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Edaphic fauna under continuous application of carnauba bagana in a Plinthosol

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ABSTRACT: The bagana de carnauba is the agroindustrial waste generated after the extraction of the wax from the leaves of the carnaúba [*Copernicia prunifera* (Miller). H. E. Moore] and is widely used as organic fertilizer. The objective of the present study was to evaluate the density, diversity and composition of soil invertebrates as a function of continuous applications of carnauba bagana in a Plintosol. The study was conducted in the dry season of 2018 and in the rainy season of 2019 on two sites fertilized with carnauba bagana for 40 and 5 years with intercropped maize and beans, a site with Fallow land, in addition to a site with Caatinga transitional forest/Cerrado deciduous used as a reference. Soil fauna was collected using pitfall traps placed in the central part of each area, where they remained for seven days. Only in the dry period the Native Forest presented a significantly higher value of average richness. Sites fertilized with carnauba bagana showed a greater number of individuals with 5-years CB showing lower values of the epigean community diversity index. The dominant groups were Aranae, Collembola, Coleoptera, Diptera, Formicidae and Coleoptera larvae in the period of higher humidity and low temperature, with a reduction of Diptera and Coleoptera larvae in the dry season. Sites with carnauba bagana applied to the soil surface about 40 years ago and native forest were associated with several taxonomic groups in the rainy season.

Key words: *Copernicia prunifera*; seasonality; soil invertebrates

Fauna edáfica sob aplicação contínua de bagana de carnaúba em um Plintossolo

RESUMO: A bagana de Carnaúba [*Copernicia prunifera* (Miller). H. E. Moore] é o resíduo agroindustrial gerado após extração da cera de suas folhas sendo muito utilizado como adubo orgânico. O objetivo do presente trabalho foi estudar a densidade, diversidade e composição dos invertebrados do solo em função de aplicações contínuas de bagana da carnaúba em um Plintossolo. O estudo foi conduzido no período seco de 2018 e no período chuvoso de 2019 em duas áreas adubadas com bagana de carnaúba durante 40 e 5 anos com cultivo de milho e feijão consorciados e uma área em repouso, além de uma mata de transição caatinga/cerrado caducifólio usada como referência. A coleta da fauna do solo foi realizada por meio de armadilhas do tipo pitfalls dispostas parte central de cada área, onde permaneceram por sete dias. Apenas no período seco a mata nativa apresentou valor significativamente maior de riqueza média. Os sistemas adubados com bagana de Carnaúba mostraram maiores número de indivíduos com a área de 5 anos apresentando menores valores de diversidade epígena nos períodos avaliados. Os grupos dominantes foram Aranae, Collembola, Coleóptera, Díptera, Formicidae e larva de coleóptera no período de maior umidade, com redução de Díptera e larva de Coleóptera na época seca. Os sistemas com bagana de Carnaúba aplicada na superfície do solo há cerca de 40 anos e mata nativa estiveram associados a vários grupos taxonômicos no período úmido.

Palavras-chave: *Copernicia prunifera*; sazonalidade; invertebrados do solo

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Introduction

Copernicia prunifera (Miller). H. E. Moore or Carnauba Palm is a tropical fan palm native to Northeastern Brazil, from the Arecaceae family and can be found in all states of the region. Carnauba bagana, a by-product of wax generation, has a waxy coating that reflects solar radiation, functioning as a protective agent against radiation, supporting up to 3,000 hours of sunlight per year, which contributes to reducing evapotranspiration (Jetter & Kunst, 2008)

The disposal of this residue in the soil favors the maintenance of soil moisture, especially in periods of prolonged drought and attenuates the soil thermal amplitude (Nascimento et al., 2021), in addition to increasing the soil organic carbon content (Gonçalves et al., 2021), favorable conditions for increased activity of edaphic invertebrates (Bartz et al., 2014).

