

Article

Diversity of Soil Gamasine Mites (Acari: Mesostigmata: Gamasina) in an Area of Natural Vegetation and Cultivated Areas of the Cerrado Biome in Northern Brazil

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Abstract: The Brazilian Cerrado biome has undergone major changes, with the incorporation of new areas for agricultural production. While this can certainly provide for the worldwide growing need for agricultural products, especially food, care should be taken to prevent possible environmental degradation. Worldwide, mites of the cohort Gamasina constitute the most abundant and diverse group of soil predatory mites, usually considered important in maintaining the ecological balance of natural environments. Little is known about the abundance and diversity of Gamasina in the Cerrado. The objective of the present work was to evaluate the abundance and diversity of Gamasina in soils of natural vegetation and of agroecosystems in Cerrado areas of the northern Brazilian state of Tocantins. This is considered the first step in the determination of possible role of the local predators as biological control agents, and their potential for practical use locally and elsewhere. Soil samples were taken monthly between July 2015 and June 2016. In total, 1373 Gamasina representing 45 species of 24 genera and 9 families were collected. The most abundant Gamasina belonged to Rhodacaridae in areas of the natural vegetation and to Ascidae in the agroecosystems. Abundance and diversity were much higher in the rainy than in the dry season. Rhodacarids and ascids have not been used commercially for pest control, but investigations conducted so far suggest their potential as biological control agents. The confirmation of this possibility and the development of techniques that would allow their maintenance in agricultural areas require subsequent research efforts.

Keywords: mesofauna; edaphic mites; prospection

1. Introduction

Cerrado is the second largest biome in Brazil, occupying an area of 2,036,448 km² or about 22% of the Brazilian territory [1]. The vegetation of this biome is predominantly constituted by relatively sparse and short twisted trees and shrubs, with scant grass species [2]. This biome is

undergoing major changes, for the expansion of the agricultural frontier from the early 2000s [1]. Large parts of the Cerrado are presently dedicated to the production of soybean, corn, rice, pasture, and cultivated forest trees, such as eucalyptus [3]. While this can certainly provide for the worldwide growing need for agricultural products, especially food, care should be taken to prevent possible environmental degradation.

Despite the efforts for the establishment of protected areas, the survival of endemic animal and plant species could be threatened in this biome [4]. Attention should be given to organisms living in different parts of the environment, including those in the soil, that are usually difficult to account, largely because of the difficulty in determining these species taxonomically. Soils of the Cerrado usually have low pH and low levels of plant nutrients, leading producers to use high inputs of lime and fertilizers in agricultural lands, modifying the natural edaphic environment [2].

Soils from natural environments generally show high mesofauna diversity and abundance. These organisms actively participate in the decomposition of organic matter, affecting soil aeration, chemical properties, and the ecological balance. Some members of the mesofauna act as predators of invertebrates, interfering in community structures and probably in the sustainability of agroecosystems [5,6].

The predominant members of the mesofauna may vary according to prevailing biotic and abiotic factors. Some studies of the edaphic fauna have been conducted to analyze the influence of agricultural practices on the main taxonomic groups, particularly mites and springtails, among other invertebrates [7–9]. Knowledge about the abundance and diversity of these organisms in a given habitat has been used as an indicator of soil quality, which can be related to levels of sustainability and affect crop yield [10].

Worldwide, the Gamasina (Mesostigmata) constitute the most abundant cohort of edaphic predatory mites [11]. These can feed on several organisms, such as other mites, small insects, and nematodes, but frequently also on fungi [11–13]. Therefore, it is believed that they can play an important role in reducing the population of agricultural pests, and some of them have been used for pest control [13].

The first step in estimating the natural effect of edaphic Gamasina on pest organisms in a specific location, as well as the potential for their practical use as biological control agents, is the determination of the components of the prevailing fauna [14]. Information on the abundance and diversity of Gamasina in agricultural crops in tropical regions is scarce, especially in the Cerrado. The objective of the present work was to determine the abundance and diversity of Gamasina in soils of natural vegetation and in agroecosystems in Cerrado areas of the northern Brazilian state of Tocantins.

2. Material and Methods

The study was conducted in four ecosystems in the municipality of Sucupira, Tocantins state, where the climate is of the Aw type, according to the Köppen-Geiger classification system [15]. The region is characterized as a subtropical savannah, with well-defined rainy (November–April, cooler months) and dry (May–October, hottest months) seasons, average annual rainfall of about 1500 mm and air relative humidity of 45–90%. Distances between ecosystems were 4.0–7.5 km.

2.1. Characterization of the Ecosystems

Natural vegetation (11°54'36'' S, 48°51'10'' W): A 208-ha patch of well-preserved vegetation of the Cerrado biome, with a litter layer of about 5 cm in thickness. Within the natural variations of this biome, the area selected for study is classified as Cerrado *sensu stricto* [2].

Soybean cultivation (11°54'80'' S, 48°52'10'' W): A 155-ha soybean plot, where the same crop has been yearly cultivated since 2003. Liming of the soil was done three months before the soybean planting. The land had been in fallow for about four months before soybean (variety M8644 IPRO from Monsoy) was seeded on 15 November 2015, under no tillage, spaced at 50 cm between lines and at a density of 13 plants/m in the lines. The area was sprayed with glyphosate (3.0 L ha⁻¹) before planting

and glyphosate - potassium salt 620 (2.0 L ha⁻¹) with mineral oil (1.0 L ha⁻¹) 26 days after plant emergence. In the crop cycle, plants were sprayed with propiconazole (0.4 L ha⁻¹) for the control of Asian rust, and with thiamethoxam (250 mL L⁻¹) and acefato (300 mL L⁻¹) for the control of caterpillars and bugs. Harvesting was done mechanically on March 24, 2016, leaving the area in fallow again until the end of the study.

Pasture (11°56'80'' S; 48°52'34'' W): A 3.5-ha plot planted to the grass *Andropogon gayanus* Kunth in 2012. The area was sprayed with 2,4-D, Picloran (3.0 L ha⁻¹). Liming was last done in the area in August 2015 and NPK 20-00-20 + 0.1% B (120 kg ha⁻¹) was applied in November 2014. No chemical was applied for the control of pests and diseases.

Integration of cultivated forest–pasture (11°57'57'' S; 48°54'34'' W): A 25-ha plot was occupied by an association of eucalyptus (*Eucalyptus grandis* W. Hill) and pasture (*A. gayanus*) since 1998. Liming and application of NPK 20-00-20 + 0.1% B (120 kg ha⁻¹) were done respectively in August and November 2015. Fipronil (15 g/plant) for ant control and 2,4-D and picloran (3.0 L ha⁻¹) for weed control were applied in May 2016.

2.2. Edapho-Climatic Characterization

Soil samples were collected from each ecosystem for physicochemical analyses in the rainy (January 2016) and dry (June 2016) seasons. In each season and in each ecosystem, a sample was composed of 20 subsamples (at least 20 m apart from each other) and each taken at a depth of 10 cm. The soil of all areas of study was classified as Dystrophic Red Yellow Latosol (LVA) [16]. The results of the analyses are shown in Table 1.

