NEMATODE COMMUNITIES AS BIOLOGICAL INDICATORS OF DISTURBANCE IN AGRICULTURAL SYSTEMS

R. R. Coutinho[1]*, V. O. Faleiro[2], A. L. F. Neto[2], J. L. P. Meneguci[2], and L. G.Freitas[1]

[1]Universidade Federal de Viçosa, Departamento de Fitopatologia, CEP 36570-000 Viçosa, MG. Telefone: +55xx (31)98757-6222; [2]Embrapa Agrossilvipastoril, Rodovia dos Pioneiros MT-222, Km 2,5, Zona Rural Caixa Postal: 343 CEP: 78550-970 - Sinop – MT; *Corresponding author: raul.coutinho@ufv.br

ABSTRACT

Coutinho, R. R., V. O. Faleiro, A. L. F. Neto, J. L. P. Meneguci, and L. G. Freitas. 2018. Nematode communities as biological indicators of disturbance in agricultural systems. Nematropica 48:186-197.

The native forest area in the Brazilian Cerrado has been replaced by agro-ecosystems and is considered the last agricultural frontier of the country. Thus, the use of sustainable agro-ecosystems can minimize damage to the environment. To assess the sustainability of these systems, there are several types of indicators, including physical, chemical, and biological. Among the biological indicators are nematodes. Thus, the aim of this study was to evaluate nematodes as bio-indicators of disturbance during the establishment of a crop-livestock-forest integrated system (iCLF). Ten farming systems were evaluated (Forest, Crop, Livestock, Crop-Livestock, Livestock-Crop, Crop-Forest, Livestock-Forest, three different Crop-Livestock-Forest, Native Forest, and Spontaneous Vegetation). A native forested area and a spontaneous vegetation area were used as controls (stable environments). Samples were taken at the establishment of the systems and another during the crop season of the second year. The nematode communities were evaluated using total and relative abundance, Shannon-Weaver and Simpson's diversity indexes and evenness, a wealth index (D), a maturity index (MI), a modified maturity index (MMI), a 2-5 maturity index (MI_{2-5}), and a plant parasite index (PPI). The data were subjected to ANOVA and Tukey's test at 5% (P <0.05) significance in order to identify the effects of treatments on the nematode community. Plant-parasitic nematodes dominated at both harvests. Fungivores and bacterivores were reduced after the implantation. A greater number of representative genera of predatory nematodes were observed in the sampling carried out in the second year of implantation of the systems. Omnivores were slightly reduced under the influence of the Crop-Livestock (CL), the three iCLF systems, and the native forest area. The largest Shannon-Weaver's diversity index and evenness were found in the Livestock-Forest (LF), the three iCLF systems, and the spontaneous vegetation area. The iCLF systems were the only systems in the second sampling that increased all diversity indexes, evenness and richness, unlike the Crop (C) system and the CL system. A lower MI value was found in the C system. The greatest MI values were observed in the CL, the three iCLF systems, and the spontaneous vegetation area. The maturity indices (MI and MI_{2-5}), modified maturity index (MMI), and plant parasite index (PPI) indexes indicated that the spontaneous vegetation and native forest areas were reference areas with stable environments. In short, diversity measures and other indexes showed that the LF and iCLF systems generated less disturbance to the environment whereas the C system caused major disturbances.

Key words: biological indicators, disturb, nematode, systems agriculture

RESUMEN

Coutinho, R. R., V. O. Faleiro, A. L. F. Neto, J. L. P. Meneguci, y L. G. Freitas. 2018. Comunidades de nematodos como indicadores biológicos de perturbaciones en sistemas agrícolas. Nematropica 48:186-197.

El área de bosque nativo en el Cerrado brasileño ha sido reemplazada por agroecosistemas y se considera la última frontera agrícola del país. Por lo tanto, el uso de agroecosistemas sostenibles puede minimizar el daño al medio ambiente. Para evaluar la sostenibilidad de estos sistemas, hay varios tipos de indicadores, incluidos los físicos, químicos y biológicos. Entre los indicadores biológicos se encuentran los nematodos. Por lo tanto, el objetivo de este estudio fue evaluar los nematodos como bioindicadores de perturbaciones durante el establecimiento de un sistema integrado de cultivos, ganado, bosques (iCLF). Se evaluaron diez sistemas agrícolas (Bosque, Cultivo, Ganado, Cultivo-Ganado, Ganado-Cultivo, Cultivo-Bosque, Ganadería-Bosque, tres diferentes Cultivo-Ganadería-Bosque, Bosque nativo y Vegetación espontánea). Se utilizaron un área boscosa nativa y un área de vegetación espontánea como controles (ambientes estables). Se tomaron muestras en el establecimiento de los sistemas y otra durante la temporada de cosecha del segundo año. Las comunidades de nematodos se evaluaron utilizando la abundancia total y relativa, los índices de diversidad y uniformidad de Shannon-Weaver y Simpson, un índice de riqueza (D), un índice de madurez (MI), un índice de madurez modificado (MMI), un índice de madurez de 2-5 (MI_{2-5}), y un índice de parásitos vegetales PPI). Los datos se sometieron a ANOVA y la prueba de Tukey al 5% (P <0.05) de importancia para identificar los efectos de los tratamientos en la comunidad de nematodos. Los nematodos parásitos de plantas dominaron en ambas cosechas. Los fungívoros y bacterívoros se redujeron después de la implementación de los sistemas. Un mayor número de géneros representativos de nematodos depredadores se observaron en el muestreo realizado en el segundo año de implantación de los sistemas. Los omnívoros se redujeron ligeramente bajo la influencia de Crop-Livestock (CL), los tres sistemas iCLF y el área de bosque nativo. El índice de diversidad y la uniformidad de Shannon-Weaver más grandes se encontraron en Livestock-Forest (LF), los tres sistemas iCLF y el área de vegetación espontánea. Los sistemas iCLF fueron el único sistema en el segundo muestreo que incrementó todos los índices de diversidad, uniformidad y riqueza, a diferencia del sistema Crop (C) y el sistema CL. Se encontró un valor de MI más bajo en el sistema C. Los mayores valores de MI se observaron en la CL, los tres sistemas iCLF y el área de vegetación espontánea. Los índices de madurez (MI y MI_{2-5}), el índice de madurez modificado (MMI) y los índices de índice de parásitos de las plantas (PPI) indicaron que la vegetación espontánea y las áreas de bosques nativos eran áreas de referencia con ambientes estables. En resumen, las medidas de diversidad y otros índices mostraron que los sistemas LF e iCLF generaron menos perturbaciones para el medio ambiente, mientras que el sistema C causó perturbaciones importantes.