Invertebrate animals of soil fauna play a fundamental role in the fragmentation of plant residues and in the indirect regulation of soil biological processes. The organisms that make up this community are influenced by environmental factors such as soil moisture, temperature and litter thickness (Nunes et al., 2019). In biological terms, soil fauna can benefit from an increase in the quality and quantity of plant residues that serve as food and shelter for these edaphic organisms (Bartz et al., 2014).

Study carried out by Balin et al. (2017) reported significant effects of cover crops on taxonomic groups and relative density of edaphic macrofauna, concluding that plants from the legume family favor a higher relative density of invertebrates in the soil, due to their low C/N ratio. However, when the litter deposited has low concentration of nutrients and high levels of lignin and total polyphenols, there is a suppression of soil invertebrate communities, since it reduces the rate of decomposition of these residues because they are digested by specific organisms (Horner et al., 1988).

Carnauba bagana has a high content of lignin (10.6%) and chemical groups that directly contribute to the resistance of this residue to decomposition (Gomes et al., 2009), which supposedly could hinder the performance of decomposing invertebrates, contributing to a formation of a dense litter when these residues are continuously added to the soil. In this sense, it is possible that the carnauba bagana applied successively affects the composition and diversity of edaphic organisms. Thus, the objective of the present study was to evaluate the density, diversity and composition of edafic fauna as a function of continuous applications of carnauba bagana in a Plinthosol.

Materials and Methods

This study was conducted out in the village of São Joaquim located in Campo Maior municipality, Brazil (04° 34' 47" S, 42° 15' 15" W, and approximate 120 m of altitude). The region is characterized by soils of the Haplic Plinthosol type (Jacomine, 1986). The Köppen climate classification characterizes the regional climate of this area as dry tropical, with two distinct seasons: a rainy summer and a dry winter. The annual average temperature is 30 °C and the annual average rainfall reach 1,200 mm with about 5 to 6 months as rainy, and the remaining period of the year in the dry season. The months of February, March, and April correspond to the wettest trimester in the region.

The study consisted of a survey of soil fauna in four management systems, namely: i) Site with fallow practice since 2015 (Fallow land). At the time of sampling, the entire area was covered by grasses; ii) Site with carnauba bagana applied to the soil surface about 5-years and under intercropped maize and beans (5-year_CB); iii) Site with carnauba bagana applied to the soil surface about 40-years and under intercropped maize and beans (40-year_CB); and iv) Transitional caatinga/cerrado deciduous forest used as reference (Native Forest). On each study site, we established one plot (100 × 100 m) which were sampled twice. The first sampling was carried out in September 2018 (dry season and air temperature around 40 °C), before the sowing of corn and beans (areas with carnauba bagana), being considered an initial evaluation. The second sampling, in March 2019 (rainy season with milder temperatures), occurred in the full development of corn and beans (areas with carnauba bagana).

The analysis of the chemical composition of carnauba bagana showed high levels of macronutrients and organic carbon, in addition to a high C/N ratio (Table 1).

Epigeal invertebrates, which inhabit the soil–litter interface, were sampled with pitfall traps (Moldenke, 1994) consisting of plastic pots (10 cm diameter and 10 cm height) filled with 300 mL of 4% formaldehyde. A total of eight traps were installed at each site. After seven days, the traps were removed (Aquino et al., 2006) and transported to the laboratory. In the laboratory, sampled individuals were removed from the formaldehyde solution to 70% alcohol. Identification of epigeal invertebrates was performed under a binocular loupe with 40× magnification. Individuals were classified according to the level of large taxonomic groups. Groups of epigeal organisms with low representativeness (< 2% of total ind.) were combined into a category named "Others". After identification, the total number of epigeal individuals was counted and calculated by dividing the number of individuals captured by the number of traps and collection days (ind trap^{-1} day^{-1}). Results are presented as mean and standard error.

