communities in soil are strongly influenced by human activities. The diversity and abundance of soil animals are altered mainly by physical disturbance in the environment and by the availability of organic matter, in terms of quantity and quality (Lavelle et al., 1993). Therefore, intensification of agricultural production, with the use of tillage, fertilization, irrigation and pesticides, can affect soil fauna populations both directly and indirectly, by altering the suitability of the soil environment. Practices normally associated with low addition of external, inorganic agricultural inputs foster the diversity and abundance of earthworms (El Titi & Ipach, 1989; Paoletti, 1999).

Long-term organic agriculture improves soil quality, increasing microbial biomass and promoting the reemergence of ecosystem engineers (earthworms, ants, termites) and natural enemies (Birkhofer et al., 2008). By the same token, these organisms can be used as indicators of environmental quality, as they are sensitive to various soil and environmental processes, including disturbance and regeneration.

In Brazil, few studies have been carried out to assess and compare the impact of organic and conventional cultivations on soil fauna populations (Bettiol et al., 2002; Cordeiro et al, 2004; Lima et al., 2007), and none of these studied earthworm biodiversity.

The aim of this work was to evaluate earthworm biomass, population density and diversity, in organic and conventional coffee cultivation, and to compare these with data collected from a forest, used as a reference for native vegetation.

Materials and Methods

This study was conducted in Lerroville, district of Londrina municipality, Paraná state, Brazil (23º40'58"S, 51º05'00"W). The area's climate is Cfa, according to Koeppen's classification, i.e. humid subtropical, characterized by humid summers and rains distributed throughout the year, with possible dry periods during the winter, and average annual precipitation of 1,600 mm.

The characteristics of the areas used to grow coffee are shown in Table 1. Three organic (CO1, CO2, CO3) and two conventional (CC1, CC2) coffee fields were selected for the present investigation, representing five treatments. CC2, CO2 and CO3 were on Latossolo Vermelho (Rhodic Hapludox), while the remaining fields were on Nitossolo Vermelho (Rhodic Kandiudox). The texture of these soils was similar, and the main difference between them is the structure of the B horizon. The Latossolos have a granular structure, and the Nitossolos have blocky and prismatic structures (Sistema brasileiro de classificação de solos, 1999).

Maize was grown between rows of coffee in the conventional cultivation (one crop per year, in rotation with beans), and the rows were otherwise bare for the rest of the year (maize straw and residue were removed). Row spacing of all coffee plantations was 4 m, except for CO3 that had a higher planting density (2 m inter-rows). CO2 and CO3 had been in organic cultivation for seven years, and CO1 for four years, respectively. CO2 had legume trees (*Leucaena* sp.) planted and weeds maintained between coffee rows; trees were regularly pruned and weeds were mowed adding organic matter to the inter-row space. CO3 had complete soil cover throughout the year, due to higher planting density and coffee plant residues on the soil surface. The inter-row space in CO1 was kept bare by manual weeding over the year. All organic coffee plantations had been previously managed through conventional practices, for at least 35 years. However, in CO2, coffee was removed in 1996 and replanted from seedlings in 1999. Conventional coffee plantations were approximately 39–42 years old. A fragment of native Mata Atlântica Forest, in the initial stage of regeneration on a Nitossolo Vermelho with clay texture (Sistema brasileiro de classificação de solos, 1999), was also sampled.

Earthworms were collected in two different periods of the year: in the dry season (winter) in July

Table 1. Characteristics of sample sites with organic and conventional coffee cultivation, in Lerroville, district of Londrina, Paraná state, Brazil.

