Nematodes as soil quality indicators in coffee agroecosystems

Nematoides como indicadores de qualidade de solos em agroecossistemas de café

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Abstract

Coffee family farmers in the Zona da Mata region implemented agroforestry systems focusing on the restoration of soil quality. The impact on soil quality of two agroecological –mature and young- and two conventional coffee agroecosystems was studied and compared to a fragment of Atlantic rainforest. Soil quality was assessed using physic-chemical characteristics together with nematode base indices using: Maturity Index (MI), Plant Parasitic Index (PPI), Channel Index (CI), Enrichment Index (EI) and Structure Index (SI). Nematode diversity was assessed using the Shannon-Wiener Index (H'). Agroecological coffee agroecosystems improved soil chemical characteristics. MI and PPI pointed out to the Atlantic rainforest as the most mature system. CI was higher in the Atlantic rainforest and one conventional system, showing a predominant fungal decomposition channel in these systems. The Atlantic rainforest had the most structured soil food web (SI) and was the least nutrient enriched (EI) system. Diversity of nematodes was higher in the Atlantic rainforest and in mature agroecological systems. These results pointed to the Atlantic rainforest as a great example of high soil quality and suggest that mature agroecological agroecosystems have the potential to achieve multifold objectives, increasing soil fertility, enhancing soil diversity and maintaining a structured soil food web.

Keywords: agroecology, agroforestry, biodiversity, family farming.

Resumo

Agricultores familiares produtores de café na região da Zona da Mata, Brasil, adotam a implementação de sistemas agroflorestais visando a restauração dos solos. O impacto do manejo sobre a qualidade do solo em dois agroecossistemas cafeeiros agroecológicos – maduro e jovem-, e dois agroecossistemas cafeeiros convencionais foi comparado com um fragmento florestal de Mata Atlântica. Além de propriedades físicas e químicas do solo, nematóides foram utilizados como indicadores biológicos para avaliar a qualidade do solo: Índice de Maturidade (MI), Índice de Parasitas de Plantas (PPI), Índice Canal (CI), Índice de Enriquecimento (EI) e Índice de Estrutura (SI). A diversidade de nematóides foi avaliada usando o índice de Shannon-Wiener (H'). Os agroecossistemas agroecológicos melhoraram as características químicas do solo. MI e PPI apontaram a Mata Atlântica como o sistema mais maduro. CI foi maior no fragmento florestal e em um sistema convencional, mostrando um canal de decomposição fúngica predominante nesses sistemas. O fragmento florestal apresentou uma cadeia alimentar do solo mais estruturado (SI), e o menor enriquecimento de nutrientes (EI) dos sistemas. A diversidade de nematóides foi maior no fragmento florestal e em sistemas agroecológicos maduros. Estes Resultados indicam que fragmentos florestais da Mata Atlântica podem ser considerados como exemplo de alta qualidade do solo e sugerem que agroecossistemas agroecológicos maduros têm o potencial para alcançar múltiplos objetivos como o aumento da fertilidade do solo, aumento da diversidade de organismos do solo, e manutenção de uma cadeia alimentar estruturada do solo.

Palavras-chave: agroecologia, sistemas agroflorestais, biodiversidade, agricultura familiar.