The diversity, evenness, and richness of epigeal community were determined. Fauna richness, corresponds to the number of identified groups, and average richness, represents

Table 1. Chemical composition of the carnauba bagana used.

pH $CaCl_2$	C (%)	N	P	K	Ca	Mg	S	Zn	Mn	Fe	Cu	B	Ratio C/N
		(g kg^{-1})						(mg kg^{-1})					
5.6	51.5	12.6	0.8	3.8	1.9	2.3	2.2	8.0	172.0	126.0	28.0	6.0	40.8

the average number of individuals per trap. The Shannon diversity index (H) was calculated using the equation H = −Spi log pi, in which pi = ni /N, and ni is the density of group i; and N is the sum of densities of all groups. Pielou evenness index (e) was determined as e = H/log R, in which R is the species richness or the number of taxonomic groups (Odum, 1986). Soil temperature and moisture were measured at all sampling points at each site, at depths of 0-10 and 10-20 cm. The temperature was measured with digital thermometer (measuring range from –50 °C to + 300 °C, accuracy ± 1 °C). After soil sampling, the samples were weighed and dried at 105 °C for 24 hours to determine the soil moisture content, according to Teixeira et al. (2017).

For diversity, evenness, and richness of epigeal community, the normality of errors was evaluated using the Shapiro-Wilk test and the homogeneity of variances using Leven test. Given that normality and homoscedasticity assumptions were met, means were compared by Scott-Knott test at a level of 5% probability ($p < 0.05$). Principal component analysis (PCA) was performed to investigate the relationship between variables of a dataset and multivariate differences between study sites. This approach involves the use of permutation tests (Monte Carlo test) to compare observed test statistics with random permutation of data. PCA was carried out using the Vegan package (Oksanen et al., 2021), and the software, R version 4.1.0 (R Core Team, 2021) was used to carry out statistical tests and prepare graphics.

Results and Discussion

The 40-year_CB and 5-year_CB systems showed higher values for the number of individuals collected in the traps in the rainy (33.37) and dry (25.97) seasons (Table 2). However, the high standard error observed at these sites reveals great spatial heterogeneity, and demonstrates that certain groups of invertebrates were found in only a few traps. This is due to a probable mosaic structure, in which some microhabitats, in these systems, were able to attract more individuals, functioning as a kind of refuge for soil fauna. This type of spatial distribution was also verified by Nunes et al. (2019), where different groups of soil fauna aggregated according to micro-habitat factors or vegetation characteristics.

Analyzing the standard deviation with the mean number of individuals, a great environmental heterogeneity was found, which in this study showed an effect of seasonality, as also observed by Menezes et al. (2009). Thus, in the rainy season, the standard deviation in all sites was close, ranging between 20 and 29% (Figure 1). However, there was a tendency for the standard deviation to increase in the dry season, in which the Fallow land and 5-year_CB sites represented 48 and 68% of the mean, being higher than the 40-year_CB and Native Forest groups, which presented standard deviation values of 21% and 24%, respectively.

The increase in spatial variability probably indicates a seasonal change in the availability of resources used by the fauna, which causes a high density due to more favorable abiotic factors (temperature and soil moisture) that vary according to the seasons of the year (seasonality) and with different types of habitats and micro-habitats, depending on the type and composition of the waste.

In function on the soil cover, it was found that the studied sites resulted in a variation of temperature and soil moisture, contributing to this heterogeneous distribution observed. There was a variation of +2 °C to +3 °C in soil temperature in Fallow land and 5-years_CB in relation to 40-years CB and Native Forest, respectively, while in soil moisture a variation of 2% was observed. in the dry season (Figure 2). This was due to the sandy texture associated with little vegetation cover in these areas, which favors water loss more easily. Furthermore, Fallow land shows a vegetation with a very open physiognomy, composed almost entirely by grasses, which barely prevents the direct incidence of solar radiation, contributing to the increase in soil temperature. Temperature is the main factor that activates metabolic regulation in individuals of the soil fauna and, together with soil moisture, determines the spatial distribution and the season of greatest activity of the soil fauna (Krolow et al., 2017).