Table 1. Physicochemical properties of soil samples (each composed of 20 subsamples) collected at four ecosystems in Sucupira, Tocantins, Brazil. Samples in January 2015 (rainy season) and July 2016 (dry season). Analyses conducted by Sellar Análises Agrícolas, Gurupi, Tocantins state. OMC: organic matter content; TOC: total organic carbon.

Parameters	Ecosystems			
	Natural Vegetation	Soybean Cultivation	Pasture	Integration of Cultivated Forest–Pasture
Physical properties				
Clay (g.kg ⁻¹)	250	257	213	244
Sand (g.kg ⁻¹)	703	694	740	710
Silt (g.kg ⁻¹)	50	50	47	47
Chemical Properties				
pH CaCl ₂				
Dry season	3.9	5.6	5.1	4.7
Rainy season	4.0	6.5	5.4	5.0
Al (cmol_c·dm⁻³)				
Dry season	0.5	0	0	0
Rainy season	0.2	0	0	0
OMC (dag·kg⁻¹)				
Dry season	1.8	1.2	1.5	1.4
Rainy season	3.3	4.4	2.3	1.9
TOC (dag·kg⁻¹)				
Dry season	1.0	0.7	0.9	0.8
Rainy season	1.9	2.5	1.3	1.1

Table 1. Cont.

Parameters	Ecosystems			
	Natural Vegetation	Soybean Cultivation	Pasture	Integration of Cultivated Forest–Pasture
			P (mg·dm⁻³)	
Dry season	10.8	12.4	20.3	24.5
Rainy season	14.85	60.1	25.6	34
			K (mg·dm⁻³)	
Dry season	36	47	49	41
Rainy season	50	91	84	57
			Ca (cmol_c/dm⁻³)	
Dry season	0.2	1.2	1.5	1.9
Rainy season	0.3	6.5	5.4	4.6
			Mg (cmol_c/dm⁻³)	
Dry season	0.2	0.6	0.8	1.2
Rainy season	0.2	3.2	2.8	1.8
			S (mg·dm⁻³)	
Dry season	2	2	2	3
Rainy season	3	5	4	5
			B (mg·dm⁻³)	
Dry season	0.1	0.1	0.1	0.1
Rainy season	0.1	0.4	0.3	0.2
			Cu (mg·dm⁻³)	
Dry season	0.2	0.3	0.3	0.4
Rainy season	0.3	0.6	0.8	1.3
			Mn (mg·dm⁻³)	
Dry season	3.8	4.7	3.4	3.4
Rainy season	5.2	5.7	11.7	5.3
			Zn (mg·dm⁻³)	
Dry season	0.5	1.1	0.6	0.8
Rainy season	0.6	1.7	0.8	0.8

Climatic data during the experiment were registered at the closest meteorological station, located in Gurupi, 3–8 km from the study sites. In the dry and rainy seasons, average temperature, air relative humidity, and total rainfall were respectively 30 ± 26 °C, 52 ± 86 RH, and 1654 mm (119 and 1535 mm in the dry and rainy seasons, respectively).

2.3. Mite Sampling, Extraction, and Identification

Soil samples for the determination of the Gamasina fauna were collected monthly between July 2015 and June 2016. On each collection date, 32 sampling sites were determined in the area of each ecosystem (total of 384 samples in each ecosystem in all study). Each sample was taken with a metal cylinder (5 cm high \times 9 cm in diameter, corresponding to a base area of about 63.6 cm² and a volume of about 318 cm³/sample), completely introduced into the soil with the help of a hammer. Sampling sites were semi-randomized, each sampling point being selected so as to contain a litter layer as thick as possible (ranging between 3 and 15 cm deep), and at least 20 m apart from each other. Each sample was placed in a plastic bag, which in turn was packed in a polystyrene box for transport to a laboratory of Universidade Federal do Tocantins, Gurupi, Tocantins state. The temperature inside the box was maintained at 12–21 °C, with the use of freezing gel containers, to reduce mite activity.

About 4 h after the collection, the samples were placed in modified Berlese-Tullgren funnels for mite extraction in vials containing 70% ethanol [17]. The extracted material was sent to the “Laboratory of Taxonomy and Biological Control of Mites and Insects” of Universidade Estadual Paulista (UNESP), in Jaboticabal, São Paulo, Brazil. The content of each vial was transferred to a Petri dish for examination under a stereomicroscope, collecting the Gamasina to be later mounted on microscopic slides in Hoyer’s medium.

The Gamasina were separated into species under an optical phase contrast microscope (Leica, DMLB, Wetzlar, Germany), and identified to family based on Lindquist et al. [11]. Then, adult females were identified to genera, especially based on the following publications: [18–21] and unpublished keys adopted by the Ohio State Acarology Summer Program. Identification to species was done (when possible) based on the original descriptions and redescriptions of the species, available in the authors' collections.

2.4. Data Analysis

Statistical analyses and graph construction were done using a RGui 3.4.0 program [22]. Shannon-Weaver, Simpson, and Equitability indexes were calculated using the Vegan package. The mean abundance was compared by the Kruskal-Wallis test ($\alpha = 0.05$), as variances were not homogenous and data were not normally distributed (Shapiro-Wilk normality test). As variances for mean richness were homogenous and data were normally distributed, values of this parameter were compared by Tukey test ($\alpha = 0.05$).

Euclidean distances were used to estimate similarity between ecosystems, based on abundances of species and physicochemical properties of soil in paired ecosystems. The analysis was performed based on the abundance of species in each paired environment plus the physico-chemical variables of the soil obtained. First, the data was standardized, and then Ward's minimum variance clustering algorithm and the Euclidean distance were used in analysis. Then, the similarity matrix was analyzed in a hierarchical cluster analysis.

Simple correspondence (CA) and correspondence canonical (CCA) analyses were conducted using the Vegan Package in R. CA analysis was used to explore the frequency of species found in each environment, while CCA analysis was used to relate the variable environmental (independent) and abundance of Gamasina (dependent). Initially, the data were subjected to the Chi-square method to standardize the frequencies of each species in relation to the environment. For this analysis, only species collected in at least two ecosystems were considered. In the graph, species found in a single ecosystem were shown next to the name of the corresponding ecosystem, within a box (only to CA). Interpretation was restricted to the ordination within the first two axes shown in the graph constructed in R.

3. Results

In total, 1373 Gamasina specimens were collected (Table 2), of which 919 were from natural vegetation, 64 from soybean cultivation, 160 from pasture, and 240 from the integration of cultivated forest–pasture. The Gamasina belonged to nine families, of which the most abundant was Rhodacaridae (49.5% of the Gamasina), followed by Ascidae (35.2%) and Laelapidae (10%). The remaining families corresponded to less than 3.0% each. The numbers of Gamasina collected in the natural vegetation, integration of cultivated forest–pasture, soybean cultivation, and pasture in the rainy season were 1.4, 1.8, 3.9, and 5.0 times higher than the corresponding numbers collected in the dry season.

Natural vegetation contained species of all families found in the study, with a predominance of Rhodacaridae (65.9%), Ascidae (20.5%), and Laelapidae (9.8%). In the other ecosystems, the predominant family was Ascidae, representing respectively 54.8%, 59.7%, and 74.9% of the Gamasina. In the soybean cultivation, the second predominant family was Laelapidae (20.3%), followed by Phytoseiidae (10.9%). In the pasture and in the integration of cultivated forest–pasture, the second predominant family was Rhodacaridae (respectively 21.3% and 18.3%), followed by Laelapidae (12.7% and 6.3%).