Area	Management	Age (years)	Crop in-between rows	Soil cover	Soil type	Texture
CC1	Conventional	42	Maize/beans	None	Nitossolo Vermelho	Clay
CO1	Organic	4	None	None	Nitossolo Vermelho	Clay
CC2	Conventional	39	Maize/beans	None	Latossolo Vermelho	Clay
CO2	Organic	7	*Leucaena* sp.	Weeds	Latossolo Vermelho	Clay
CO3	High-density organic	7	None	Residues	Latossolo Vermelho	Clay

2007, and in the rainy season (summer) in March 2008. Eight points were sampled in each area per season, at regular 5-m intervals. Samples were taken according to the TSBF (Tropical Soil Biology and Fertility) method, described by Anderson & Ingram (1993), and 25x25 cm monoliths were collected at 0–20 cm depth. Monoliths were packed individually in plastic bags and transported to the entomology laboratory, at the Universidade Estadual de Londrina, where the earthworms were handsorted and preserved in 4% formaldehyde. Later, counting, weighing and taxonomic classification were done at the levels of family, genus and species. For earthworm identification, keys and descriptions of families, genera and species were used (Righi, 1990; Blakemore, 2002). Values obtained for biomass and population density were expressed in g m^{-2} and individuals m^{-2}, respectively.

Soil pH ($CaCl_2$) and organic carbon were assessed in each area (Table 2), aecording to Pavan et al. (1992).

The biomass and population density values were transformed using log (x+1) and submitted to analysis of variance and means were compared by the Scott-Knott test, at 5% of probability, to assess the effects of treatment and sample date effects, using the Sisvar statistics program (Ferreira, 2003). A principal component analysis (PCA) was also conducted with the data from all sample dates using Canoco 4.5 (ter Braak & Smilauer, 2002). The data obtained in the two collecting periods were totaled, in order to assess the overall effects of different coffee managements. Earthworm species (Pc, *Pontoscolex corethrurus*; Ag, *Amynthas gracilis*; Gsp, *Glossoscolex* sp.; Ds, *Dichogaster saliens*; Dg, *D. gracilis*; Dsp, *D.* sp. and Juv, juvenile specimens), population density (Dens) and biomass (Bio) were used as response variables, while pH ($CaCl_2$) and organic matter (OM) were plotted as passive variables, after the analyses, and formed no part of the PCA calculation.

Table 2. Values of soil pH ($CaCl_2$) and organic matter content (OM%), in conventional (CC1 and CC2) and organic (CO1, CO2, CO3) coffee cultivations and in the native forest fragment (MT).

	CC1	CC2	CO1	CO2	CO3	MT
pH_{CaCl_2}	6.3	6.6	6.5	6.4	6.6	6.5
OM%	2.6	4.5	2.3	6.0	4.9	4.6

Results and Discussion

Within each sample date, earthworm biomass was significantly higher in CO1 and CO3 (2.18 and 5.39 g m^{-2}, respectively) in July 2007 (Table 3). In the remaining treatments, biomass values were low, ranging between 0 and 0.18 g m^{-2}. In March 2008, CO3 had significantly higher biomass (29.83 g m^{-2}) than the remaining treatments that had low biomass values (0.17 to 1.76 g m^{-2}). When comparing the two sampling dates, within each treatment, a significantly higher earthworm biomass was observed only in CO3 (Table 3).

Earthworm population density, in winter and summer, was significantly higher in CO1 (600 and 96 individuals m^{-2}, respectively), and in CO3 (66 and 154 individuals m^{-2}, respectively), than in the remaining treatments. When comparing the two sampling periods, within each treatment, significant differences were observed only for CO1 (higher density in July); the remaining treatments had no differences between sample dates. It is worth noting that most earthworms in the areas CO1, CC1 and part of CO2 were found in aestivation in the winter samples (July, 2007).

Earthworm species identified in the five treatments and in the native forest fragment are shown in Table 4. The organic treatments had the highest species diversity. Excluding juvenile specimens, six species were found overall, of which five were observed in organic coffee. Conversely, conventional coffee systems had only three species. All of the species found in the coffee plantations (both conventional and organic) were peregrine or exotic. The native forest fragment (MT) had two species; one of them, *Glossoscolex* sp., is

Table 3. Average earthworm biomass and population density, in conventional (CC1 and CC2) and organic (CO1, CO2 and CO3) coffee cultivations and in a native forest fragment (MT), on each sample date (July 2007, March 2008)[1].