There was no difference in species richness between the studied soil management systems. As for the average richness, there were no significant differences for the sites in the rainy

Table 2. Number of individuals (± standard deviation), and diversity, evenness, and richness of epigeal community for the dry (September 2018) and rainy season (March 2019) in in areas of Fallow land, 5-years with carnauba bagana, 40-years with carnauba bagana and native forest.

Site	ind trap^{-1} day^{-1} ± Standard deviation	Richness	Average richness	Diversity[1]	Evenness[2]
Dry season					
Fallow land	5.93 c ± 2.17	12	6.67 b	1.66 b	0.46
5-year_CB	25.97 a ± 12.46	12	6.80 b	1.42 b	0.40
40-year_CB	15.13 b ± 3.27	12	6.83 b	1.97 a	0.55
Native forest	7.38 c ± 1.83	13	8.00 a	2.55 a	0.69
Rainy season					
Fallow land	15.82 c ± 5.26	17	11.2	2.63 a	0.64
5-year_CB	24.17 b ± 6.91	16	10.2	2.06 b	0.52
40-year_CB	33.37 a ± 7.11	16	11.8	2.45 a	0.58
Native forest	12.25 c ± 3.19	16	12.0	2.57 a	0.64

[1] Shannon diversity index; [2] Pielou evenness index. Equal letters in the column indicate no statistical differences between sites according to Scott & Knott test ($p < 0.05$) ($n = 8$).

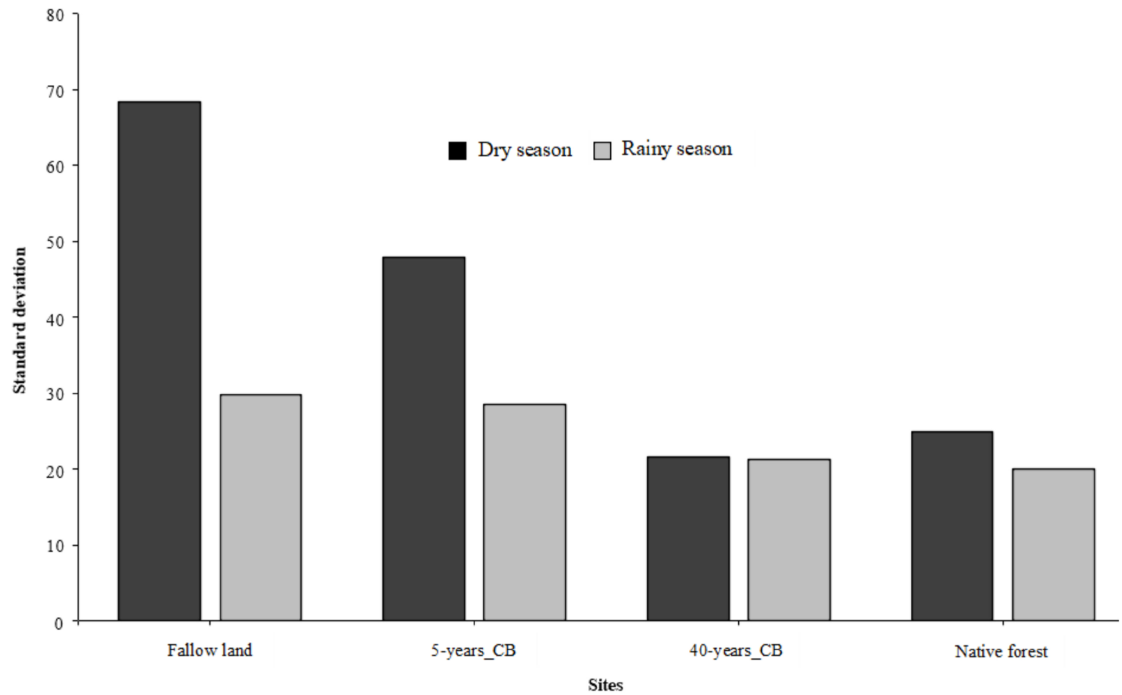

Figure 1. Seasonal variation of the standard deviation of the mean density of the edaphic macrofauna for the dry (September 2018) and rainy season (March 2019) in in areas of Fallow land, 5-years with carnauba bagana, 40-years with carnauba bagana and native forest.