Palabras clave: indicadores biológicos, disturbios, nematodos, sistemas agrícolas

INTRODUCTION

Brazil is among the countries with the highest biodiversity in the world. The Cerrado contains the second largest biome yet is considered the last agricultural frontier in the country. The Cerrado has undergone the replacement of native vegetation ecosystems with agricultural ecosystems (Mittermeier *et al*., 1997; Borlaug, 2002). Sustainable agro-ecological systems are needed in order to preserve the biodiversity and functioning of the Cerrado ecosystem.

Agroforestry systems (AFS), in addition to reducing the risks of environmental degradation generated by agricultural practices, improve the chemical, physical, and biological characteristics of the soil. According to Daniel *et al.* (1999), AFS are forms of natural resource use and management in which woody species such as trees, shrubs, and palms are used in intentional association with agricultural crops or animals on the ground, simultaneously or in time sequence. AFS may be classified as agroforestry, silvopastoral, or agrosilvopastoral. The integration of Crop-Livestock-Forest (iCLF), the basis of the agrosilvopastoral system, has been studied as an alternative production system. iCLF uses technical principles for maximizing productivity and providing greater economic and environmental efficiency by diversifying production with intercropped trees, agricultural crops, pasture, and/or animals (Marques, 1990; Alvarenga, 2010). The iCLF system stands out due to the benefits it has demonstrated over the years. iCLF systems improve the chemical, physical, and biological properties of the soil, increase efficiency of input use, reduce costs of agricultural activities, reduce the costs of management of livestock and forestry, allow eco-wood production, and reduce the use of marginal land for agricultural production (Dantas, 1994; Medrado, 2000).

Several methods have been used to evaluate the performance of ecosystems, including chemical, physical, and biological indicators. Nematodes act as biomarkers for soil quality assessments and environmental changes because they: a) occur in any environment that provides a source of organic carbon, b) occur in any type of soil and climatic condition, c) can establish multi-species communities, d) contain taxa that have different sensitivities to disturbances, and e) present trophic diversity that is easily identified by morphological analysis (Neher, 2001; Goulart, 2002; Neilson, 2005; Cares, 2006; Tomazini, 2008). According to Whitford *et al.* (1982), one of the greatest reasons to use soil nematodes as quality indicators and for assessing environmental changes is their regulatory roles in nutrient cycling (e.g., organic matter decomposition). Abundance, diversity, and richness attributes are used to characterize nematode communities that promote their use as environmental change, soil quality, and sustainability indicators (Neher, 2001). An additional approach to obtaining the performance data for nematodes against disturbances in a system is the use of ecological indexes which take into consideration the life strategies nematodes have developed over the years. Nematodes are assigned a rating from 1 to 5 for the cp value, where cp means ”colonizer” and ”persister”, respectively, compared to “r strategists” and “k strategists” (Bongers, 1990).

According Bongers and Bongers (1998), nematodes with cp values of 1 and 2 are considered colonizers and have tolerance to various disturbances in the environment. Nematodes with cp values of 4 and 5 are considered persistent and sensitive to disturbances. Nematodes with a cp value of 3 have characteristics between groups 2 and 4 and are relatively sensitive to disturbances. Since soil nematode communities are sensitive to changes in plant complexity and anthropogenic disturbances in agricultural areas, these organisms can be used as bioindicators in monitoring in areas of soil quality recovery, such as Crop-Livestock-Forest systems. Thus, the objective of this study was to evaluate the changes in nematode communities in the establishment of a sustainable baseline iCLF system for the use of these organisms as a bio-indicators of disturbance in areas with different plant composition.

MATERIALS AND METHODS

Location, description, and history of the area

The experimental area belongs to the research unit of agrosilvopastoral Embrapa, located in the municipality of Sinop, in the north of Mato Grosso State, in a region of transition in the Cerrado/Amazon Rainforest. Its geographic position is latitude 11°50'53" south and longitude 55°38'57" west. According to the Embrapa system of soil classification, the soil was a Typic Hapludox dystrophic typical Argillaceous, A-Moderate with flat terrain and vegetation called Rainforest Subperenifólia. Previously, the entire experimental area was deforested and then planted with cassava (*Manihot esculenta*), rice (*Oryza sativa* L.), soybean (*Glycine max* L.), soybean and corn (*Zea mays* L.) in winter, soybean and cotton (*Gossypium hirsutum* L.) in summer, and then left fallow for the subsequent assembly of the experiment.

Under these conditions, a long-term experiment was conducted to evaluate the establishment of iCLF systems in the state of Mato Grosso. Soil samples were collected at 10 different farming system sites (Table 1) and in an adjoining area with spontaneous natural vegetation and a native forest area, which were both used as references.

Experimental design

The experimental design was randomized blocks with 10 treatments and 4 repetitions, totaling an experimental area of 80 ha. Each plot was 2 ha, except treatments F and C which were 1 ha (Fig.1).

