NEOTROPICAL
BIOLOGY AND CONSERVATION

Neotropical Biology and Conservation
14(2): 275–289 (2019)
doi: 10.3897/neotropical.14.e38094

RESEARCH ARTICLE

Effects of weed management on soil mites in coffee plantations in a Neotropical environment

Efeito dos diferentes tipos de métodos de manejo de ervas daninhas em ácaros de solo em plantações de café

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Academic editor: *A.M. Leal-Zanchet* | Received 28 October 2018 | Accepted 31 March 2019 | Published 25 July 2019

Citation: Pádua Marafeli P, Reis PR, Oliveira Bernardi LF, Alcântara EN, Martinez PA (2019) Effects of weed management on soil mites in coffee plantations in a Neotropical environment. Neotropical Biology and Conservation 14(2): 275–289. https://doi.org/10.3897/neotropical.14.e38094

Abstract

Environmental disturbance, as a result of land use change and/or different agricultural practices, may have negative impacts on the richness and abundance of edaphic mites. The objective of this study was to evaluate the effects of different weed management methods in coffee plantations on edaphic mites, and to compare these results with mite communities of native forest habitats in southeastern Brazil. Soil samples were taken between the rows of a coffee plantation under different weed management methods, such as without weeding, manual weeding, agricultural grid, contact herbicide (glyphosate), residual herbicide (oxyfluorfen), mechanical tiller, and mechanical mower, and in a native forest area. Weed management affected edaphic mite communities, with the residual herbicide treatment having the greatest impact on species composition, abundance, richness and diversity. The use of manual weeding and the maintenance of unweeded areas were the practices that preserved mite communities closest to those found in native forest habitats. Thus, such practices are recommended as best practices in coffee plantations. Among the studied mites, the groups Oribatida and Mesostigmata were found in all sites, presenting the greatest abundance and richness, and were sensitive to different forms of weed control. On this basis, we suggest these groups as indicators of soil quality in coffee plantations.

Resumo

Ácaros edáficos podem responder a mudanças ambientais, diferentes tipos de usos da terra e as diferentes práticas agrícolas, alterando sua riqueza e abundância. Assim, o objetivo deste trabalho foi avaliar os efeitos nestes organismos de diferentes métodos de manejo de plantas daninhas em cafezais, além de comparar esses resultados com uma área de floresta nativa. Amostras de solo foram coletadas em floresta e nas linhas de cafezais que receberam diferentes métodos de manejo de plantas daninhas: sem capina, capina manual, grade agrícola, herbicida de contato (glifosato), herbicida residual (oxifluorfen), grade rotativa e roçadeira mecânica. O estudo foi realizado na Estação Experimental da EPAMIG, em Minas Gerais, Brasil, durante o ano de 2013. Em geral, o manejo de plantas daninhas afetou a comunidade de ácaros edáficos, sendo o uso de herbicida residual o método que resultou em uma maior mudança na composição de espécies, além da maior redução na abundância, riqueza e diversidade de ácaros. Já o uso de capina manual e a manutenção de locais sem capina, são as práticas que mantiveram a acarofauna de solo em parâmetros similares aqueles encontrados em solo de mata nativa, e por isso são aqueles mais que devem ter seu uso recomendados. Dentre os ácaros estudados, a coorte Oribatida e os Mesostigmata foram aqueles presentes em todos os locais, apresentando maior riqueza e abundância, além de serem afetados pelas diferentes práticas de controle de erva daninha. Assim, sugere-se sua utilização como indicadores da qualidade do solo.

Keywords

Coffea arabica, communities, edaphic mites, seasonality, weed management

Palavras-chave

ácaros edáficos, *Coffea arabica*, comunidades, manejo de ervas daninhas, sazonalidade

Introduction

Intensive management of weedy vegetation in agricultural plantations can be accomplished by means of manual, mechanized or chemical techniques. However, such management can compromise production costs and lead to loss of soil functioning when conducted without concern for biodiversity or without critical evaluation of the effects on soil properties (Melloni et al. 2012).