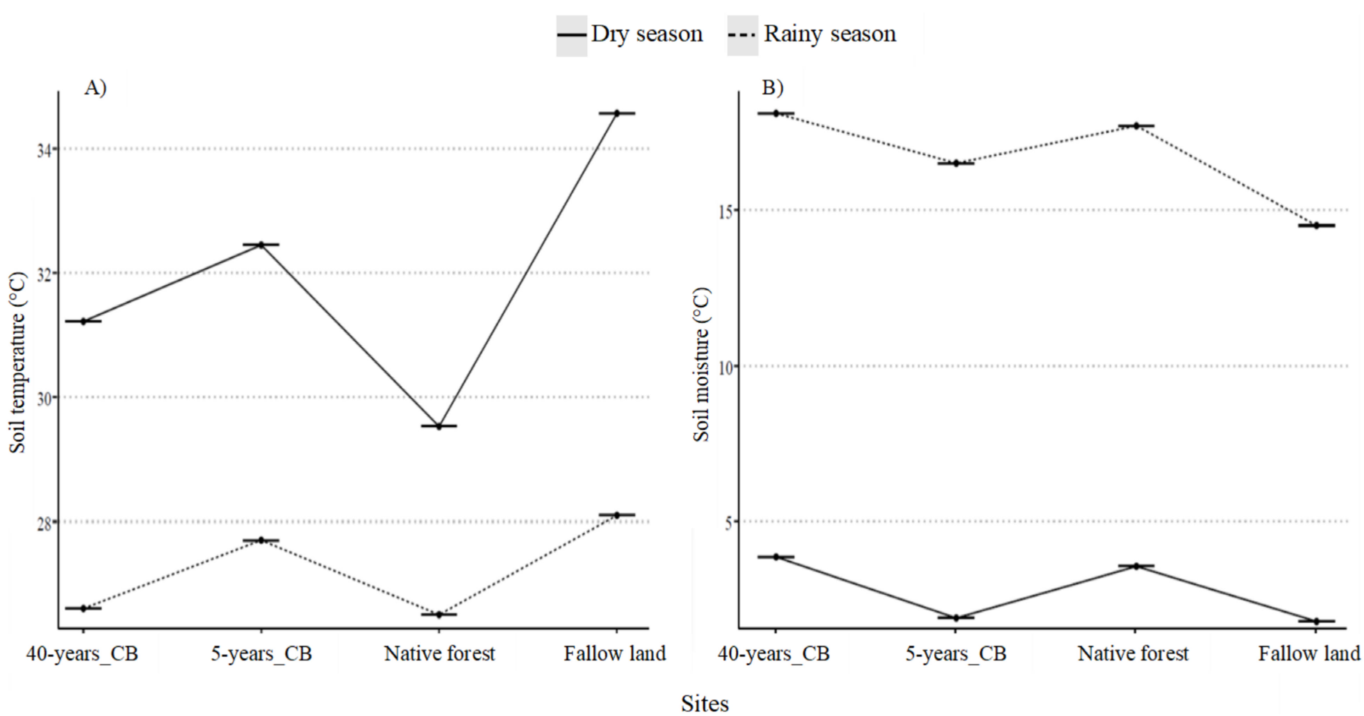

Figure 2. Soil temperature (A) and moisture (B) for the dry season (September 2018) and rainy season (March 2019) in areas of 40-years with carnauba bagana, 5-years with carnauba bagana, native forest and Fallow land

season. In the dry season the Native Forest showed higher values (8.0), for this variable, in relation to the other sites. The Cerrado is a tropical savanna with low vegetation, formed mainly by grasses that coexist with shrubs and sparse trees, providing a large amount and variety of residues in the soil (Nunes et al., 2019) that favor the reproduction of invertebrates, with availability of food and shelter (Araújo et al., 2017).