Assembling and processing of samples

Two soil samplings were performed. The first soil sample was collected at the establishment of

Table 1. Different plant systems established and monitored for nematode communities in the Brazilian Cerrado.

Farming system	Code	Description
Forest	F	952 eucalyptus (*Eucalyptus urograndis*) plants per hectare
Crop	C	First year was soybean, followed by corn; Second year was soybean followed by off-season maize intercropped with pasture
Livestock	L	Bread grass (*Urochloa brizantha* cv. Marandu) pasture
Crop-Livestock	CL	An integrated system with crop cultivation in the first two years, as described in treatment "C." For the next 2 yr, pasture farming was established, as described in "L."
Livestock-Crop	LC	Grass grown for first two years, as described in treatment "L"; crops were cultivated, as described in treatment “C” for 2 yr
Crop-Forest	CF	Forest was cultivated (eucalyptus) in triple rows spaced 30 m apart (300 plants/ha), and the space between the lines was cultured with crop treatment "C.”
Livestock-Forest	LF	An integrated system with forest crops (eucalyptus) planted in triple lines spaced 30 m apart, and the space between the lines was cultivated with pasture, as described in treatment "L."
Crop Livestock Forest	$iCLF_1$	An integrated system with the cultivation of forest (eucalyptus) in triple lines spaced 30 m apart, and the space between the lines was planted with crops for the first 2 yr, as described in treatment "C" and then cultivated as pasture for 2 yr, as “L”
System iCLF	$iCLF_2$	Forest crops (eucalyptus) were planted in spaced triple lines 30 m apart, and the space between the lines was cultured with pasture in the first two years, as described in treatment "L", and then planted with tillage crops, as described in treatment "C ", in the two subsequent years.
System iCLF	$iCLF_3$	Forest crops (eucalyptus) were planted in spaced triple lines 30 m apart with soybean grown annually in the space between the lines in summer. Corn was grown along with grazing in the off-season; with the corn harvest, there was pasture establishment in the winter for grazing animals (growing/finishing).
Native Forest	NF	Remaining fragment of secondary forest, second generation of RADAM Brazil (1979), as Seasonal Semideciduous Forest. Located within the experimental field, composed of a total area of 3,0 km in length with an average of 200 m.
Spontaneous Vegetation	SV	Predominant species *Urochloa brizantha* cv. Marandu. Mixed with *Penisetum setosum, Eleusine indica, Commelina benghalensis, Conyza bonariensis, Cenchrus echinatus, Ipomea sp.*

the systems, when the area was still uncultivated, and the second was in the second year of the experiment. Both samplings corresponded to the rainy season in the region. With the aid of a Dutch auger, 6 subsoil samples at a depth of 0-20 cm were collected and homogenized to create a composite sample of approximately 500 g to 1 kg of soil. Nematode extraction was performed according to the method by Jenkins (1964) using 250 cm^3 of soil for the process. The extracted nematodes were fixed in Golden solution (Hopper, 1970) for further evaluation. In the forest and spontaneous vegetation areas, a composite sample was taken.

Morphological identification and quantification of nematode communities

The identification of communities was performed by classical taxonomy using an optical microscope with an inverted position objective. The entire volume of the sample was evaluated. To confirm the identification of each species, slides were mounted and taken to an optical light microscope, which increased the magnification 100× with the aid of immersion oil.

For plant-parasitic nematodes, identification relied upon descriptions found in Mai (1996) and in C. I. H descriptions of plant-parasitic nematodes (Sheila, 1900). For the suborder Criconematina, we additionally used Wouts (2006). Free-living nematodes were identified according to Smart and Khoung (1983). The classification of eating habits was based upon Yeates *et al*. (1993).

Characterization of nematode communities

From the identification and quantification of genera in each sample, the following measures and ratios were calculated: a) total abundance of nematodes (i.e. total number of individuals per sample) and relative abundance (percentage of each genus in the total abundance) (Magurran, 1988); b) diversity of genera (D) given by the formula (D = (S-1)/log N, where S is the number of genera and N the number of individuals) (Magurran, 1988); c) Shannon-Weaver's diversity index (H') and evenness (J') were calculated using the formulas H' = ΣPi x logPi and J' = H '/H'max where Pi is the proportion of species in relation to the total number of species found in the surveys, and H'max is the maximum diversity of the environment under study calculated as H'max = logS, where S is the number of sampled genera (Shannon, 1948; Elliot, 1990); and d) Simpson's diversity index (DS) and evenness (ED) were calculated as DS = 1-Σ (ni/N)2 where ni is the number of individuals for each genus and N is the total number of individuals, and ED = Ds/DSmax where Dmax is the maximum diversity given by Dmax = (S-1)/S, where S is the number of sampled genera (Simpson, 1949; Elliott, 1990).

To evaluate disorder, the maturity index (MI), the plant-parasite index (PPI) (Bongers, 1990), the modified maturity index (MMI) (Yeates, 1994), and the maturity index (MI_{2-5}) based only on cp values from 2 to 5 for nematodes (Bongers and Korthals, 1993) were used. All of these indexes were calculated as Σv(i) x f(i), where v(i) is the nematode cp value and f(i) is the relative frequency of the genus "i" in the sample. Smaller values in the indexes indicate that the environment suffered a higher level of disturbance.

Statistical analyses

For analysis of total and relative abundance only a descriptive statistic of the data was applied. For the other indices studied, the data were submitted to analysis of variance (ANOVA), at a significance level (α) of 5%, and the mean was compared by the Tukey test (*P*≤0.05).