Table 2. Gamasina mites from soil samples collected at four ecosystems in Sucupira, Tocantins, Brazil, in the dry (July–October 2015 and May–June 2016) and rainy season (November 2015–April 2016).

Gamasina Species	Code	Ecosystems/Seasons								Total
		Natural Vegetation		Soybean Cultivation		Pasture		Integration of Cultivated Forest–Pasture		
		Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy	
Rhodacaridae										
<i>Binodacarus</i> n. sp.	Bino	15	65	0	2	0	0	0	0	82
<i>Multidentorhodacarus tocantinensis</i> Azevedo and Castilho	Musp	24	54	0	1	0	8	1	5	93
<i>Multidentorhodacarus squamosus</i> Karg	Msqu	225	201	0	3	5	30	20	18	502
<i>Protogamasellopsis dioscorus</i> (Manson)	Pdio	0	1	1	0	0	0	0	0	2
<i>Protogamasellopsis zaeheri</i> Abo-Shnaf, Castilho, and Moraes	Pzah	1	0	1	0	0	0	0	0	2
<i>Rhodacarus</i> n. sp.	Rhod	2	9	0	0	0	0	0	0	11
Ologamasidae										
<i>Neogamaselleovans</i> sp.	Neog	1	0	0	0	0	0	0	0	1
<i>Ologamasus</i> sp.	Olog	0	0	1	0	0	0	0	0	1
Macrochelidae										
<i>Macrocheles muscaedomesticae</i> (Scopoli)	Macr	0	6	0	0	0	0	0	0	6
Podocinidae										
<i>Podocinium sagax</i> (Berlese)	Podo	0	1	0	0	0	0	0	0	1
Laelapidae										
<i>Androlaelaps</i> sp.	Andr	6	2	0	0	0	0	0	0	8
<i>Cosmolaelaps barbatus</i> Moreira, Klompen and Moraes	Cbar	1	0	1	0	0	0	2	3	7
<i>Cosmolaelaps guttulatus</i> (Karg)	Cgut	0	0	0	0	3	1	0	0	4
<i>Cosmolaelaps pampaensis</i> Duarte, Moreira, Cunha & Moraes	Cpam	0	1	0	0	0	0	0	0	1

Table 2. Cont.

Gamasina Species	Code	Ecosystems/Seasons								Total
		Natural Vegetation		Soybean Cultivation		Pasture		Integration of Cultivated Forest–Pasture		
		Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy	
<i>Cosmolaelaps</i> sp. 1	Cos1	0	1	0	0	0	0	0	0	1
<i>Cosmolaelaps</i> sp. 2	Cosm	1	14	0	3	1	6	0	0	25
<i>Gaeolaelaps</i> sp. 1	Geo1	6	11	0	2	1	1	2	4	27
<i>Gaeolaelaps</i> sp. 2	Geo2	0	1	0	1	0	0	0	0	2
<i>Gaeolaelaps</i> sp. 3	Geo3	0	2	0	0	0	0	2	1	5
<i>Gaeolaelaps</i> sp. 4	Geo4	2	3	0	1	0	0	0	0	6
<i>Gaeolaelaps</i> sp. 5	Geo5	0	0	0	3	0	2	1	0	6
<i>Gaeolaelaps</i> sp. 6	Geo6	1	4	0	0	0	0	0	0	5
<i>Gaeolaelaps</i> sp. 7	Geo7	0	0	0	0	0	1	0	0	1
<i>Gaeolaelaps</i> sp. 8	Geo8	1	0	0	0	0	0	0	0	1
<i>Gaeolaelaps</i> sp. 9	Geo9	0	0	0	1	0	0	0	0	1
<i>Gaeolaelaps</i> sp. 10	Geo10	0	0	0	1	0	1	0	0	2
<i>Laelaspisella cavitatis</i> (Karg)	Pogo	7	5	0	0	0	0	0	0	12
<i>Oloopticus reticulatus</i> Karg	Oloo	5	27	0	0	0	1	0	0	33
<i>Pseudoparasitus</i> sp.	Pseu	0	1	0	0	0	0	0	0	1
Phytoseiidae										
<i>Euseius citrifolius</i> Denmark and Muma	Econ	0	1	0	0	0	0	0	0	1
<i>Neoseiulus barkeri</i> Hughes	Nann	0	1	0	3	0	0	0	0	4
<i>Neoseiulus gracilis</i> (Muma)	Nide	0	1	0	0	0	0	0	0	1
<i>Propriozeiopsis mexicanus</i> (Garman)	Pmex	0	0	0	1	0	0	0	0	1
<i>Typhlodromus transvaalensis</i> (Nesbitt)	Ttra	2	4	0	3	1	4	3	1	18

Table 2. Cont.

Gamasina Species	Code	Ecosystems/Seasons								Total
		Natural Vegetation		Soybean Cultivation		Pasture		Integration of Cultivated Forest–Pasture		
		Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy	
Ascidae										
<i>Asca garmanni</i>	Ager	2	0	0	0	0	0	0	0	2
Hurlbutt										
<i>Asca</i> sp.	Asca	35	9	0	0	2	1	8	3	58
New genus	Assp	4	30	0	0	0	8	1	7	50
<i>Protogamasellus mica</i> (Athias-Henriot)	Pmic	18	31	1	18	3	47	4	25	147
<i>Protogamasellus sigillophorus</i> Mineiro, Lindquist and Moraes	Psig	8	24	8	7	9	18	38	75	187
<i>Protogamasellus pantanal</i> Yamada and Moraes	Prot	7	18	0	1	0	1	1	5	33
Blattisocidae										
<i>Cheiroseius pugiunculus</i> Karg	Cher	0	1	0	0	0	0	0	0	1
<i>Lasioseius</i> n. sp.	Lasi	0	0	0	0	0	2	0	1	3
Melicharidae										
<i>Proctolaelaps bickleyi</i> (Bram)	Pbic	0	0	0	0	0	1	0	0	1
<i>Proctolaelaps paulista</i> Mineiro, Lindquist and Moraes	Ppau	2	5	0	0	0	2	3	6	18
<i>Proctolaelaps</i> sp.	Pctl	2	7	0	0	0	0	0	0	9
Total abundance		378	541	13	51	25	135	86	154	1383
Mean abundance (mites/sample) *		65.8 ± 9.8 A	87.3 ± 26.7 a	2.3 ± 0.3 C	8.5 ± 3.2 c	4.3 ± 0.7 C	22.2 ± 5.9 b	13.7 ± 1.9 B	26.3 ± 12.9 b	
Species richness		24	31	6	16	8	18	13	13	
Mean richness (species/sample) *		12.2 ± 0.5 A	13.7 ± 2.1 a	1.8 ± 0.3 C	4.5 ± 0.9 b	3.0 ± 0.4 BC	7.2 ± 0.8 b	4.8 ± 0.7 B	6.0 ± 1.6 b	
Shannon-Weaver index		1.70	2.34	1.29	2.27	1.79	2.03	1.77	1.75	
Simpson index		0.63	0.82	0.59	0.83	0.79	0.82	0.73	0.72	
Equitability		0.54	0.68	0.72	0.82	0.86	0.69	0.69	0.68	

* Means followed by the same uppercase letters or the same lowercase letters are not significantly different at $p = 0.05$ by Kruskal-Wallis (mean abundance) and Tukey (mean richness) tests.