Area	Biomass (g m^{-2})		Density (individuals m^{-2})	
	Jul/07	Mar/08	Jul/07	Mar/08
CC1	0.094aA	0.159aA	32aA	26aA
CC2	0aA	1.764aA	0aA	48aA
CO1	2.187bA	0.719aA	600cA	96bB
CO2	0.370aA	1.146aA	18aA	20aA
CO3	5.392bA	29.835bB	66bA	154bA

[1]Values accompanied by different lowercase letters represent treatments with significant differences, within the same sample date; values followed by different uppercase letters represent differences between sample dates within the same treatment. Scott-Knott test at 5% probability.

native and represents a new undescribed species. The few *Dichogaster* sp. encountered (Table 4) also require further study, as their morphological characteristics do not fit existing descriptions of any species known in Brazil. It may be an exotic species that has not yet been identified in the country or that is a new species to be still described.

Pontoscolex corethrurus, the second most abundant earthworm encountered, is a peregrine species native to the Amazon region and of widespread distribution and environmental tolerance (Brown et al., 2006; Barois et al., 1999). The other four species, belonging to the genera *Dichogaster* and *Amynthas*, are exotic earthworms to the region, widely distributed around the world, and adaptable to diverse environmental conditions (Brown et al., 2006). The nonidentified juvenile earthworms probably belong to the *Dichogaster* genus. In previous samples, performed in soybean agroecosystems in the region of Lerroville, many individuals belonging to the genus *Dichogaster* were also found (Brown et al., 2004).

Native species are rarely found in transformed or intensively-managed ecosystems. Agroforestry systems, perennial cultivation, improved pastures, and grain production in organic cultivation and in no-tillage systems are known to favor earthworm populations, generally of peregrine (*P. corethrurus*) and exotic (*Dichogaster* and *Amynthas* spp.) species (Brown & James, 2007). Therefore, it is not surprising that all of the earthworm species found in coffee were either peregreine or exotic, and that the only native species (*Glossoscolex* sp.) was found in the forest.

The greater number of species, population density and earthworm biomass found in the organic coffee are probably related to the availability of organic resources, and to the absence of pesticide use in these cultivation. In the region, for many years, BHC (1, 2, 3, 4, 5, 6-Hexachlorocyclohexane, now banned), and other pesticides toxic to earthworms – e.g. organochlorine insecticides, carbamates and copper-based fungicides (Paoletti, 1999; Edwards & Bohlen, 1992) – were regularly used in conventional coffee cultivation against pests and coffee rust (Abramovay, 1999). The potential long-term impact of these pesticides on earthworm populations under coffee is still unknown. The organic management practices associated with treatment CO3 were particularly favorable for increasing *P. corethrurus* and *Amynthas* sp. populations. In CO2, the planting of coffee using plastic transplant bags containing soil may have introduced the earthworm *P. corethrurus*, which has often been found in ornamental plant bags.

The first (F1) and second (F2) axes of the PCA accounted for 36.1 and 32% of the variance, respectively, totaling 68.1% of total inertia. Axis 1 was represented mainly by the total earthworm density (Dens), species of the genus *Dichogaster* (Ds, Dg and Dsp), and by the nonidentified juvenile earthworm specimens (Juv) in the positive quadrant. Axis 2 was mainly related to total earthworm biomass, and associated with higher abundance of the larger (and heavier) species *P. corethrurus* (Pc) and *A. gracilis* (Ag), opposing the density of the native species (Gsp), found only in the native forest (MT) (Figure 1). CC1, CC2, CO1, CO2, CO3 and MT were significantly aligned ($p<0.05$), along Axis 1, opposing CC_1 and CO_1 – which had higher abundance, mainly of *Dichogaster* species and juvenile specimens – to the remaining treatments (MT, CO2, CC2 and CO3), which had fewer earthworm individuals and higher soil OM contents. Axis 1 also

Table 4. Number of individuals earthworm species of (individuals m^{-2}), collected using the handsorting monolith method (TSBF), in conventional (CC1 and CC2) and organic (CO1, CO2 and CO3) coffee cultivations, and in a native forest fragment (MT), on each sample date (July 2007, March 2008).