Edaphic mesofauna are directly associated with soil quality and plant growth. This group of organisms is involved in decomposition and mineralization of organic matter, and the regulation of nutrient cycles, as well as soil-plant interactions. The most important active organisms in the soil are bacteria, fungi, nematodes, mites, springtails and earthworms. The vital processes of each soil organism contribute in such a way that the combination of their activities results in nutrient cycling, including the decomposition of soil organic matter (Bohm et al. 2010).

Natural and anthropogenic factors are related to changes in the biodiversity of edaphic mites. Soil management is one of the most common anthropogenic factors that negatively affects biodiversity by causing changes in microclimatic conditions and food availability. Evaluations of the impacts of soil management systems on soil mesofauna are very important from an environmental quality perspective (Rieff et al. 2010).

Soil mites are one of the most important indicators of soil quality. For this reason, the identification and evaluation of the density and diversity of these organisms in soil is essential to understanding the adequacy of management systems. This type of information is very important when evaluating the sustainability of agroecosystems, and may be essential in the identification of a bioindicator or biological indicator of sustainability or a biological indicator of sustainability, such as soil quality (Silva et al. 2007). However, the effects of different methods of soil management on the diversity of soil fauna are still poorly known, especially for Neotropical mites. It is worth mentioning that edaphic mite monitoring for the evaluation of soil quality is very complex (Cluzeau et al. 2012). Studies that mainly involve identification at the family, genus and species levels may be useful for revealing changes in more detail (Postma-Blaaw et al. 2010). This type of information is vital for the proper choice of management methods that minimize effects on the edaphic fauna.

The objectives of this work were to 1) evaluate the effects of six methods of management of unwanted weedy vegetation between rows of coffee plants on the edaphic mites of the soil mesofauna, and 2) compare these areas with a local native forest soil biota.

Material and methods

Study site

The study was conducted at the Experimental Station of *Empresa de Pesquisa Agropecuária de Minas Gerais – EPAMIG Sul* (20°54'27"S, 47°09'49"W, WGS84), in the municipality of São Sebastião do Paraíso, Minas Gerais (MG), Brazil. The site is 837 m a.s.l. The region has a mean annual temperature of 20.8 °C and a mean annual rainfall of approximately 1400 mm. The rains mainly occur between October and April.

The site had already implemented an experiment involving different methods of managing weed plants in coffee (*Coffea arabica* L.) plantations of the cultivar Paraíso. The plants, growing in Dystroferric Red Latosol (Oxisol) soil, were six years of age and spaced 0.7 m apart in rows separated by 4 m.

Experimental design

The experiment was conducted in an open area of a conventional coffee plantation without any control of the environmental factors. A randomized block design was used with eight treatments and three replications. The treatments were: (1) no weeding, (2) manual weeding, (3) agricultural grid, (4) contact herbicide (glyphosate), (5) residual herbicide (oxyfluorfen), (6) agricultural mechanical tiller, (7) agricultural mower machine and (8) native forest as a control area. Management practices in the studied coffee plantations followed conventional protocols (Alcântara and Cunha 2010), with management occurring when weedy vegetation reached a height of 15 cm. As plant growth may vary according to local climatic and soil conditions, the frequency of management can also vary between sites, but four to six cuts per year using either manual or mechanical mowing, and two to four applications of herbicides, dependent on their mode of action, are considered typical of the study region. Naturally, areas designated to the control treatment were left without management throughout the experimental period.

The native forest was located about 500 m from the coffee plantation and had the same type of soil. It consisted of tropical sub-perennial native forest, and served as a reference treatment (control), representing the vegetation on the soil type prior to agricultural exploitation.

Experimental plots consisted of four rows of coffee plants (50 plants/row, 140 m^2), with the focal part of the plot being comprised of two central rows totaling 80 plants (40 plants/row, 112 m^2), while the remaining rows served as borders.