In total, 45 species of 24 genera were identified (Table 2). The highest diversity of genera was found in Laelapidae (five), Phytoseiidae, and Rhodacaridae (four genera each); other families contained one to three genera. The highest diversity of species was also observed in Laelapidae (19), followed by Rhodacaridae and Ascidae (six each); other families contained one to five species. At least four of the species collected are new to science, belonging to the families Ascidae and Melicharidae (one species each) and Rhodacaridae (two species).

As to the possible effect of rainfall, species richness and both diversity indexes were higher in the rainy season in natural vegetation, soybean cultivation, and pasture (Table 2). However, in the integration of cultivated forest–pasture, these parameters were exactly the same or about the same in both dry and rainy seasons.

The mean abundance was the highest in the natural vegetation in the dry (mean: 65.8, range 39–111; $\chi^2 = 20.57$; $df = 3$; $p > 0.001$) and in the rainy (mean: 87.3, range 22–195; $\chi^2 = 12.21$; $df = 3$; $p = 0.006$) seasons. The mean richness was also the highest in the natural vegetation, both in the dry (mean: 12.2 \times mean: 1.8–4.8; $F_{3,20} = 74.87$; $p < 0.001$) and in the rainy (mean: 13.7 \times mean: 4.5–7.2; $F_{3,20} = 7.72$; $p = 0.001$) seasons. Both parameters were lowest in the soybean cultivation and pasture.

In the dry season, Shannon-Weaver's and Simpson's indexes were lowest in soybean cultivation and similar to each other in other ecosystems, whereas in the rainy season, these indexes were lowest in the integration of cultivated forest–pasture. Equitability was lowest in the natural vegetation in the dry season and highest in soybean cultivation in the rainy season but similar to each other in other ecosystems at each of those seasons.

When pooling the data for both dry and rainy seasons, Shannon-Weaver's and Simpson's indexes were higher for soybean cultivation (respectively 2.35 and 0.84) than for the natural vegetation (2.16 and 0.76), pasture (2.09 and 0.81), or for the integration of cultivated forest–pasture (1.81 and 0.73). The equitability indexes of the pooled data were respectively 0.78, 0.71, 0.68, and 0.60 for soybean cultivation, pasture, integration of cultivated forest–pasture, and natural vegetation.

Considering the different ecosystems separately, the highest species diversity was found in natural vegetation (36 species), followed by soybean cultivation, pasture, and integration of cultivated forest–pasture, respectively, of 20, 19, and 14 species. Only seven species were found in all ecosystems (*Multidentorhodacarus tocantinensis*, *Multidentorhodacarus squamosus*, *Gaeolaelaps* sp.1, *Typhlodromus transvaalensis*, *Protogamasellus mica*, *Protogamasellus sigillophorus*, *Protogamasellus pantanal*). Nineteen species were found exclusively in the natural vegetation, while three species were found exclusively in the soybean cultivation and other three in the pasture; no species were found exclusively in the integration of cultivated forest–pasture.

In natural vegetation, the rhodacarids *M. squamosus*, *M. tocantinensis*, and a new species of *Binodacarus* were the predominant species (at least 78 specimens each). In addition, other 10 species were represented by more than 10 specimens each. In the other ecosystems, the predominant species were *p. mica* and *p. sigillophorus*, but in pasture and in the integration of cultivated forest–pasture, *M. squamosus* also predominated (at least 27 specimens in each). All of the predominant species in the different ecosystems were found in all ecosystems. All other species were represented by less than 10 specimens in each ecosystem, except *Asca* sp. (11 specimens in the integration of cultivated forest–pasture), and none of them were found in more than three ecosystems.

Similarity Analysis

In the similarity analysis (Figure 1), natural vegetation was positioned distant from the other ecosystems based on the abundances of species and physicochemical properties of soil. The highest similarity was observed between soybean cultivation and pasture, with the integration of cultivated forest–pasture in an intermediate position to the previous two ecosystems in one extreme and natural vegetation in the other.

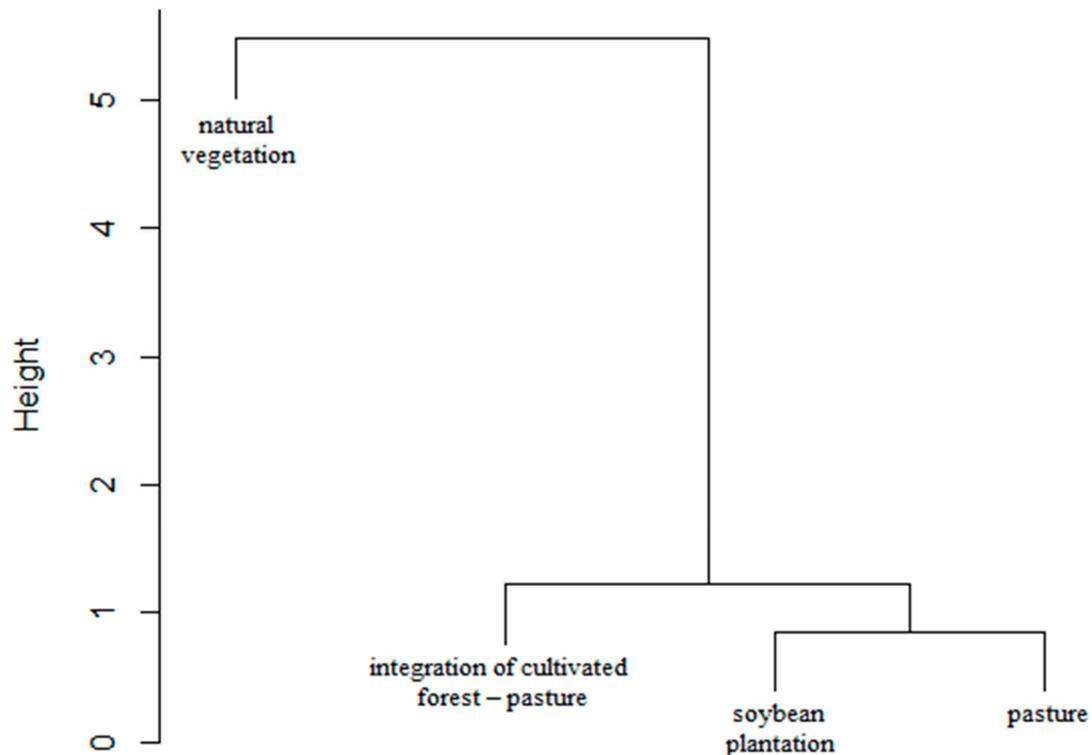


Figure 1. Similarity in mite communities between ecosystems (based on Euclidean distances) taken into account in this study: natural vegetation; soybean cultivation; pasture; integration of cultivated forest–pasture; physicochemical properties of soil, at Sucupira, Tocantins, Brazil.