Introduction

In 1994, as an alternative to the predominant conventional coffee systems associated with soil degradation and negative environmental impacts some family farmers in Zona da Mata region started to implement agroforestry systems (SAF) following agroecological principles (Cardoso et al., 2001) to restore soil quality. Nematodes used as biological indicators present perfect characteristics to assess soil quality and have contributed to expand the knowledge about soil functioning (Bongers, 1990) complementing the information derived from physicochemical characteristics. Climax soils developed under their climax vegetation, such the Atlantic rainforest soils, can be considered a reference of highest soil quality (Gil-Sotres et al., 2005). Several nematode-base indices have been developed to assess soil quality. The maturity index (MI) (Bongers, 1990) gives an indication of the condition or disturbance of an ecosystem based on the composition of the nematode community. High MI values correspond to higher soil quality ratings, which will be represented by a higher number of nematode families of higher trophic levels and which are representative of mature systems. Plant parasitic nematodes are included in the plant parasitic index (PPI) that has the inverse response of MI. Relative abundances of nematode trophic groups affect nutrient cycling in decomposition and primary production channels (Verhoef & Brussaard, 1990). In more intense agricultural fields, such as those managed under conventional systems, the C/N ratio is generally low and bacteria dominate soil decomposition processes. In less intense agricultural fields, such in agroecological systems, and natural systems, like forest areas, there are more recalcitrant compounds, the C/N ratio is generally higher and fungi dominate soil decomposition processes (Ferris et al., 2004). The relative contribution of bacterial and fungal feeding nematodes to de decomposition channels can be expressed using the Channel Index (CI) (Yeates, 2003). Furthermore, nematodes reflect changes in ecological structure and function of soils (Fiscus & Neher, 2002). Several types of soil disturbance such as those created by the application and form of nutrients applied affect the structure and successional status of nematode communities. The Structure Index (SI) and the Enrichment Index (EI), provides useful information about the structure, the function and most probably the soil food web resiliency to disturbances (Ferris et al., 2001). In addition, diversity of nematodes has been reported to be greater in less disturbed systems (Yeates et al., 2009). Nematode diversity is commonly assessed using the Shannon-Wiener index (H'). The objectives of this study were to identify the nematode populations and diversity of the Atlantic rainforest and the different coffee agroecosystems, in the Zona da Mata region, and compare their soil quality in terms of soil physical, chemical and biological properties through nematode-base indices (MI, PPI,

CI, SI, EI) and H'). We hypothesized that physic-chemical properties are improved in agroecological coffee agroecosystems, and that soil quality measured through nematode-base indices (MI, PPI, SI, EI and H'), is higher in the Atlantic rainforest followed by agroecological coffee agroecosystems, and with conventional coffee agroecosystems accounting for the lowest soil quality.

Material and Methods

The study systems are located in Pedra Redonda, in the surroundings of Brigadeiro State Park. Soils in the study area are classified as humic red-yellow latosol, red-yellow latosol and humic cambisol (Valverde, 1958). The climate of Zona da Mata region is tropical highland climate. Information about the characteristics and management of the farms and forest fragments was obtained through dialogues with farmers. All farmers produce Arabica coffee. The farming systems studied are characterised based on shade regime and type of amendment used as follows: AGR1co: mature agroecological farm 1 with tree shade and cow amendments, AGR1ch: mature agroecological farm 1 with tree shade and chicken amendments, AGR1na: mature agreocological farm 1 with tree shade and natural amendments, AGR2sh: agroecological farm 2 with tree shade and chicken amendments, AGR2su: agroecological farm 2 with no shade and chicken amendments, CNV1: conventional farm 1 with no shade and chemical fertilizers, CNV2: conventional farm 2 with no shade and chemical fertilizers and, RFO: Atlantic rainforest. Field work was conducted in September 2015 to characterize the coffee systems and collect soil. Nematode populations were sampled selecting 5 coffee plants at random and taking 5 composed samples of 100 cc of soil at a depth of 0-10 cm. Five soil samples per system were collected from 0-5cm to determine physical characteristics including: humidity, soil texture, soil bulk density, macroporosity, microporosity and total porosity. A composed sample of every system was brought to the lab for soil chemical analysis, including: Soil pH, exchangeable cations (Ca, Al, Mg), potential acidity (H+Al), K and P, cation exchange capacity (CEC), base saturation (%BS), soil organic matter (OM) and total nitrogen (N), assessed according to EMBRAPA (1997). Nematode extraction was done following the sucrose flotation methodology developed by Jenkins (1964). We identified 100 nematodes per sample to family, or genus when possible, randomly selected, using a stereo microscope and identification guides. Nematode-base indices (MI, PPI, CI, EI and SI were calculated using the NINJA Programme (Sieriebriennikov et al., 2014). One-way ANOVA and multiple comparison tests (Tukey's Honestly Significant Difference) were performed to explore differences between all study systems.