Herbicide treatments between coffee rows were effected by means of spraying with a CO_2-pressurized backpack sprayer or, where appropriate, by a spraying apparatus coupled to an agricultural tractor, with an average volume of 400 liters of spray per hectare. The residual herbicide used was oxyfluorfen (Goal BR – Dow Agrosciences Industrial Ltd.), which was applied at 3 liters of commercial product/ha, with the intention of keeping the coffee free of weed plants for the entire year. Treatment with the herbicide glyphosate (Roundup Original – Monsanto Do Brasil Ltd.) was used as necessary as a contact herbicide at 3 liters of commercial product/ha. Rows (projection of the coffee skirt) were always kept free of weed plants throughout the year by applying the same residual herbicide, oxyfluorfen (Goal BR), at a dose of 3 liters/ha as necessary. Throughout the experimental period, data on precipitation levels was collected from a local meteorological station Vantage Pro2Wireless Weather Station (Davis Instruments, USA).

Soil sampling

To quantify edaphic mites in each plot, two soil samples were collected, one at the end of the rainy season (May 2013), and the other at the end of the dry season (October 2013) (Fig. 1), totaling four samples in each treatment. Two soil samples of each treatment were taken in each sampling round, one at 5 m from the beginning of a plot, and the other at 5 m from the end. All soil samples were taken at a central position between the rows of coffee plants in the useful part of the experimental plot. Two samples were also taken in the forest during each sampling event. Soil samples were taken using a stainless steel cylindrical probe (50 mm internal diameter and 53 mm high; volume of 100 cm^3), known as a cylinder for collecting non-deformed soil samples (Bravifer, Brazil).

Extraction and identification of edaphic mites

Extraction of edaphic mites from the soil samples was performed by means of a Berlese-Tullgren funnel extractor (Mineiro and Moraes 2002). In the extractor, samples were subjected to light and heat for seven days (Rieff et al. 2010) to create a temperature and humidity gradient, making the environment unfavorable for mites, and forcing them down until they fall into a collector vial containing 70% alcohol.

After being extracted, mites were counted and removed from the alcohol of the collector vial with the use of a fine paintbrush and the assistance of a binocular stereomicroscope at 40× magnification. All specimens were then mounted on a glass slide in Hoyer's medium and covered by a glass coverslip. Identification was made under a phase-contrast microscope.

Mite extraction and taxonomic identification were conducted in the Laboratory of Agricultural Acarology of EPAMIG Sul/Research Center in Ecological Management of Pests and Plant Diseases – EcoCenter, in Lavras, MG, Brazil.

The classification used in the present study was that presented by Lindquist et al. (2009) in the Manual of Acarology, with Endeostigmata ranked as order, as suggested by Pepato and Klimov (2015). To better visualize the results, species of Astigmatina are presented separately from the other species that belong to the suborder Oribatida; thus, when "Oribatida" is mentioned, it means "Oribatida except Astigmatina".

Statistical analysis

Abundance and richness of edaphic mites in the different weed management systems were submitted to a generalized linear mixed model (GLMM), using a contrast analysis by means of the Tukey test to compare means, at a 5% level of significance, using the software R (R Development Core Team 2017).

Mite communities found in the different sampling plots were analyzed via ecological analysis. Comparisons among treatments were made using the sum of the samples from the end of the dry season and the end of the rainy season. Faunal richness, abundance, diversity (Shannon index) and equitability (Pielou index) were calculated. A decline in Shannon's diversity index reflects the domination of a species to the detriment of others. The Pielou uniformity index, an equitability index, reflects the evenness of abundance among species.

Non-metric multidimensional scaling (NMDS) was used to elucidate the degree of similarity among samples. This exploratory analysis transformed the similarity between pairs of samples by fitting them into sets defined by two dimensions. The analysis was performed using the quantitative composition of edaphic mites and the Bray Curtis index. Analyses were performed using R (R Development Core Team 2017).

Since oribatid mites have special significance for the environment, acting as important cyclers of organic matter, data for this group are presented separately from the other Sarcoptiformes.

Results and discussion

Effects of weed vegetation management between coffee rows on soil mites

Considering all soil samples, a total of 4,035 mite specimens belonging to 159 species were collected (Table 1; Suppl. material 1: Table S1). The highest abundance of mites was found in soil samples collected in plots with manual weeding management (1,369 specimens), while the lowest abundance was found in samples from plots where the management was carried out by means of residual herbicide (11 specimens). A total of 522 specimens were sampled in samples from the adjacent natural forest (Table 2).