In the bi-plot analysis (Figure 2), the eigenvalues of the simple correspondence analysis were significant for axes 1 ($\lambda = 0.63$) and 2 ($\lambda = 0.37$) (axes considered significant when eigenvalue is higher than 0.3, according to Dekkers et al. [23]), explaining 92.6% (axis 1: 58.5%; axis 2: 34.1%) of the variation in the data. In regard to the similarity levels between ecosystems, a greater distance was observed between soybean cultivation and pasture, as well as between any of these and natural vegetation or integration of cultivated forest–pasture. Axis 1 separated soybean cultivation and pasture from natural vegetation and integration of cultivated forest–pasture, while axis 2 separated soybean cultivation from pasture.

In the canonical correspondence analysis, both axes explained 95.32% of the variance. The first axis (CCA1) was negatively correlated with the most evaluated chemical parameters, except aluminum (Al) and manganese (Mn). It was highly correlated with total organic carbon (TOC) (-0.98), organic matter content (OMC) (-0.97), and pH (-0.71). Other parameters had lower correlations with CCA1: Boron (B, -0.45), zinc (Zn, -0.47), phosphorus (P, -0.52), and potassium (K, -0.53). TOC, MOC, and pH had a greater correlation with the soybean environment in the upper left quadrant, manganese was correlated with pasture in the lower left quadrant, copper (Cu) with the integration of cultivated forest–pasture in the upper right quadrant, and aluminum with the natural vegetation in the lower right quadrant.

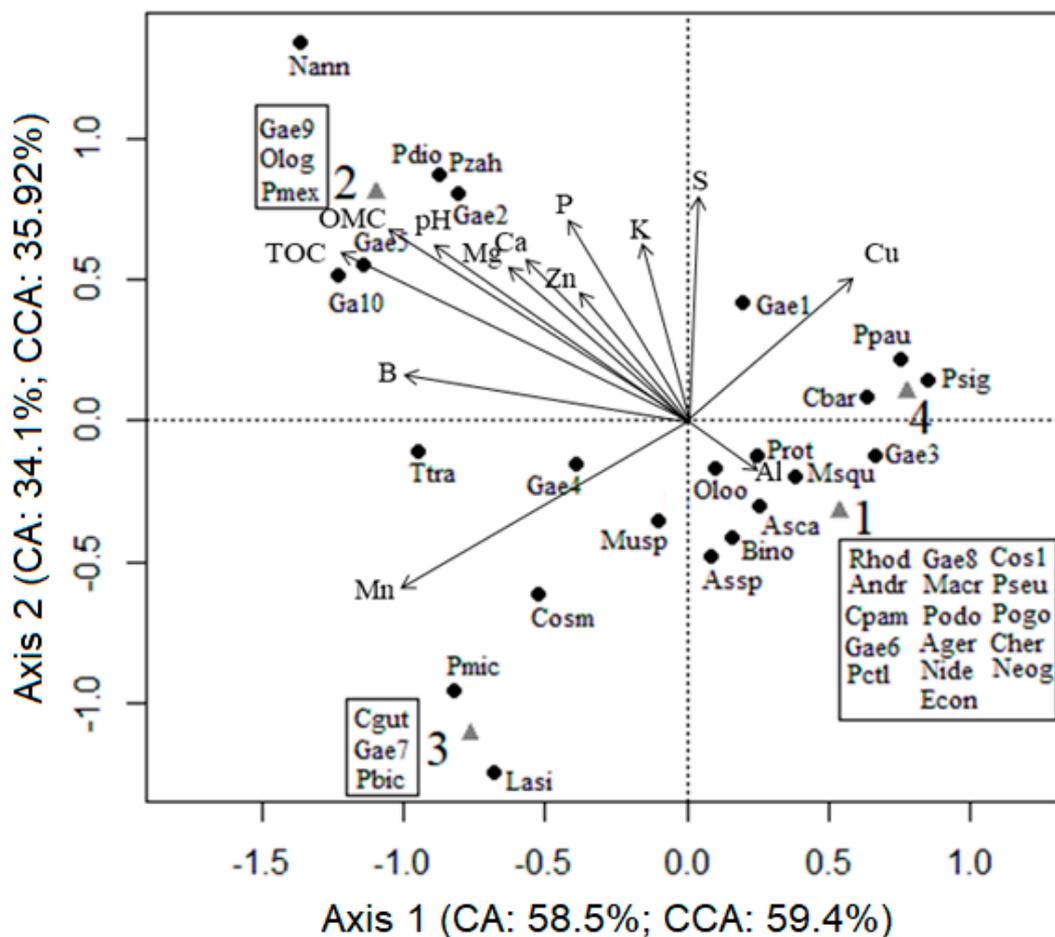


Figure 2. Biplot of simple and canonical correspondence analyses between the abundance of Gamasina and soil environmental parameters (pH; OMC, organic matter content; TOC, total organic carbon and chemical elements) in four ecosystems (1, natural vegetation; 2, soybean cultivation; 3 pasture; 4, integration of eucalyptus–pasture) at Sucupira, Tocantins, Brazil. Eigenvalues: CA: axis 1 = 0.59, axis 2 = 0.34; CCA: axis 1 = 0.59, axis 2 = 0.36. Habitats represented by triangles and species by circles. Species abbreviations shown in Table 2.

4. Discussion

The results of this work showed a major difference between the number of Gamasina in the soils of the natural vegetation and the numbers in cultivated areas, given that almost two thirds of all Gamasina specimens were collected in the former. In a distant second place were the Gamasina from the ecosystem consisting of the integration of cultivated forest–pasture, in turn followed by pasture and finally soybean cultivation. This sequence is in line with what would be expected by considering plant diversity (and diversity of other organisms) in those respective ecosystems. The strikingly low number of Gamasina in the soybean cultivation corresponded to only about 7% of the number found in the natural vegetation.

These results are compatible with findings of other authors, who also reported larger abundance and richness of mites in soils of areas of natural vegetation than in cultivated soils [24–26]. In soybean cultivation, the repeated disturbance caused by agricultural practices has been reported to result in low Gamasina abundance [26], even when the production system includes no tillage, as in the present study.

In each ecosystem, a comparison of mite abundances in rainy and dry seasons showed the smallest differences in the area of natural vegetation and of the integration of cultivated forest–pasture. In addition, the richness was higher in natural vegetation than the other ecosystems. These results suggest a relation between soil coverage (by the canopy and/or litter) with Gamasina population.

Although soil coverage was not quantified in this study, the difference between the areas was notorious. Despite the fact that soybean was cultivated under no tillage, the amount of litter in the soybean cultivation area was small, corroborating the low value of organic matter content (OMC) for this area in the dry season, when the area was bare and the lack of pronounced rain led litter to dry, exposing the soil to sunlight, and probably causing high Gamasina mortality.

However, it is curious that OMC was much higher in the rainy season in the soybean cultivation than in other areas, possibly as a result of the input of N-P-K and micronutrients in this agroecosystem in the rainy season. No tillage reduces the impact of soil management, protecting it from erosion and allowing significant increases in the levels of carbon and nitrogen, in parallel with an increase in the organic matter content [27,28], which also favors the persistence of Gamasina. In this study, difference between ecosystems was not restricted to abundance but also in terms of species richness, with the number of species in the area of natural vegetation being practically at least twice as high as in other areas.