The diversity analysis in the Fallow land and 5-years_CB sites showed lower values (1.42 and 1.66), respectively, in the dry season. Furthermore, lower diversity values were observed in the rainy season only for the 5-years_CB site. No significant difference was observed in the analysis of evenness. Carnauba bagana has a lower biodegradability due to the wax component present, so that the complex mixture of acid and hydro-acid esters, wax components, limits the dehydration and hydration of carnauba straw, consequently protecting it against breakage and decomposition (Villa Lobos-Hernández & Muller-Goyman, 2005). In addition, carnauba bagana has a high content of lignin (12%) and chemical groups that directly contribute to the resistance of this residue to decomposition (Gomes et al., 2009), which makes it difficult to establish a greater diversity and uniformity of the residues soil invertebrates.

The relative distribution of the edaphic fauna community in the different sites studied for the two study seasons (rainy and dry season) can be seen in Figures 3 and 4. The influence of seasonality on soil fauna can occur in the life cycles of organisms - latency of events such as mating, reproduction, egg laying and dispersal of young - and in the supply of resources, which will temporarily change the community structure and increase the population, as found by other studies (Silva et al., 2019).

In the rainy season, the groups Aranae, Collembola, Coleoptera, Diptera, Formicidae and Coleoptera larvae were present at all sites. In turn, the Aranae group, a predatory organism, was present in greater proportions in the dry season, due to greater competition and a smaller number of ecological niches, which favored its presence, results similar to those found by Nunes et al. (2012) in pastures and by Abreu et al. (2014) in sugarcane straw. Seasonality influenced the presence of fauna groups, such as the beetle larva that occurred only in the rainy season, since this insect is in the larval stage only under adequate soil moisture conditions. The same situation also occurred in studies carried out by Nunes et al. (2021) in the savannah of Piaui.

In the rainy season, the presence of Oligochaeta was found only on the Fallow land site, although pitfall traps, aimed at individuals that transit on the ground, are not efficient

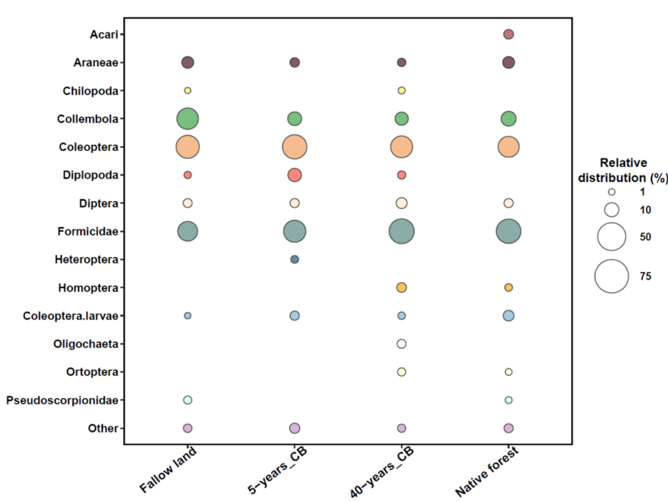

Figure 3. Relative distribution of Epigeal fauna in sites under different management systems in reference to native forest in the rainy season. The color of the circle is associated with each group of epigeous fauna, and the size of the circle represents the relative distribution of each group. Thus, the larger the circle, the more distributed the group is in each study site.