Earthworms species	CC1		CC2		CO1		CO2		CO3		MT	
	Jul/07	Mar/08	Jul/07	Mar/08	Jul/07	Mar/08	Jul/07	Mar/08	Jul/07	Mar/08	Jul/07	Mar/08
Pontoscolex corethrurus	-	-	-	20	-	-	14	10	22	146	-	-
Glossoscolex sp.	-	-	-	-	-	-	-	-	-	-	6	4
Amynthas gracilis	-	-	-	-	-	-	-	-	38	-	-	-
Dichogaster gracilis	-	2	-	10	10	4	4	2	-	-	-	-
Dichogaster saliens	-	-	-	-	16	2	-	-	-	-	2	-
Dichogaster sp.	6	4	-	-	50	20	-	-	-	-	-	-
Juveniles NI(1)	26	26	-	24	524	70	-	8	6	6	10	-

(1)Young earthworms not identified at genus/species level. Probably *Dichogaster* spp.

separated the sites according to soil types: CO2, CO3 and CC2 were on Latossolos, while CO1, CC1 and MT were on Nitossolos. However, since MT had the highest levels of OM and was associated with the presence of native species (Gsp) and low biomass and population density it is shown in the negative quadrant of Axis.

The association of *P. corethrurus* and *A. gracilis* with higher soil OM contents and organic management highlights the importance of food resources and permanent soil cover (CO2 and CO3) for their populations (e.g., *A. gracilis* was only found in CO2), in addition to the organic management effect. Furthermore, the results of the PCA also seem to confirm the relative resistance of *Dichogaster* spp. to more disturbed environments with lower OM levels. Similar results were reported for soybean agroecosystems in the region (Brown et al., 2004).

The development of sustainable agroecosystems, which replace inorganic with organic fertilizers have the ability to sustain greater earthworm populations and biomass (Whalen et al., 1998). This was confirmed in the present study with coffee cultivation in comparison to conventional practices. The adoption of organic agricultural production systems that reduce environmental impacts and stimulate the appearance and development of earthworms, and other beneficial soil organisms should be encouraged, due to the positive effects and "environmental services" of these animals to soil, plants and other organisms (Lavelle et al., 2006). This biodiversity enhances nutrient recycling and provides greater biological control, by reducing the pressure of harmful pests, thereby reducing production costs.

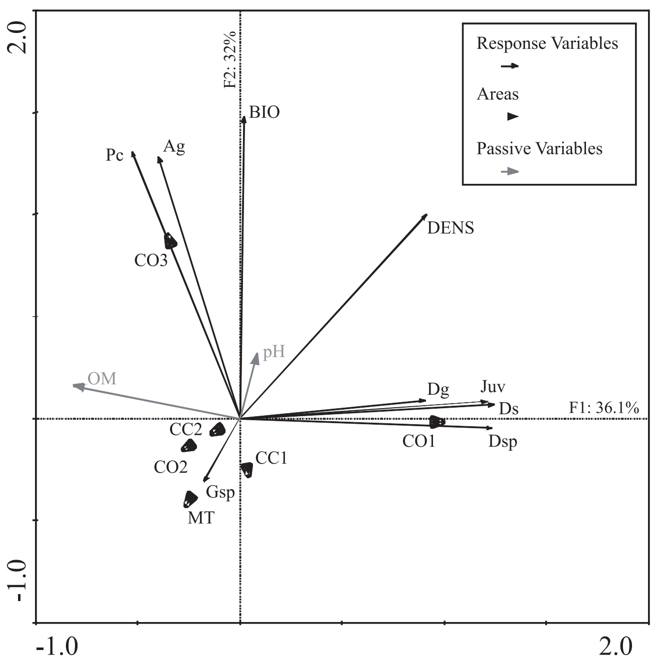

Figure 1. Principal component analysis of the response variables biomass (BIO), population density (DENS), identified earthworm species (Pc, *Pontoscolex corethrurus*; Ag, *Amynthas gracilis*; Gsp, *Glossoscolex* sp.; D, *Dichogaster saliens*; Dg, *D. gracilis* and Dsp, *D.* sp.; and Juv, juvenile specimens), and the passive variables pH_{CaCl_2} (pH) and organic matter (OM).

Conclusion

The biomass, population density and species diversity of earthworms are sensitive indicators of organic management practices; these variables are higher in organic coffee cultivation and are influenced by soil type.

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