Results and Discussion

Soil texture was similar in all system considered as clay and sandy clay. The Atlantic rainforest had the lowest soil density, in between 26 and 41%, and highest porosity, in between 10% and 30% compared to all systems. Both conventional systems had the highest pH values. Soil nitrogen content was similar in all agroecosystems. P, K, Ca^{2+} and Mg were higher in all agroecological systems and organic matter content was higher for all agroecological systems and the Atlantic rainforest (Table 1).

Table 1: Means of chemical parameters for all study systems

	pH	N (%)	P (mg/ dm^3)	K (mg/ dm^3)	Ca^{2+} (mg/ dm^3)	Mg (cmolc/ dm^3)	H + Al (cmolc/ dm^3)	CEC (cmolc/ dm^3)	BS (%)	OM (dag/ kg)
AGR1ch	5.5	0.28	705.6	977	9.53	6.83	2.5	18.87	88.3	28.69
AGR1co	5.6	0.27	46.7	329	5.92	2.26	6.1	9.02	59.7	14.02
AGR1na	5.8	0.27	15.4	319	7.30	3.79	5.0	11.91	70.4	15.32
AGR2sh	5.4	0.24	242.6	259	5.81	2.83	4.5	9.30	67.4	9.46
AGR2su	5.7	0.28	66.3	299	6.45	3.45	2.3	10.67	82.3	7.83
CNV1	6.1	0.27	10.7	73	1.65	0.46	4.5	2.70	33.8	5.48
CNV2	6.2	0.28	3.5	141	3.93	1.10	5.8	5.39	48.2	6.39
RFO	5.7	0.29	3.0	60	0.46	0.22	18.2	3.23	4.4	22.17

MI and PPI pointed out to the Atlantic rainforest as the most mature system, but provided contradictory results for coffee agroecosystems. CI was higher in the Atlantic rainforest and one conventional system, showing a predominant fungal decomposition channel, and was not sensitive enough to account for differences between coffee agroecosystems.

Table 2: Means of MI, PPI, and CI for al study locations

Index	AGR-1ch	AGR-1cw	AGR-1na	AGR-2sh	AGR2u	CNV1	CNV2	RFO	ANOVA,p
MI	1,49	1,62	1,9	1,45	1,57	1,76	1,39	2,35	<0.001
PPI	2,86	2,67	2,98	3	2,98	2,99	2,94	2,96	0,016
CI	1,17	8,09	7,02	9,91	8,34	45,26	6,01	44,09	0,001

The Atlantic rainforest had the most structured soil food web (SI) together with all mature agroecological systems and was the least nutrient enriched (EI) of all study systems

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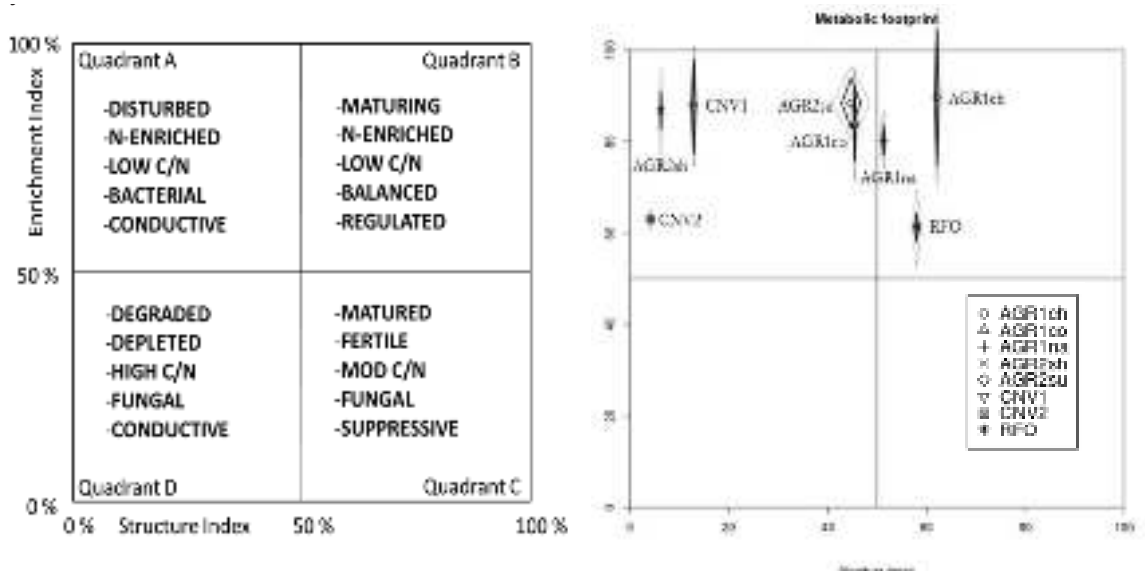