RESULTS AND DISCUSSION

Total and relative abundance

All treatments showed an increase in the total abundance of the nematodes from the first to the second sampling (Table 2). The forest area possessed the greatest values because this area had a greater diversity of fauna and flora, thus generating a higher addition of organic matter and greater root volume (Santiago *et al*. 2005). The increase in the total abundance in the treatments in the second sampling was mainly due to the population of Pratylenchus since the crops in this experiment were nematode hosts.

Table 2. Total nematode abundance per 250 cm^3 of soil in the different systems of agriculture, native forest and spontaneous vegetation collected at the moment of conversion of the Brazilian Cerrado (1^{st}) for the different agricultural systems and in the second year of systems implantation (2^{nd}).

Farming system	Total abundance^z	
	1^{st}	2^{nd}
Forest	115	304
Crop	105	1543
Livestock	106	253
Crop-Livestock	105	684
Livestock-Crop	79	171
Crop-Forest	138	636
Livestock-Forest	76	151
System $iCLF_1$	119	861
System $iCLF_2$	74	270
System $iCLF_3$	110	900
Native Forest	387	215
Spontaneous Vegetation	0	10

^{z}Mean of four replicates.

In all treatments at both sampling times, the plant-parasite trophic group had the highest relative abundances (Table 3). The PPI showed a significant increase at the second sampling, which can be correlated with the increase in food availability due to increased root volume with the implementation of the systems (Norton, 1978). *Helicotylenchus* and *Macroposthonia* were the dominant genera and were present in all systems, including the forest area, at both sampling times. These genera were only missing in the spontaneous vegetation area. The dominance of these genera has been reported in other studies where different systems and agricultural uses predominated (Figueira, 2008; Tomazini, 2008). As these two genera are found abundantly in all systems and also in the forest area, they are not a good reference in the evaluation of environmental disturbances, analyzing only the abundance, but they were

Table 3. Relative abundance of nematodes in different agricultural farming systems, native forest and spontaneous vegetation collected at the time of conversion from native Brazilian Cerrado (1st) for the different agricultural systems and in the second year of systems implantation (2nd).

Genres	*cp* Value	Forest 1st	Forest 2nd	Crop 1st	Crop 2nd	Livestock 1st	Livestock 2nd	Crop-Livestock 1st	Crop-Livestock 2nd	Livestock-Crop 1st	Livestock-Crop 2nd	Crop-Forest 1st	Crop-Forest 2nd
Plant Parasites													
Helicotylenchus	3	23.14	31.25	15.48	55.04	6.87	0.99	18.66	46.80	8.20	0.73	18.00	48.07
Macroposthonia	3	37.77	48.85	44.29	23.49	36.73	24.95	18.66	11.33	43.22	37.54	48.73	5.27
Pratylenchus	3	0.44	2.88	0.24	16.22	_	55.05	1.20	28.83	1.89	29.62	0.73	36.12
Meloidogyne juveniles	3	1.31	0.49	0.71	0.26	0.71	_	0.72	0.77	_	1.47	0.55	0.51
Paratrichodorus	4	0.44	0.08	0.48	0.66	_	0.59	0.96	1.75	_	0.73	0.55	1.69
Discocriconemella	3	_	_	_	_	_	_	_	_	_	_	_	_
Fungivores													
Aphelenchoides	2	0.66	0.25	0.95	0.13	2.61	0.40	1.20	0.07	1.58	0.29	0.55	0.39
Aphelenchus	2	9.61	7.40	6.90	0.57	22.99	1.68	11.48	2.63	11.99	1.17	6.00	2.16
Ditylenchus	2	0.44	_	0.48	_	0.71	_	4.07	_	1.58	_	0.55	0.16
Tylenchus	2	1.09	0.90	1.43	0.11	2.37	1.19	1.91	0.26	2.84	1.32	0.18	0.16
Bacterivores													
Acrobeles	2	4.15	3.62	4.52	0.92	3.55	5.25	9.09	2.81	4.42	8.94	4.36	2.24
Rhabditis	1	6.33	0.33	5.48	0.62	7.11	0.79	7.89	0.40	12.30	0.88	5.09	0.59
Chiloplacus	2	1.75	0.33	2.62	0.44	3.32	0.50	0.48	0.91	0.32	0.59	1.27	0.75
Diploscapter	1	_	0.08	_	0.05	_	0.69	_	0.04	_	_	_	0.16
Eucephalobus	2	_	_	_	0.24	_	_	_	0.07	_	0.15	_	_
Predators													
Prionchulus	4	_	0.25	0.48	0.02	0.47	0.10	0.72	0.07	0.32	0.88	1.09	_
Miconchus	4	_	_	_	_	_	0.10	_	_	_	_	_	_
Tobrilus	3	_	0.41	_	0.18	_	0.40	_	0.33	_	0.44	_	0.31
Tripyla	3	_	_	_	_	_	_	_	_	_	0.29	_	_
Mononchus	4	_	_	_	_	_	0.10	_	0.04	_	0.59	_	_
Iotonchus	4	_	_	_	_	_	_	_	_	_	_	_	0.04
Sporonchulus	4	_	_	_	0.03	_	_	_	0.04	_	_	_	_
Omnivores													
Dorylaimus	4	8.95	1.15	12.14	0.71	5.92	2.77	17.70	1.61	5.68	2.93	7.27	0.71
Aporcelaimus	5	_	0.08	_	0.05	_	0.10	_	0.11	_	0.15	_	_
Pungentus	4	3.93	1.64	3.81	0.26	6.64	4.36	5.26	1.13	5.68	11.29	5.09	0.67

Table 3. Continued.