The highest species richness was found in the forest environment (72 species), followed by plots where weed management was not performed or performed manually (71 and 64 species, respectively). Only eight species were observed in the plots managed by residual herbicide. Not all management methods differed significantly from each other, but the most significant result was the effect of residual herbicide treatment, which had significantly lower abundance and richness than all other treatments (Fig. 1, Table 3).

Oribatids were the most abundant mites in all treatments; however, their abundance and the proportion of species of this group in relation to the others, varied among samples. Plots where oribatids were most abundant were those with the treatment of manual weeding, followed by those without weeding and the adjacent natural forest environment.

Species richness of Oribatida was always higher than those of other groups, except in the plots with the agricultural mechanical tiller treatment, in which Mesostigmata had the highest richness with 24 species, followed by Oribatida with 16 species (Tables 1, 2).

Table 1. Abundance of soil mites associated with different weed management systems applied between coffee rows, and in an adjacent natural forest environment in southeastern Brazil. Endeos: Endeostigmata; Meso: Mesostigmata; Sarcop (others): Sarcoptiformes except Oribatid mites; Sarcop (oribatid): only oribatid mites; Tromb: Trombidiformes.

Treatments	Meso	Tromb	Sarcop (others)	Sarcop (oribatid)	Endeos	Total
Residual herbicide	0	2	1	5	3	11
Without weeding	103	41	75	406	18	643
Manual weeding	229	148	350	582	60	1,369
Agricultural grid	29	24	106	129	6	294
Contact herbicide	54	64	138	208	9	473
Agricultural mechanical tiller	108	81	55	209	22	475
Agricultural mower machine	38	48	27	96	39	248
Forest	138	58	3	315	8	522