However, quite a different picture was observed in relation to the diversity indexes, when mites of the dry and rainy seasons were pooled. The highest index for soybean cultivation, rather than reflecting species richness, reflected the highest level of equitability. The reverse can be said for the natural vegetation, where species richness was much higher than in other ecosystems but where equitability was lowest. The low equitability index in the area of natural vegetation, in turn, reflected the high predominance of a single species, *M. squamosus*, which accounted for 46% of the Gamasina in this area in comparison with only 5% in the soybean cultivation, and to 16–19% in the other areas.

Rhodacaridae has been reported as a predominant family in temperate forest soils in other parts of the world [29–31]. However, the predominance of rhodacarids in the area of natural vegetation in this study differs from the results of similar studies in other parts of Brazil, where other families have been shown as dominant [32–34]. Within the rhodacarids, *M. squamosus* had only been reported in a primary forest in Costa Rica [35] and in soybean cultivation in Mato Grosso, Brazil [36]. Another two of the dominant species were only recently described, namely *M. tocantinensis*, found in the course of this study [37], and *P. pantanal*, found in a similar study conducted in the Brazilian section of the Pantanal biome [38].

Important factors that could have contributed to determining the faunistic differences between ecosystems could obviously include the respective abiotic and biotic natural differences. However, an additional factor that might have contributed to the observed difference in Gamasina density (and possibly diversity) refers to the use of chemical products, especially in the area of soybean cultivation, but also in the area of integration of cultivated forest–pasture. Some studies have shown the negative impact of pesticides [24,39] and specifically fipronil [40,41] on edaphic organisms.

4.1. Effect of Abiotic Soil Factors

A high abundance of Ascidae species could be related to management practices in agroecosystems, influencing soil physical and chemical and properties and probably also affecting mite communities [24,39]. Ascids have been mentioned as common predators in soils of cultivated tropical areas [42]. In the present study, the physical characteristics of the soil of the four studied ecosystems seemed quite similar, and probably should not have affected the observed faunistic differences much. For all ecosystems, the soil consisted of about 70–74% sand, 21–26% clay, and 5% silt. However, the chemical characteristics were more variable. Thus, pH ranged between 4.7 and 6.5 in cultivated areas, where aluminum was not detected, differing from the soil of the natural vegetation area, where pH was 3.9–4.0 and where aluminum was detected. Under the prevailing circumstance of higher pH, *Protogamasellus* species were the most abundant mites. In a pasture area in Colombia where pH was 6.3, an undetermined species of *Protogamasellus* was reported as the most abundant Gamasina [43], whereas in pasture and agricultural areas of Argentina, where the pH was around 5.0–6.5, a high abundance of another *Protogamasellus* species was reported [44].

Protogamasellus mica, one of the predominant species in the present study in soybean cultivation, is apparently well adapted to agricultural areas. It has been reported in several locations in Brazil, mainly in agroecosystems of different biomes in the widespread states of São Paulo [26,32], Mato Grosso [36], and Pernambuco [45]. This species was reported as one of the predominant Mesostigmata in areas of cultivation of corn and beans [32].

The biplot analysis confirmed the highest species diversity in the natural vegetation than in other ecosystems and their positive correlation with aluminum and negative correlation with pH. The detection of that element only in the natural vegetation and not in other ecosystems is most certainly due to lime application in the latter, as usual in cultivations in Cerrado areas, where pH is usually low. Other studies have also shown a negative correlation between pH and mite abundance [46–48]. However, it is still not possible to tell the meaning of the observed correlation. In other words, does Al and/or pH have a direct effect on these mites, or is there an effect on other environmental factors that in turn affect the Gamasina? This seems an interesting subject to be evaluated in future works concerning the mites found in this study.

4.2. Interaction of Gamasina with Other Organisms

In addition to the direct effect provided by litter soil coverage (moisture retention, reduction of the incidence of light and excessive heat), an indirect effect is expected to occur, affecting the availability of other organisms, especially other mites, small insects, nematodes, and fungi, that could serve as food for predatory mites [44,49–51]. There is abundant information in the literature on the ability of Gamasina to feed on these organisms [13].

Among the organisms regularly consumed by gamasine mites, there are species potentially harmful to cultivated plants or animals. Soybean is one of the main crops in Brazil. This crop is not known to be severely damaged by edaphic mites but it is attacked by edaphic insects [52]. These insects are not known to be significantly attacked by predatory mites, as occurs for Sciaridae fly larvae in mushroom crops [53]. However, soybean can be severely damaged by nematodes [54,55], a group of organisms known to be consumed by Gamasina. Nematode species reported as important soybean parasites in Brazil are *Meloidogyne javanica* (Treub), *Meloidogyne incognita* (Kofoid and White), *Heterodera glycines* Ichinohe, and *Pratylenchus brachyurus* (Godfrey) [54,55]. Some of these could be attacked by local gamasine species, and in that case, it would be worthwhile to conserve those predatory mites as naturally occurring biological control agents.

The results of this study show the effect of anthropic activities on Gamasina diversity. A pragmatic question to be asked is whether the presently adopted cultivation practices and their effect on the local gamasine fauna is tolerable. The work carried out does not allow a conclusion in this regard, given our insufficient knowledge about the role of these mites in the Cerrado biome. This subject seems another important topic for future research.

Additionally, what would be a practical recommendation for growers in the region, in order to maintain as much as possible the natural qualities of the environment, while allowing agricultural production to take place? Most certainly, what was shown in this work is the prevailing situation in most grain production areas worldwide, and the ecological impact is expected to be related to the extent of the cultivated area. A mitigating measure would be the establishment of preservation areas. It is expected that areas of preserved natural vegetation close to the cultivation systems can serve as a reservoir of native species, from which they could migrate to neighboring areas. As verified in this study, of the total of 45 gamasine species collected, 36 occurred in the area of natural vegetation. It is possible, however, that at least part of these species cannot manage to survive in the agricultural environment, and that their presence is always restricted to soils of natural vegetation. The determination of this possibility and the development of techniques that would allow their maintenance in agricultural areas still require major research efforts.