		Livestock-Forest		$iCLF_1$		$iCLF_2$		$iCLF_3$		Native forest		Spontaneous vegetation	
	cp Value	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Plant Parasites													
Helicotylenchus	3	33.66	21.89	38.24	54.53	23.41	9.64	28.96	49.56	1.03	0.36	_	_
Macroposthonia	3	23.76	31.67	41.81	19.92	35.91	30.77	41.75	24.47	7.49	3.43	_	_
Pratylenchus	3	_	20.73	_	16.93	0.91	24.00	1.01	17.50	2.33	5.05	_	52.63
Meloidogyne juveniles	3	_	0.17	0.21	0.87	0.23	5.19	0.34	0.19	4.13	0.90	_	_
Paratrichodorus	4	_	1.49	_	0.78	1.36	1.85	_	0.81	_	_	_	5.26
Discocriconemella	3	_	_	_	_	_	_	_	_	56.07	47.47	_	_
Fungivores													
Aphelenchoides	2	_	_	0.42	_	0.91	_	_	0.19	0.26	1.81	_	_
Aphelenchus	2	17.16	1.49	2.94	0.78	5.68	2.59	5.05	1.61	3.10	2.35	_	5.26
Ditylenchus	2	0.66	0.33	0.63	0.06	2.05	0.46	0.34	0.03	_	0.36	_	_
Tylenchus	2	_	0.50	0.42	0.17	1.36	1.48	1.01	0.31	10.59	14.80	_	5.26
Bacterivores													
Acrobeles	2	5.28	7.46	2.10	1.97	2.95	8.80	3.70	1.50	8.01	14.26	_	10.53
Rhabditis	1	4.62	3.32	6.09	0.70	5.00	1.30	4.04	0.64	2.84	0.54	_	_
Chiloplacus	2	0.99	_	0.63	0.64	2.95	0.74	2.02	0.72	0.26	0.54	_	_
Diploscapter	1	_	0.33	_	_	_	_	_	0.08	_	_	_	_
Eucephalobus	2	_	_	_	_	_	_	_	_	_	_	_	_
Predators													
Prionchulus	4	_	0.83	_	0.20	1.14	0.09	0.34	0.14	1.03	_	_	_
Miconchus	4	_	_	_	0.03	_	_	_	_	_	1.99	_	_
Tobrilus	3	_	0.17	_	0.12	_	0.74	_	0.11	_	1.62	_	_
Tripyla	3	_	_	_	_	_	0.09	_	_	_	0.18	_	_
Mononchus	4	_	_	_	0.03	_	0.09	_	0.06	_	1.99	_	_
Iotonchus	4	_	_	_	_	_	0.09	_	0.03	_	0.18	_	_
Sporonchulus	4	_	_	_	_	_	_	_	_	_	_	_	_
Omnivores													
Dorylaimus	4	7.59	2.32	4.20	1.25	12.27	3.71	3.37	0.97	1.03	1.44	_	21.05
Aporcelaimus	5	_	1.00	_	0.38	_	0.37	_	0.03	_	_	_	_
Pungentus	4	6.27	6.30	2.31	0.64	3.86	7.97	8.08	1.06	1.81	0.72	_	_

essential in the results of the other ecological indices presented in this work.

Overall, the fungivores and bacterivores experienced reduced numbers in the second sampling, except in the native forest, showing the impact that each farming system had on the soil microbial community. The predator trophic group contributed little to the ecosystem measurements. Only the F, L, and LF systems had greater abundance of predators compared to the first sampling, but there was an increase in the number of genera of this trophic group in all treatments, mainly in the iCLF and except in the area of spontaneous vegetation. The low dominance of the predator group in agricultural ecosystems has been described by some researchers (Freckman and Ettema, 1993; Mattos, 2002; Tomazini, 2008; Torres, 2006), showing that the greater the human intervention in the land-use system, the greater the disturbance caused to the environment, since this group of nematodes presents high sensitivity to changes in the environment (Bongers and Bongers, 1998).

The population of omnivorous nematodes increased in the second sampling only in the CL system and maintained values close to the $iCLF_2$ system and native forest compared to the other treatments (Table 3). We infer that these farming systems had less disturbance on the environment compared to the other farming systems. Omnivore nematodes occupy higher levels of the food chains and are thus considered sensitive to environmental changes (Wasilewska, 1997; Niles and Freckman, 1998).

Diversity, equitability, and richness

In the first sampling, although the CL and the $iCLF_2$ farming systems had greater species diversity (D), they did not differ from measures in the other farming systems (P>0.05) (Table 4). D was ineffective in differentiating the ecosystem disturbance of the farming systems to the environment. Freckman and Ettema (1993) also considered the diversity index as a means to distinguish communities when they studied eight different systems composed of perennial and annual crops. Additionally, in the first sampling, the Shannon-Weaver (H') and Simpson's (DS) diversity indexes and their respective indexes of evenness (J and ED) showed no significant differences (P>0.05). These results show a very homogeneous experimental area, inferring that any change in these indices after the implementation of the treatments was caused by the establishment of each treatment.

The native forest area, despite having greater total abundance of nematodes in the first sampling, provided low values of diversity, evenness and richness indexes. According to Andrade *et al.* (2004) and Figueira (2008), greater abundance does not always imply greater diversity.

In the second sampling (Table 4), D showed the same behavior as the first sample and did not differ between the treatments. This lack of significance was observed in the diversity indexes and Simpson's evenness. Greater values in the Shannon-Weaver's diversity index were observed under the influence of LF and $iCLF_2$, which differed from the other farming systems but had similar values as the reference native forest and spontaneous vegetation areas. Gomes and Ferreira (2004) stated that the increase in environmental stress levels have been linked to decreased diversity, evenness and richness. Therefore, the lower values of these indexes observed in C suggests that this farming system caused greater stress on the environment. The LF and $iCLF_2$ farming systems were less harmful to the environment. Furthermore, C allowed dominance of some genera, as J' reflected very low values in a non-normal distribution of the nematode community, suggesting an imbalance in the ecosystem (Daget, 1976). Cares and Huang (1991) stated that the use of monoculture often favors certain groups of plant-parasitic nematodes. In addition, the continued use of monocultures in the same area causes negative effects on the ecosystem, such as increased presence of pests and diseases and a disorder in the physical and chemical structure of the soil (Zimmermann, 2009).