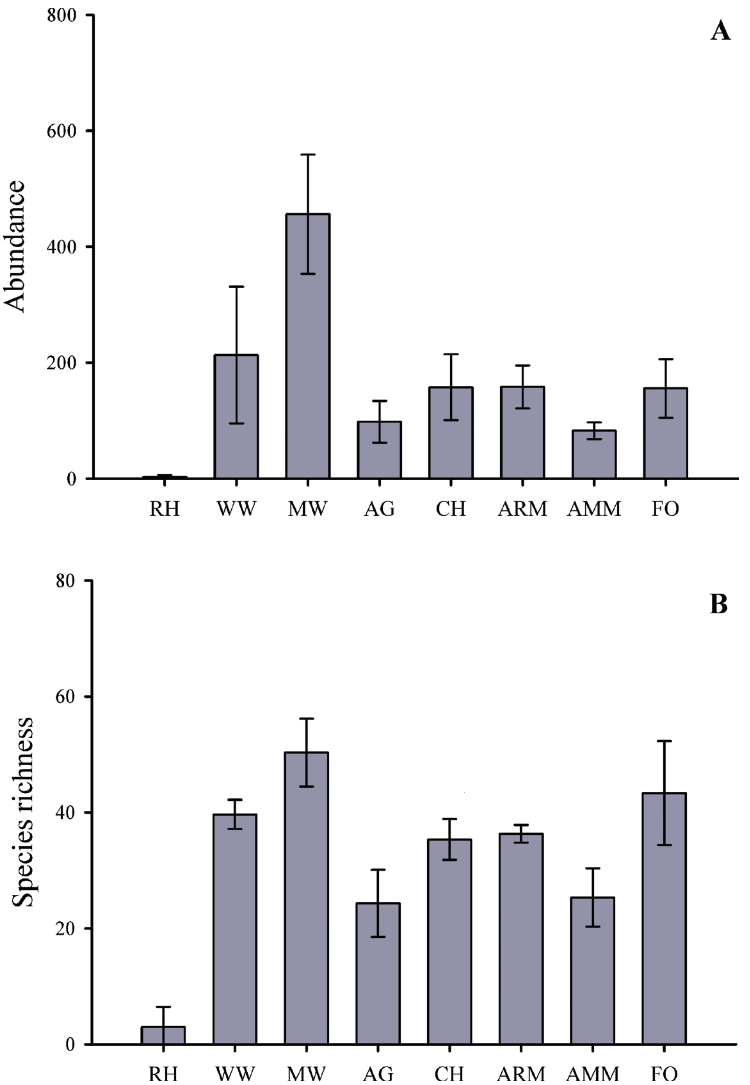

Figure 1. GLMM test comparing the abundance (A) and richness (B) of soil mites associated with each of the different weed management systems applied between coffee rows, and in an adjacent natural forest environment in southeastern Brazil. Tukey contrast ($p \leq 0.05$). AG: agricultural grid; AMM: agricultural mower machine; ARM: agricultural mechanical tiller; CH: contact herbicide; FO: forest; MW: manual weeding; RH: residual herbicide; WW: without weeding.

The choice of the appropriate method of weed management in agricultural production is important because it can influence all of the fauna associated with the area. Furthermore, the way soil is managed can directly influence the maintenance of the various environmental services provided by biodiversity (Altieri 1999). As observed in this study, weed management can directly affect richness and abundance

Table 2. Richness of soil mites associated with different weed management systems between coffee rows and in an adjacent natural forest environment in southeastern Brazil. Endeos: Endeostigmata; Meso: Mesostigmata; Sarcop (others): Sarcoptiformes except Oribatid mites; Sarcop (oribatid): only oribatid mites; Tromb: Trombidiformes.

Treatments	Meso	Tromb	Sarcop (outros)	Sarcop (oribatid)	Endeos	Total
Residual herbicide	0	2	1	4	1	8
Without weeding	23	13	1	31	3	71
Manual weeding	23	13	3	22	3	64
Agricultural grid	14	9	4	17	2	46
Contact herbicide	13	15	4	24	4	60
Agricultural mechanical tiller	24	11	3	16	3	57
Agricultural mower machine	16	8	3	18	3	48
Forest	20	15	1	33	3	72

Table 3. Comparison of abundance and richness of soil mites associated with each of the weed management systems applied between rows of coffee trees, and in an adjacent natural forest environment, in southeastern Brazil, by means of GLMM test with Tukey contrast ($p \leq 0.05$). AG: agricultural grid; AMM: agricultural mower machine; ARM: agricultural mechanical tiller; CH: contact herbicide; FO: forest; MW: manual weeding; RH: residual herbicide; WW: without weeding.

Treatments	p value (abundance)	p value (richness)
AMM – AG	p = 0.458	1
ARM – AG	p < 0.001	0.126
CH – AG	p < 0.001	0.199
FO – AG	p < 0.001	p = 0.0018
MW – AG	p < 0.001	p < 0.001
RH – AG	p < 0.001	p < 0.001
WW – AG	p < 0.001	p = 0.0201
ARM – AMM	p < 0.001	p = 0.217
CH – AMM	p < 0.001	p = 0.321
FO – AMM	p < 0.001	p = 0.004
MW – AMM	p < 0.001	p < 0.001
RH – AMM	p < 0.001	p < 0.001
WW – AMM	p < 0.001	p = 0.041
CH – ARM	p = 1	p = 1
FO – ARM	p = 1	p = 0.865
MW – ARM	p < 0.001	p = 0.144
RH – ARM	p < 0.001	p < 0.001
WW – ARM	p < 0.001	p = 0.997
FO – CH	p = 1	p = 0.757
MW – CH	p < 0.001	p = 0.087
RH – CH	p < 0.001	p < 0.001
WW – CH	p < 0.001	p = 0.987
MW – FO	p < 0.001	p = 0.907
RH – FO	p < 0.001	p < 0.001
WW – FO	p < 0.001	p = 0.996
RH – MW	p < 0.001	p < 0.001
WW – MW	p < 0.001	p = 0.498
WW – RH	p < 0.001	p < 0.001

of mites, especially oribatid. Additionally, our results show that the right choice of weed management methods, such as manual weeding, can preserve a great diversity of these mites. Some weeding practices can help to maintain oribatid fauna similar to natural forests and may represent a viable alternative to improve the environmental quality of planting sites. The presence of oribatids in soil systems is essential for adequate nutrient cycling, because they renew and incorporate organic matter into the soil. In addition, this group is sensitive to environmental changes, and its low abundance may be an indicator of environmental disturbance (Behan-Pelletier 1999; Crossley et al. 1992; Minor and Cianciolo 2007).