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References

1. MMA—Ministério do Meio Ambiente. Cerrado Biome. Available online: https://www.mma.gov.br/estruturas/chm/_arquivos/mapas_cobertura_vegetal_ingles.pdf (accessed on 10 May 2020).
2. Ribeiro, J.F.; Walter, B.M.T. As principais fitofisionomias do Bioma Cerrado. In *Cerrado Ecologia e Flora*; Sano, S.M., Almeida, S.P., Ribeiro, J.F., Eds.; Embrapa Informação Tecnológica: Brasília, Brazil, 2008; p. 406.
3. Companhia Nacional de Abastecimento (2019) Boletim da Safra de Grãos. Available online: <https://www.conab.gov.br/info-agro/safras/graos/boletim-da-safra-de-graos> (accessed on 18 May 2020).
4. Machado, R.B.; Ramos Neto, M.B.; Pereira, P.; Caldas, E.; Gonçalves, D.; Santos, N.; Tabor, K.; Steininger, M. *Estimativas de Perda da Área do Cerrado Brasileiro*; Conservation International do Brasil: Brasília, Brazil, 2004; relatório técnico não publicado.
5. El Titi, A. (Ed.) Implications of soil tillage for weed communities. In *Soil tillage in Agroecosystems*; CRC Press: Boca Raton, FL, USA, 2003; pp. 147–185.
6. Bedano, J.C.; Domínguez, A.; Arolfo, R.; Wall, L.G. Effect of Good Agricultural Practices under no-till on litter and soil invertebrates in areas with different soil types. *Soil Tillage Res.* **2016**, *158*, 100–109. [[CrossRef](#)]
7. Bzuneck, H.L.; Santos, H.R. Efeitos de dois sistemas de preparo do solo e sucessões de cultura, na população de ácaros Galumnidae (Cryptostigmata). *Rev. Ciência Agrária* **1991**, *11*, 1–2.
8. Lopes Assad, M.L. Fauna do solo. In *Biologia dos Solos dos Cerrados*; Vargas, M.A.T., Hungria, M., Eds.; EMBRAPA, CPAC: Planaltina, Brazil, 1997; pp. 363–444.
9. Silva, J.; Casalinho, H.; Verona, L.; Schwengber, J. Avaliação da mesofauna (colêmbolos e ácaros) do solo em agroecossistemas de base familiar no Rio Grande do Sul. *Rev. Bras. Agroecol.* **2007**, *2*, 539–542.
10. Kibblewhite, M.G.; Ritz, K.; Swift, M.J. Soil health in agricultural systems. *Phil. Trans. R Soc. B Biol. Sci.* **2008**, *363*, 685–701. [[CrossRef](#)] [[PubMed](#)]
11. Lindquist, E.E.; Krantz, G.W.; Walter, D.E. Order Mesostigmata. In *A Manual of Acarology*, 3rd ed.; Krantz, G.W., Walter, D.E., Eds.; Texas Tech University Press: Lubbock, TX, USA, 2009; p. 807.
12. Gerson, U.; Smiley, R.L.; Ochoa, R. *Mites (Acari) for Pest Control*; Blackwell Science: Oxford, MA, USA, 2003; p. 539.
13. Carrillo, D.; Moraes, G.J.; Peña, J.E. *Prospects for Biological Control of Plant Feeding Mites and Other Harmful Organisms*; Springer: London, UK, 2015; p. 344.
14. Roubinet, E.; Straub, C.; Jonsson, T.; Staudacher, K.; Traugott, M.; Ekbom, B.; Jonsson, M. Additive effects of predator diversity on pest control caused by few interactions among predator species. *Ecol. Entomol.* **2015**, *40*, 362–371. [[CrossRef](#)]
15. Peel, M.C.; Finlayson, B.L.; McMahon, T.A. Updated world map of the Köppen-Geiger climate classification. *Hydrol. Earth Syst. Sci.* **2007**, *11*, 1633–1644. [[CrossRef](#)]
16. EMBRAPA—Empresa Brasileira de Pesquisa Agropecuária. *Sistema Brasileiro de Classificação de Solos*; Embrapa Informação Tecnológica: Brasília, Brazil, 2018; p. 195.
17. Oliveira, A.R.; Moraes, G.J.; Demétrio, C.G.B.; Nardo, E.A.B. *Efeito do Vírus da Poliedrose Nuclear de Anticarsia Gemmatalis sobre Oribatida Edáficos (Arachnida: Acari) em um Campo de Soja*; Embrapa Meio Ambiente: Jaguariúna, Brazil, 2001; p. 32.

18. Chant, D.A.; McMurtry, J.A. *Illustrated Keys and Diagnoses for the Genera and Subgenera of the Phytoseiidae of the World (Acari: Mesostigmata)*; Indira Publishing House: West Bloomfield, MI, USA, 2007; p. 219.
19. Castilho, R.C.; Moraes, G.J.; Halliday, B. Catalogue of the family Rhodacaridae Oudemans, with notes on the classification of Rhodacaridae (Acari: Mesostigmata). *Zootaxa* **2012**, *3471*, 1–69. [[CrossRef](#)]
20. Moraes, G.J.; Britto, E.P.J.; Mineiro, J.L.C.; Halliday, B. Catalogue of the mite families Ascidae Voigts & Oudemans, Blattisociidae Garman and Melicharidae Hirschmann (Acari: Mesostigmata). *Zootaxa* **2016**, *4112*, 1–299. [[CrossRef](#)]
21. Castilho, R.C.; Silva, E.S.; Moraes, G.J.; Halliday, B. Catalogue of the family Ologamasidae Ryke (Acari: Mesostigmata). *Zootaxa* **2016**, *4197*, 1–147. [[CrossRef](#)]
22. R Development Core Team. *R: A Language and Environment for Statistical Computing, v.3.0.1*; R foundation for Statistical Computing: Vienna, Austria, 2013.
23. Dekkers, T.B.; van der Werff, P.A.; van Amelsvoort, P.A.M. Soil Collembola and Acari related to farming systems and crop rotations in organic farming. *Acta Zool. Fennica* **1994**, *195*, 28–31.
24. Koehler, H. Predatory mites (Gamasina, Mesostigmata). *Agric. Ecosys. Environ.* **1999**, *74*, 395–410. [[CrossRef](#)]
25. Bedano, J.C.; Ruf, A. Soil predatory mite communities (Acari: Gamasina) in agroecosystems of Central Argentina. *Appl. Soil Ecol.* **2007**, *36*, 22–31. [[CrossRef](#)]
26. Junqueira, B.R. Diversidade de Ácaros Edáficos em um Fragmento de Mata Atlântica e Três Cultivos Agrícolas, em Jaboticabal/SP, com Ênfase nos Gamasina (Mesostigmata). Master's Thesis, Universidade Estadual Paulista (UNESP), Jaboticabal, Brazil, 2017.
27. Nelson, D.W.; Sommers, L.E. Total carbon, organic carbon and organic matter. In *Methods of Soil Analysis: Chemical and Microbiological Properties. Part 2*; Page, A.L., Miller, R.H., Keeney, D.R., Eds.; Soil Science Society of America: Madison, WI, USA, 1982; pp. 539–579.
28. Sisti, C.P.J.; Santos, H.P.; Kohhan, R.; Alves, B.J.R.; Urquiaga, S.; Boddey, R.M. Change in carbon and nitrogen stocks in soil under 13 years of conventional or zero tillage in southern Brazil. *Soil Tillage Res.* **2003**, *76*, 39–58. [[CrossRef](#)]
29. Price, D.W. Abundance and vertical distribution of microarthropods in the surface layers of a California pine forest soil. *Hilgardia* **1973**, *42*, 121–147. [[CrossRef](#)]
30. Evans, G.O.; Till, W.M. Mesostigmatic mites of Britain and Ireland (Chelicerata: Acari-Parasitiformes): An introduction to their external morphology and classification. *Trans. Zoo. Soc. Lond.* **1979**, *35*, 139–262. [[CrossRef](#)]
31. Coleman, D.C.; Crossley, D., Jr. *Fundamentals of Soil Ecology*; Academic Press, Inc.: San Diego, CA, USA, 1996; p. 205.
32. Mineiro, J.L.C.; Moraes, G.J. Gamasida (Arachnida: Acari) edáficos de Piracicaba, Estado de São Paulo. *Neotrop. Entomol.* **2001**, *30*, 379–385. [[CrossRef](#)]
33. Silva, E.S.; Moraes, G.J.; Krantz, G.W. Diversity of edaphic rhodacaroid mites (Acari: Mesostigmata: Rhodacaridae) in natural ecosystems in the State of São Paulo, Brazil. *Neotrop. Entomol.* **2004**, *33*, 547–555. [[CrossRef](#)]
34. Santos, J.C. Ácaros (Arthropoda: Acari) Edáficos do Estado de Alagoas, com Ênfase nos Mesostigmata. Master's Thesis, Universidade Estadual Paulista (UNESP), Jaboticabal, Brazil, 2013.
35. Karg, W. Zur Systematik der Raubmilbenfamilien Hypoaspidae v. Vitzthum, 1941 und Rhodacaridae Oudemans, 1902 (Acarina, Parasitiformes) mit neuen Arten aus Süd- und Mittelamerika. *Mitt. Mus. Naturkunde Berl.* **2000**, *76*, 243–262. [[CrossRef](#)]
36. Castro, M.C. Diversidade de Ácaros Gamasina (Mesostigmata) Edáficos em Sistema de Plantio Direto e Sistema de Integração Lavoura, Pecuária e Floresta (ILPF) no Estado do Mato Grosso. Master's Thesis, Universidade Estadual Paulista (UNESP), Jaboticabal, Brazil, 2019.
37. Azevedo, E.B.; Sarmiento, R.A.; Castilho, R.C. A new species of *Multidentorhodacarus* (Mesostigmata: Rhodacaridae) from Brazil, complementary description of *Multidentorhodacarus squamosus* Karg and a key to the world species of the genus. *Syst. Appl. Acarol.* **2019**, *24*, 324–336. [[CrossRef](#)]
38. Yamada, M.; Moraes, G.J. A key to the species of *Protogamasellus* (Acari: Ascidae), with a new species from the Brazilian Pantanal. *Zootaxa* **2020**, *4801*, 343–354. [[CrossRef](#)]
39. Ruf, A.; Beck, L. The use of predatory soil mites in ecological soil classification and assessment concepts, with perspectives for oribatid mites. *Ecotox. Environ. Safe* **2005**, *62*, 290–299. [[CrossRef](#)] [[PubMed](#)]