Another factor that implies that the $iCLF_2$ system caused less stress to the environment was the fact that it had greater abundance of omnivores, especially *Dorylaimus*. The Dorylaimidae has been reported to be sensitive to different cultural practices (Yeates *et al*., 1993; Rodrigues, 2011; Arieira, 2012). Campos *et al.* (2010) showed that crop-livestock-forest integrated systems using *Eucalyptus* as a forest component with *Urochloa* in the early years, as described for the systems LF and $iCLF_2$, provides a better ecosystem for nematodes, mostly free-living nematodes, which are directly related to soil ecological processes.

Table 4. Diversity, richness and evenness of nematode community and indices used to verify ecosystem disruption at establishment of 10 different farming systems compared to an undisturbed native forest and a spontaneous vegetation area at the time of establishment and in the second year of implantation of the systems. F (Forest), C (Crop), L (Livestock), CL (Crop-Livestock), LC (Livestock-Crop), CF (Crop-Forest), LF (Livestock-Forest), Crop Livestock Forest ($iCLF_{1,2,3}$), NF (Native Forest) and SV (Spontaneous Vegetation).

	1st Sampling											
Index[y]	F	C	L	CL	LC	CF	LF	$iCLF_1$	$iCLF_2$	$iCLF_3$	NF	SV
D	4.07 a[z]	4.40 a	3.92 a	5.20 a	4.45 a	4.50 a	3.55 a	3.78 a	3.91 a	5.01 a	3.89	-
H'	0.68 a	0.67 a	0.68 a	0.82 a	0.65 a	0.69 a	0.65 a	0.65 a	0.60 a	0.74 a	0.62	-
J'	0.73 a	0.68 a	0.73 a	0.78 a	0.69 a	0.69 a	0.75 a	0.75 a	0.67 a	0.71 a	0.66	-
DS	0.76 a	0.72 a	0.73 a	0.85 a	0.75 a	0.72 a	0.74 a	0.77 a	0.71 a	0.78 a	0.65	-
ED	0.83 a	0.78 a	0.80 a	0.90 a	0.80 a	0.78 a	0.83 a	0.86 a	0.78 a	0.84 a	0.73	-
MI	1.36 a	1.25 a	1.65 a	1.78 a	1.55 a	1.33 a	1.41 a	1.02 a	1.10 a	1.17 a	0.57	0
MMI	2.83 a	2.93 a	2.76 a	2.92 a	2.77 a	3.02 a	2.84 a	2.90 a	2.99 a	3.00 a	2.73	0
MI_{2-5}	2.77 a	2.87 a	2.70 a	2.85 a	2.62 a	2.97 a	2.80 a	2.80 a	2.94 a	2.95 a	2.67	0
PPI	1.42 a	1.65 a	1.09 a	1.13 a	1.21 a	1.68 a	1.43 a	1.87 a	1.87 a	1.81 a	2.16	0

	2nd Sampling											
Index	F	C	L	CL	LC	CF	LF	$iCLF_1$	$iCLF_2$	$iCLF_3$	NF	SV
D	3.80 a	3.94 a	4.16 a	4.34 a	5.38 a	4.17 a	4.63 a	4.28 a	4.88 a	4.12 a	5.01	5.33
H'	0.57 bc	0.47 c	0.56 bc	0.53 bc	0.65 ab	0.56 bc	0.66 a	0.55 bc	0.77 a	0.52 bc	0.65	0.81
J'	0.60 ab	0.41 b	0.55 ab	0.47 ab	0.58 ab	0.52 ab	0.63 a	0.50 ab	0.72 a	0.47 ab	0.59	0.80
DS	0.64 a	0.54 a	0.62 a	0.56 a	0.69 a	0.64 a	0.71 a	0.61 a	0.76 a	0.57 a	0.62	0.82
ED	0.71 a	0.59 a	0.68 a	0.61 a	0.74 a	0.69 a	0.77 a	0.66 a	0.83 a	0.62 a	0.67	0.89
MI	0.74 ab	0.08 b	0.76 a	0.27 ab	0.93 a	0.18 ab	0.73 a	0.35 ab	0.85 a	0.20 ab	0.68	1.32
MMI	2.88 a	2.97 a	2.97 a	2.96 a	3.01 a	2.97 a	3.06 a	2.98 a	2.96 a	2.97 a	2.91	2.63
MI_{2-5}	2.80 b	2.96 a	2.93 a	2.97 a	3.02 a	2.94 ab	2.96 a	3.00 a	2.97 a	2.97 a	2.76	2.61
PPI	2.06 a	2.25 a	2.19 a	2.70 a	2.10 a	2.77 a	2.27 a	2.66 a	2.14 a	2.78 a	2.08	1.32

[y]D=richness; H '= Shannon-Weaver Diversity; J '= Equitability Index Shannon-Weaver; DS = Simpson's Diversity; ED = Equitability Index Simpson; MI = Maturity Index; MMI = Modified Maturity Index; MI_{2-5} = Maturity Index considering nematodes with *cp* values 2-5; PPI = Plant Parasite Index.

[z]Means followed by the same letter on the line by sampling, do not differ significantly at 5% by Tukey test.

Disturbance

No index used to measure disturbance in an area was significantly different in the first sampling (Table 4). These results confirmed the hypothesis that the experimental area was uniform, as seen by the indexes D, H', J', DS, and ED. In the second sampling (Table 4), C caused greater disturbance to the ecosystem and presented the lowest values for MI, significantly differing from L, LC, LF and $iCLF_2$. These latter four farming systems presented results more similar to that observed in the reference native forest and spontaneous vegetation areas. Theses farming systems behaved as more stable environments. Bongers (1990) classified disturbance levels using MI where a value less than 2 represented environments with high disturbance and values of 4 or more represented stable environments.