Similarly to the oribatid fauna, other mite groups, such as the families Laelapidae, Macrochelidae and Ascidae of Mesostigmata, or some families of Trombidiformes, such as Cunaxidae and Stigmaeidae, also play important roles in agricultural ecosystems by performing various ecological services, such as controlling potential pests (Carrillo et al. 2015). Thus, it is important to opt for the type of management that maintains these taxa in the system. The methods of managing weeds between rows of coffee trees that maintained the largest number of mites of these groups were without weeding, manual weeding, contact herbicide and agricultural mechanical tiller.

All of the weed management methods studied here presented species similarities above 30%, except for the residual herbicide treatment, which was less than 5% similar to any other type of weed management. In plots with chemical control, the inhibition of growth of all types of vegetation was observed, and the soil remained completely barren and exposed to the direct influence of environmental variables. These plots were characterized by dry, rigid and exposed soil, which are conditions that are not conducive to the development and maintenance of a healthy edaphic fauna (Fig. 2, Table 4). It has already been shown that the type of soil management can alter pH, amount of organic matter and levels of temperature and humidity, which are important factors in determining the presence and abundance of soil mite species (Bedano et al. 2011).

The use of residual herbicide in a continuous way, as it was done in this study, leaves the soil surface compacted and without vegetation, causing homogeneity in the soil system. This then can affect soil mite communities, since they are subjected to higher temperatures and less organic matter input, which may explain the low number of edaphic mites found in plots where this type of management was used. Simplification of ecosystems, which in agriculture is usually a direct result of loss of species through the inappropriate use of different types of weed management, can lead to the loss of important ecological services, such as nutrient cycling and natural pest control, and thus lead to increased production costs. The loss of biodiversity leads to the breakdown of natural cycles, and the subsequent loss of significant soil fertility. This, in turn, leads to an increase in the need to supply external inputs in order to maintain, artificially, the regulated and functional environment for agricultural production (Swift and Anderson 1994; Altieri 1999).

In the present study, the method for managing weeds that produced results most similar to the adjacent natural forest system was without weeding, which