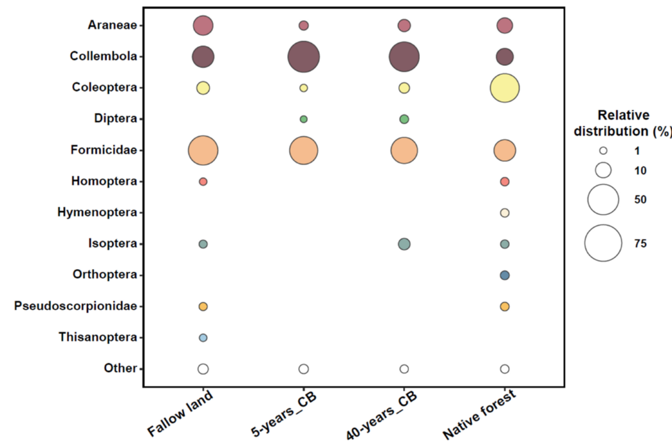

Figure 4. Relative distribution of Epigeal fauna in sites under different management systems in reference to native forest in the dry season. The color of the circle is associated with each group of epigeous fauna, and the size of the circle represents the relative distribution of each group. Thus, the larger the circle, the more distributed the group is in each study site.

for capturing this group of edaphic fauna that live in the subsurface. According to Lavelle et al. (2006), the earthworm population present in a given environment is a function of, among other factors, the organic matter content, type of vegetation and vegetation cover. Abreu et al. (2014) found the presence of Oligochaeta in different levels of sugarcane straw in pitfall traps, exclusively in the period of highest soil moisture. Some authors have shown that cover crops with a high C:N ratio, such as carnauba bagana, have a low rate of decomposition, which increases organic matter content, soil moisture, and earthworm abundance (Roarty et al., 2017; Euteneuer et al., 2020).

In the dry season, Formicidae and Collembola groups predominated on sites with carnauba bagana, showing a percentage of 93% on the 5-years_CB site and 76% on the 40-years_CB site, thus contributing to a decrease in Uniformity. This is probably due to the high C:N ratio presented by carnauba bagana, which makes it difficult to physically modify the litter through fragmentation of plant debris, one of the main roles of soil invertebrates.

Native systems in an advanced stage of conservation are indicative of the preference of Collembola. However, the successive application of organic residues to the soil favored the presence of this group, since it shows a strong interaction with the soil due to eating habits, participating in the cycling of nutrients, either by decomposing organic matter or feeding fungi and bacteria (Arenhardt et al., 2021). In turn, the order Formicidae is responsible for several ecological functions, acting as seed dispersers, soil structuring, predation, nutrient cycling, among others, always occurring under the most adverse conditions, comprising one third of the total insect biomass in the Brazilian forests (Bolico et al., 2012).

The study of the relationship between the distribution of individuals of each taxonomic group and the sites studied was carried out through an ordering generated by the principal components (CP) (Figure 3). The variables were distributed