Although not being significantly different among the treatments, the MMI with the lowest value was observed in the F farming system. F probably suffered the fewest effects of the plant-parasitic group of nematodes. The F farming system mainly consisted of the genus *Pratylenchus* in the second sampling (Table 4).

The maturity index for the cp values for nematodes varied from 2 to 5 (MI2-5). Little change was observed in MMI (Table 4), indicating that nematodes with a cp value of 1 were considered opportunistic-settlers and did not influence MMI calculations. A similar result was found by Figueira (2008) when using nematodes as soil quality indicators in agro-ecosystems. Low relative abundances were found with cp 1 nematodes. This may have been due to the farming systems being under no-tillage cultivation. Without the incorporation of organic matter, a process that favors cp 1 species, these nematodes would not be expected to increase (Ettema and Bongers, 1993; Ferris *et al*., 1996). With regards to the reference areas, native forest and spontaneous vegetation, in the two sampling periods, it was observed that in the native forest, the index values were similar between collections. Little change occurred and, consequently, greater ecological stability was observed. Several studies have demonstrated that native forests are more stable when compared to cultivated areas (Hánėl, 1995; Mattos, 1999; Tomazini, 2008).

The plant parasite index (PPI) had greater values in the second sampling due to an increase in the abundance of the plant parasite trophic group (Table 4). Featuring a minimal population of plant-parasitic nematodes, the spontaneous vegetation area was the system with the lowest PPI value. The farming systems were enriched at similar levels because the PPI tends to respond to enrichment and/or stress, decreasing the MI (Bloemers *et al.* 1997; Neher, 2001), which occurred in this study. The inverse relationship of PPI and A has been described by various authors (Mondino *et al.,* 2009; Mondino, 2010; Rodrigues, 2011; Arieira, 2012).

The greatest abundance of genera occurred in Discocriconemella (Criconematidae) and was the main factor of high PPI values in F. This abundance suggests less disturbance, since the genera of the Criconematidae have been reported as showing a predilection to live in environments without agricultural intervention (Arieira, 2012; Tomazini, 2008).

CONCLUSIONS

The nematode communities in soils are a reflection of the vegetation composition of the areas and can be used as indicators of environmental disturbances, with a reduction in the populations of these organisms in areas with less plant complexity.

LITERATURE CITED

Alvarenga, C. 2010. Sistema integração lavoura-pecuária-floresta: Condicionamento do solo e intensificação da produção de lavouras. Informe Agropecuário 31:59–67.

Andrade, E. P., S. P. Huang, and C. H. B. Miranda. 2004. Comunidade de nematoides em oito sistemas de uso da terra em Mato Grosso do Sul. Fitopatologia Brasileira 29:186.

Arieira, G. 2012. Diversidade de nematoides em sistemas de culturas e manejo do solo. Universidade Estadual de Londrina.

Bloemers, G. F., M. Hodda, and P. J. D. Lambshead. 1997. The effects of forest disturbance on diversity of tropical soil nematodes. Oecologia 111:575-582.

Bongers, A. M. T., and G. Korthals. 1993. The maturity index: An instrument to monitor changes in the nematode community structure. Summaries of the 45th International symposium on Crop protection, Gent, p. 80.

Bongers, T. 1990. The maturity index: An ecological measure of environmental disturbance based on nematode species composition. Oecologia 83:14-19.

Bongers, T., and M. Bongers. 1998. Functional diversity of nematodes. Applied Soil Ecology 10:239-251.

Borlaug, N. E. 2002. Feeding a world of 10 billion people: The miracle ahead. In Vitro Cellular and Developmental Biology Plant 38:221-228.

Campos, D. T. S., W. L. M. P. Scaramuzza, F. J. Wruck, and T. Cobucci. 2010. Comportamento microbiano em solos sob o sistema de lavoura pecuária floresta Pp. 23 in Relatório parcial de atividades. Universidade Federal de Mato Grosso, Cuiabá.

Cares, J. E. 2006. Nematóides como indicadores ambientais de solo. Pp. 14-16 *in* Congresso Brasileiro de Nematologia, 26 ed. Sociedade Brasileira de Nematologia, Campos dos Goytacazes.

Cares, J. E., and S. P. Huang. 1991. Nematode fauna in natural and cultivated cerrados of central Brazil. Fitopatologia Brasileira 16:199-209.

Daget, J. 1976. Les modèles mathématiques en écologie. Masson.

Daniel, O., L. Couto, R. Garcia, and C. A. M. Passos. 1999. Proposta para padronização da terminologia empregada em sistemas agroflorestais no Brasil.

Dantas, M. 1994. Aspectos ambientais dos sistemas agroflorestais. Pp. 433-453 *in* Congresso Brasileiro Sobre Ecossistemas Agroflorestais. Embrapa-CNPF, Porto Velho.

Elliot, C. 1990. Diversity index. Pp. 370 *in* Principles of managing forest for biogical diversity. Englewood Cliffs NI, Prentice Hall.

Ettema, C. H., and T. Bongers. 1993. Characterization of nematode colonization and succession in disturbed soil using the Maturity Index. Biology and Fertility of Soils 16:79–85.

Ferris, H., R. C. Venette, and S. S. Lau. 1996. Dynamics of nematode communities in tomatoes grown in conventional and organic farming systems, and their impact on soil fertility. Applied Soil Ecology 3:161-175.