Figure 1 - Diagnosis of the food soil web organized in quadrants based on SI and EI.

The Atlantic rainforest and all AGR1 systems had the highest diversity; conventional systems and both AGR2 systems had the lowest diversity values, and did not differ among them (Table 2). AGR1na is the most similar system to the Atlantic rainforest, regarding diversity and distribution of nematode families within feeding guilds. Both conventional systems and AGR2 systems had less nematode families representing each feeding guild, compared to AGR1 systems and RFO (Figure 2).

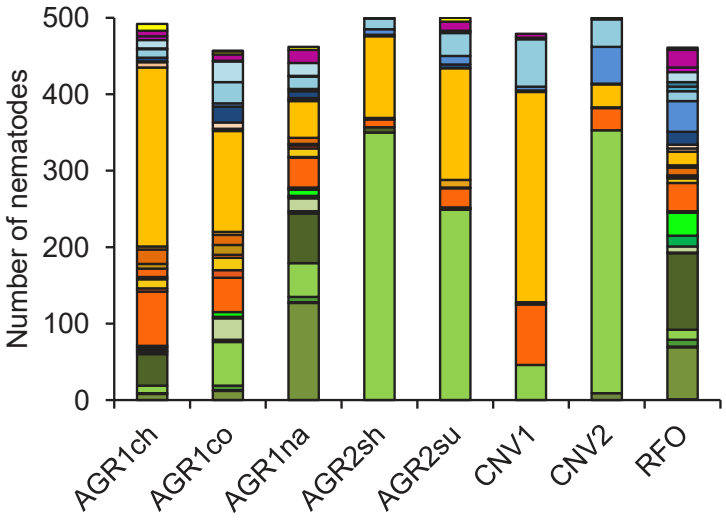

Figure 2 Diversity of nematode families in every study system. Each colour represents each feeding guild: green=plant feeders, orange=bacterial feeders, blue=fungal feeders, purple=omnivore nematodes, yellow=predators. Each tonality within one colour represents one family.

Table 3: Means of Shannon diversity index for all study systems

	AGR1ch	AGR1co	AGR1na	AGR2sh	AGR2su	CNV1	CNV2	RFO
Shannon (H')	1.67bc	2.09c	2.35c	0.68a	1.26ab	1.14ab	0.94a	2.29c

Means with different letters show significant differences (p-value <5%) established by the Tukey's test

Conclusions

Soils developed under the Atlantic rainforest are great examples of high soil quality. Management practices in coffee systems such the use of shade trees and the application of organic amendments, play a major role on achieving high quality soils. Mature agroecological coffee agroecosystems have the potential of achieving multifold objectives, increasing soil fertility, enhancing soil diversity and maintaining a structured soil food web, proper of regulated soils with a balanced decomposition channel. Less mature agroecological systems and conventional systems have a large room for improvement regarding soil physicochemical and biological properties in order to achieve substantial changes in soil quality towards more sustainable systems. Nematode base indices

provide a large amount of information of the soil condition and can be combined with more traditional soil physicochemical analyses to have a more detailed picture of the soil status.

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