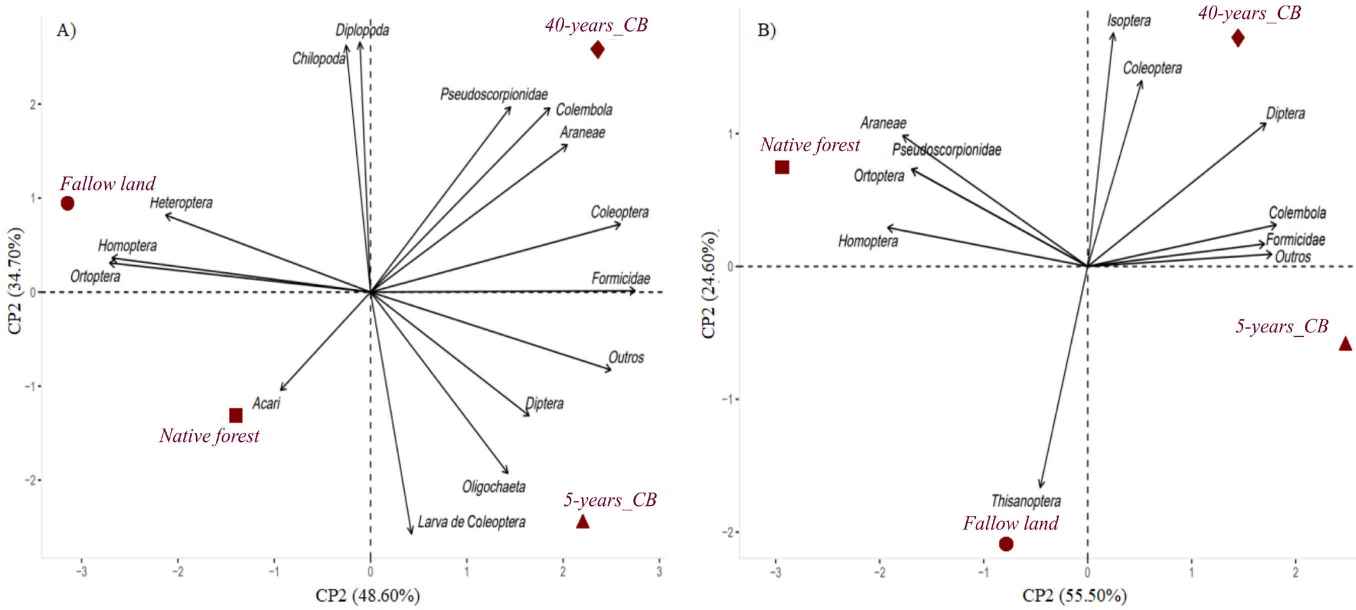

Figure 5. Principal component analysis showing the relationship between principal component 1 (CP1) and principal component 2 (CP2), considering the sites and groups of edaphic fauna in the rainy (A) and dry (B) seasons. In the PCA chart, the values on the x and y axes represent the percentage change explained by axes 1 and 2, respectively.

into two main components that explained 83.3% of the total variation in the wet season (Figure 5A), and 84.1% of the total variability in the dry season (Figure 5B).

With principal component analysis (PCA) it is possible to separate the sites studied by their specificities in the composition of the edaphic macrofauna community. The interpretation of this diagram shows that sites with carnauba bagana were associated with several taxonomic groups in the rainy season, inferring that the continuous addition of this waste creates favorable conditions for the establishment of several groups of soil fauna in the rainy season, probably due to improvement in hydrothermal soil variables.

Research carried out by Santos et al. (2016) concluded that management systems present a considerable amount of organic residues on the soil surface, providing a more favorable environment for food, shelter and reproduction of individuals of the edaphic fauna. In turn, Gualberto et al. (2021) showed that the presence of several important groups of soil fauna, including Formicidae, Coleoptera, Ortoptera and Colembola, is favored by soils with a good amount of organic matter in the surface layer.

On the other hand, the native forest in the dry season showed affinity with several groups including Aranae and Pseudoscorpionidade that are predators, probably due to a greater diversity of organic matter. The Fallow land site showed a relationship with Homoptera, Heteroptera and Orthoptera in the wet season and Thisanoptera in the dry season.

Conclusions

Sites with carnauba bagana applied to the surface of the soil for about 5 years and in a corn and bean consortium contributed to a greater number of individuals, but presented a lower index of epigeal community diversity.

The dominant groups were Aranae, Collembola, Coleoptera, Diptera, Formicidae and Coleoptera larvae in the rainy season, with a reduction of Diptera and Coleoptera larvae in the dry season.

Sites with carnauba bagana applied to the surface of the soil for about 40 years and under a corn and bean consortium and native forest were associated with various taxonomic groups (Coleoptera, Diptera, Collembola, Formicidae and Isoptera; and Aranae, Pseudoscorpionidade, Orthoptera and Homoptera, respectively) in the rainy season.

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Compliance with Ethical Standards

Author contributions: Conceptualization: LAPLN, RSS; Data curation: RMO; EMSL, JDCS; Formal analysis: RSS; Investigation: RMO; EMSL; Methodology: LAPLN, RSS, JDCS; Project administration: LAPLN; Resources: RSS; Software: RSS; Supervision: RSS; Validation: RMO, EMSL, JDCS; Visualization: RMO, EMSL; Writing – original draft: RSS, RMO, EMSL, JDCS; Writing – review & editing: LAPLN, RSS.

Conflict of interest: The authors declare that there is no conflict of interest.

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