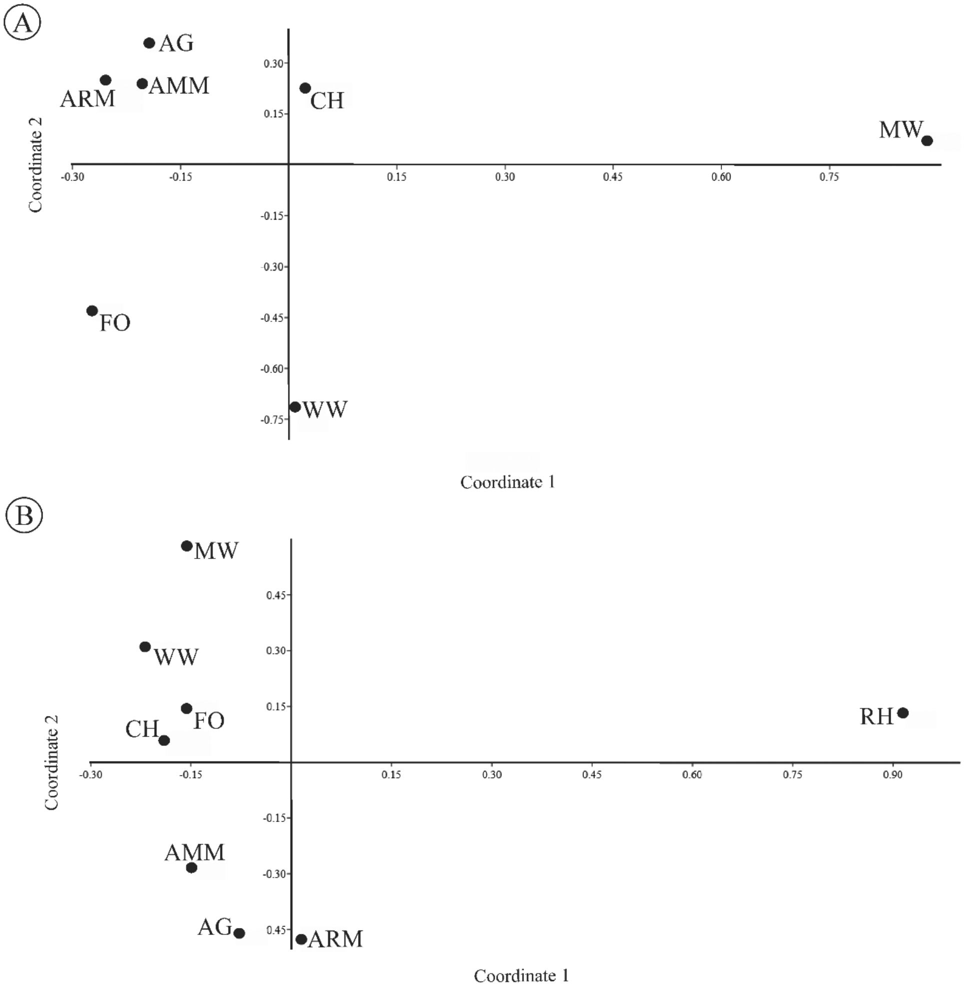

Figure 2. Non-metric multidimensional scaling (NMDS), using Bray-Curtis index, of the soil mite fauna of areas treated with different methods for the management of weedy vegetation between coffee rows in southeastern Brazil. A: calculated without residual herbicide. B: calculated with all sites and samples. – RH: residual herbicide; WW: without weeding; MW: manual weeding; AG: agricultural grid; CH: contact herbicide; ARM: agricultural mechanical tiller; AMM: agricultural mower machine; FO: native forest.

left the vegetation to grow freely and without control (46.3%), followed by contact herbicide (46%) (Table 4). The management of weeds with contact herbicide promotes the maintenance of a layer of organic matter on the soil, as does management without weeding. Consequently, the superficial layer of the soil is not impacted by physical disturbances, or at least is impacted less, which can benefit edaphic organisms and maintain their populations in better conditions than in places where other types of vegetation management are used between rows of coffee trees.

Although it is not possible to predict exactly how changes in the abundance and richness of soil mite communities can influence the chemical and physical prop-

Table 4. Similarity (%; Bray-Curtis index) among the soil mites fauna found in areas between coffee rows treated with different weed management systems in southeastern Brazil. AG: agricultural grid; AMM: agricultural mower machine; ARM: agricultural mechanical tiller; CH: contact herbicide; FO: forest; MW: manual weeding; RH: residual herbicide; WW: without weeding.

	RH	WW	MW	AG	CH	ARM	AMM
WW	1.84						
MW	1.15	51.1					
AG	4.59	37.7	24.8				
CH	3.3	55	42	42.5			
ARM	3.29	44.5	35.7	52	45.5		
AMM	6.1	30.8	23.3	32.8	38.5	39.5	
FO	2.25	46.3	32.9	31.3	46	39.5	30.6

erties of the soil, or the quality and cost of agricultural production, it is believed that the most suitable management systems are those that maintain characteristics similar to those found in natural environments. In the present study, management with residual herbicide had an abrupt negative influence on the population of edaphic mites.

In studies investigating the influence of residual herbicide on the soil fauna in sugarcane (*Saccharum officinarum* L., Poaceae) plantations, the herbicide ametryn (triazine), used alone or in association with another herbicide, was shown to also reduce the abundance of soil fauna (Silva et al. 2012). This low abundance of soil mites may be a direct result of the breakdown of the proper functioning of the system, which then impacts negatively the soil fauna.

The results of the present study reveal the complexity of the effects of different methods of control of weeds vegetation on soil acarofauna. Therefore, these effects, evaluated in a generalized way or in specific groups, must be considered in the evaluation and choice of the method to be used for the control of weeds, while also considering other aspects related to the edaphic, social and economic environment, as has also been suggested by Ishida (2003).

Effects of weed management between coffee rows on ecological parameters of edaphic mite communities

Ecological indices, such richness (S), abundance (A) dominance (D), Shannon diversity index (H) and equitability (J), used as indicators of changes to the environment, are shown in Table 5.

The highest value for species richness (S), that is, the number of different species of mites identified, was found in the adjacent natural forest environment in both evaluated periods. The same was true for the Shannon diversity index (H) (Table 5). These results reinforce the idea that forest areas have higher environmental quality than those under anthropogenic use. The edaphic arthropod fauna, including mites, may suffer alterations when the management of soil is changed, especially

Table 5. Ecological parameters of the edaphic mite community found in areas with different weed management systems between coffee rows. AG: agricultural grid; AMM: agricultural mower machine; ARM: agricultural mechanical tiller; CH: contact herbicide; FO: forest; MW: manual weeding; RH: residual herbicide; WW: without weeding.

Parameters	Treatments							
	RH	WW	MW	AG	CH	AMM	ARM	FO
Richness (S)	8	71	64	46	60	57	48	72
Abundance (A)	11	643	1369	294	473	475	248	522
Dominance (D)	0.157	0.05959	0.09445	0.08575	0.08305	0.04943	0.06435	0.03754
Diversity (H)	1.9720	3.3560	3.0280	2.9530	3.2190	3.404	3.2150	3.6470
Equitability (J)	0.9485	0.7873	0.7282	0.7713	0.7861	0.842	0.8305	0.8528

when natural systems are replaced by monocultures (Crossley et al. 1992; Minor and Cianciolo 2007). The higher diversity of plants in the native forest environment is likely to make more food available and provide favorable microclimates for all edaphic species. The results found in the present study are similar to those reported in areas with degraded soils, where undisturbed forest areas had the highest species richness (Minor and Cianciolo 2007; Minor et al. 2017; Postma-Blaaw et al. 2010; Vicente et al. 2010).

On the basis of the results obtained herein, we can conclude that management protocols for weed control can greatly influence the soil acarofauna, with application of herbicides having the strongest negative impacts on their communities. Accordingly, we strongly recommend that the use of this type of weed control should be limited in coffee plantations to avoid negative impacts on soil biota. The use of mechanical or manual weeding are recommended as practices that retain diverse mite communities similar to those found in native forest habitats. Of the mites studied, the cohort Astigmatina, and the rest of suborder Oribatida, had the greatest richness of edaphic species, both in the native forest environment and in the coffee plantation, and thus show potential as indicators of soil quality. Developing management practices that maintain the richness and abundance of edaphic invertebrates species should be a clear priority in agricultural systems, as the presence of diverse species assemblages can also help with the maintenance of essential ecosystem processes, such as nutrient cycling and pest control, that can also benefit agricultural production.

Acknowledgements

We thank the *Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – CAPES* (Coordination of Improvement of Higher Level (Education) Personnel), and *Conselho Nacional de Desenvolvimento Científico e Tecnológico – CNPq* (National Council for Scientific and Technological Development) for financial support and grants. We thank Dr. Pavel Klimov, University of Michigan, for identifying mites of the family

Acaridae, and Dr. Antônio Carlos Lofego, State University of São Paulo, Campus of São José do Rio Preto, for identifying mites of the family Tarsonemidae. LFOB received scholarships (PNPD/CAPES). We thank the reviewers for their valuable comments and their suggestions which helped us to improve the quality of the manuscript.

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Supplementary material 1

Table S1

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Data type: species data

Explanation note: Taxonomic groups of the soil mite fauna that were identified in each of the systems studied in areas treated with different methods for the management of weedy vegetation between coffee rows in southeastern Brazil.

Link: https://doi.org/10.3897/neotropical.14.e38094.suppl1