40. Mesléard, F.; Garnero, S.; Beck, N.; Rosecchi, E. Uselessness and indirect negative effects of an insecticide on rice field invertebrates. *C. R. Biol.* **2005**, *328*, 955–962. [[CrossRef](#)] [[PubMed](#)]
41. San Miguel, A.; Raveton, M.; Lempérière, G.; Ravanel, P. Phenylpyrazoles impact on *Folsomia candida* (Collembola). *Soil Biol. Biochem.* **2008**, *40*, 2351–2357. [[CrossRef](#)]
42. Moraes, G.J.; Venancio, R.; Santos, V.L.V.; Paschoal, A.D. Potential of Ascidae, Blattisociidae and Melicharidae (Acari: Mesostigmata) as biological control agents of pest organisms. In *Prospects for Biological Control of Plant Feeding Mites and Other Harmful Organisms*; Carrillo, D., Moraes, G.J., Peña, J.E., Eds.; Springer: London, UK, 2015; pp. 33–75.
43. Rueda-Ramírez, D.M. Ácaros Edáficos Mesostigmata de Grandes Altitudes na Colômbia e os Possíveis Efeitos de Mudanças Edafo-Climáticas sobre as Populações destes Ácaros. Master's Thesis, Escola Superior de Agricultura "Luiz de Queiroz", Universidade de São Paulo, São Paulo, Brazil, 2012.
44. Bedano, J.C.; Ruf, A. Sensitivity of different taxonomic levels of soil Gamasina to land use and anthropogenic disturbances. *Agric. For. Entomol.* **2010**, *12*, 203–212. [[CrossRef](#)]
45. Torris, A.F. Diversidade e Flutuação Populacional de Ácaros Edáficos em um Fragmento de Caatinga e Três Cultivos Agrícolas, no Vale do São Francisco (Pernambuco), com Ênfase nos Gamasina (Mesostigmata). Master's Thesis, Universidade Estadual Paulista (UNESP), Jaboticabal, Brazil, 2019.
46. Birkhofer, K.; Schoning, I.; Alt, F.; Herold, N.; Klärner, B.; Maraun, M.; Marhan, S.; Oelmann, Y.; Wubet, T.; Yurkov, A.; et al. General relationships between abiotic soil properties and soil biota across spatial scales and different land-use types. *PLoS ONE* **2012**, *7*, e43292. [[CrossRef](#)]
47. Miller, J.; Battigelli, J.P.; Willms, W.D. Grazing protection influences soil mesofauna in ungrazed and grazed riparian and upland pastures. *Rang. Ecol. Manag.* **2014**, *67*, 429–434. [[CrossRef](#)]
48. Bedano, J.C.; Cantú, M.P.; Doucet, M.E. Influence of three different land management practices on soil mite (Arachnida: Acari) densities in relation to a natural soil. *Appl. Soil Ecol.* **2006**, *32*, 293–304. [[CrossRef](#)]
49. Edwards, C.A.; Lofty, J.R. The influence of cultivations on soil animal populations. In *Progress in Soil Zoology*; Vanek, J., Ed.; Academia Publishing House: Prague, Czech Republic, 1975; pp. 399–406.
50. Fox, C.A.; Fonseca, E.J.A.; Miller, J.J.; Tomlin, A.D. The influence of row position and selected soil attributes on Acarina and Collembola in no-till and conventional continuous corn on a clay loam soil. *Appl. Soil Ecol.* **1999**, *13*, 1–8. [[CrossRef](#)]
51. Koukoura, Z.; Mamolos, A.P.; Kalburtji, K.L. Decomposition of dominant plant species litter in a semi-arid grassland. *Appl. Soil Ecol.* **2003**, *23*, 13–23. [[CrossRef](#)]
52. Oliveira, L.J.; Roggia, S.; Salvadori, J.R.; Ávila, C.J.; Fernandes, P.M.; Oliveira, C.M. Insetos que atacam raízes e nódulos da soja. In *Soja—Manejo Integrado de Insetos e outros Artrópodes-Praga*; Hoffmann-Campo, C.B., Corrêa-Ferreira, B.S., Moscardi, F., Eds.; Embrapa: Brasília, Brazil, 2012; pp. 75–144. Available online: <http://www.cnpso.embrapa.br/artropodes/Capitulo2.pdf> (accessed on 10 June 2020).
53. Castilho, R.C.; Moraes, G.J.; Silva, E.S.; Freire, R.A.P.; Eira, F.C. The predatory mite *Stratiolaelaps scimitus* as a control agent of the fungus gnat *Bradysia matogrossensis* in commercial production of the mushroom *Agaricus bisporus*. *Int. J. Pest Manag.* **2009**, *53*, 181–185. [[CrossRef](#)]
54. Dias, W.P.; Garcia, A.; Silva, J.F.V.; Carneiro, G.E.S. *Nematóides em Soja: Identificação e Controle*; Embrapa Soja: Londrina, Brazil, 2010; p. 8.
55. Mattos, V.S.; Furlanetto, C.; Silva, J.G.P.; Santos, D.F.; Almeida, M.R.A.; Correa, V.R.; Moita, A.W.; Castagnone-Sereno, P.; Carneio, R.M.D.G. *Meloidogyne* spp. populations from native Cerrado and soybean cultivated areas: Genetic variability and aggressiveness. *Nematology* **2016**, *18*, 505–515. [[CrossRef](#)]