Figueira, A. F. 2008. Nematóides como indicadores de qualidade do solo em agroecossistemas no cerrado do Estado do Mato Grosso do Sul. Universidade Federal Rural do Rio de Janeiro.

Freckman, D. W., and C. H. Ettema. 1993. Assessing nematode communities in agroecosystems of varying human intervention. Agriculture, Ecosystems and Environment 45:239–261.

Gomes, A. S., and S. Ferreira. 2004. in Apostila: Análise de Dados Ecológicos. Universidade Federal Fluminense, Niterói.

Goulart, A. M. C. 2002. Diversidade de nematóides em áreas de vegetação nativa e cultivada em São Carlos, Estado de São Paulo, Brasil. Universidade de São Paulo.

Hánèl, L. 1995. Secondary successional stages of soil nematodes in cambisols of South Bohemia. Nematologica 41:197-218.

Hopper, D. J. 1970. Handling, fixing, staning and mountaing nematodes. Pp. 34-38 *in* Commonwealth Agricultural Bureaux H (ed) Laboratory methods of word with plant soil nematodes. Technology Bull, Herts.

Magurran, A. E. 1988. Ecological Diversity and Its Measurement. Springer Netherlands, Dordrecht.

Mai, W. F. 1988. Pictorial key to genera of plant-parasitic nematodes. Pp. 31-34 *in* Nematode identification and expert system technology. Boston: Springer.

Marques, L. C. T. 1990. Comportamento inicial de paricá, tatajuba e eucalipto, em plantio consorciado com milho e capim-marandu, em Paragominas, Pará. Universidade Federal de Viçosa.

Mattos, J. K. 1999. Caracterização das comunidades de nematóides em oito sistemas de uso da terra no cerrado central do Brasil. Universidade de Brasília.

Mattos, J. K. A. 2002. Nematóides do solo como indicadores da interferência humana nos sistemas naturais: aspectos gerais e alguns resultados obtidos no Brasil. Revisão Anual de Patologia de Plantas 10:373-390.

Medrado, M. J. 2000. Sistemas agroflorestais: aspectos básicos e indicações. Pp 269-312 *in* Reflorestamento de propriedades rurais para fins produtivos e ambientais: um guia para ações municipais e regionais. Embrapa Florestas, Colombo.

Mittermeier, R. A., C. M. Goettsch, and P. G. Robles. 1997. Megadiversidad : Los países biológicamente más ricos del mundo. Cemex.

Mondino, E. A., O. C. H. Tavares, A. G. Ebeling, A. F. Figueira, E. I. Quintero, and R. L. L. Berbara. 2009. Avaliação das comunidades de nematoides do solo em agroecossistemas orgânicos. Acta Scientiarum Agronomy 31:509-515.

Mondino, E. 2010. Comunidade de nematóides do solo, no ecossistema do Pampa Austral da Argentina, sob diferentes sistemas de cultivo. Universidade Federal Rural do Rio de Janeiro.

Neher, D. A. 2001. Role of nematodes in soil health and their use as indicators. Journal of Nematology 33:161-168.

Neilson, R. 2005. Nematode ecology: A current perspective. Pp. 18-23 in Congresso Brasileiro de Nematologia. Piracicaba: Sociedade Brasileira de Nematologia.

Niles, R. K., and D. Freckman. 1998. From the ground up: Nematode ecology in bioassessment and ecosystem health. Plant and Nematode Interactions 65-85.

Norton, D. C. 1978. Ecology of plant-parasitic nematodes. Wiley.

Rodrigues, C. 2011. Comunidades de nematoides associadas às principais fitofisionomias do cerrado do Parque Nacional de Brasília. Instituto de Ciências Biológicas da Universidade de Brasília. Brasília.

Santiago, J., M. C. da Silva Júnior, and L. C. Lima. 2005. Fitossociologia da regeneração arbórea na mata de galeria do Pitoco (IBGE-DF), seis anos após fogo acidental.

Shannon, C. E. 1948. A mathematical theory of communication. Bell System Technical Journal 27:379-423.

Sheila, C. I. H. 1900. Descriptions of plant parasitic nematodes. Commonwealth Agricultural Bureaux, St. A., Farnham Royal.

Simpson, E. H. 1949. Measurement of diversity. Nature 163:688.

Smart, C. G., and B. N. Khoung. 1983. Illustrated key for identification of common nematodes in Florida, 2nd rev. Entomology and Nematology Department, Institute of Food and Agricultural Sciences, University of Florida.

Tomazini, M. D. 2008. Caracterização das comunidades de nematoides em mata nativa e áreas contíguas submetidas a diferentes tipos de uso agrícola em Piracicaba. Universidade de São Paulo.

Torres, G. R. C. 2006 Aspectos ecológicos de comunidades de nematoides associada a cultivo de Cucumis melo no Rio Grande do Norte. Nematologia Brasileira 30:1-9.

Wasilewska, L. 1997 Soil invertebrates as bioindicators, with special reference to soil-inhabiting nematodes. Russian Journal of Nematology 5:113-126.

Whitford, W., D. Freckman, and P. Santos. 1982. Nematodes in ecosystems. University of Texas Press, Austin.

Wouts, W. M. 2006. Criconematina (Nematoda:Tylenchida). Manaaki Whenua Press, Landcare Research.

Yeates, G. W. 1994 Modification and qualification of the nematode Maturity Index. Pedobiologia 38:97-101.

Yeates, G. W., T. Bongers, and R. G. De Goede. 1993. Feeding habits in soil nematode families and genera-an outline for soil ecologists. Journal of Nematology 25:315-31.

Zimmermann, C. L. 2009. Monocultura e transgenia: Impactos ambientais e inseguraça alimentar. Veredas do Direito 6: 79-100.

Received: 13/III/2018
Recibido:

Accepted for Publication: 5/VII/2018
Aceptado para publicación: