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CARNAUBA BAGANA IMPROVES THE SOIL QUALITY CULTIVATED WITH CORN IN THE SEMIARID PIAUIENSE[1]

BAGANA DE CARNAÚBA MELHORA A QUALIDADE DO SOLO CULTIVADO COM MILHO NO SEMIÁRIDO PIAUIENSE

Cássio de Moura Santos[2], Ana Clara Caminha de Carvalho[3], Vinícius de Sousa Araújo[3], Rafael de Sousa Nobre[3], Ana Karina Silva Costa[4], Ronilson Carvalho Veloso[4], Lucila de Sousa Nunes[4], Daniel de Moura Silva[4], Maria do Socorro de Sousa Menezes[4], Irys de Moura Rêgo[4] e Jefrejan Souza Rezende[5]

ABSTRACT

The Corn an important role in agriculture, and can be used in both human and animal food, production of ethanol, medicines and glue. However, is verified cultivation practices and soil inappropriate management have led to soil deterioration. Thus, the importance of vegetation cover and the incorporation of organic matter in these cultivated soils. The objective of this work was to evaluate the effect of Carnauba bagana maintained on the soil as mulch and incorporated in macrofauna and soil organic carbon, in the municipality of Itainópolis, in the semi-arid region of Piauí. The areas to be studied will be: corn area with carnauba bagana, as mulch and incorporated into the soil; corn area with uncovered soil and an area of preserved native vegetation. The epigean and edaphic macrofauna will be collected, sorted and identified at the order level. Soil samples will be collected to determine soil organic carbon. Carnauba bagana improved the macrofauna community and soil organic carbon content. The cultivation of corn on uncovered soil reduced the uniformity and diversity of the epigeal macrofauna, the Wealth and Abundance of the edaphic macrofauna and the soil organic carbon content. The variables Larvae, Abundance, Richness, Shannon and Pielou indices, and COS in layers 0.00-0.05 and 0.05- 0.10 m were selected for future studies of the impact of maize cultivation in the region.

Keywords: Organic carbon, Macrofauna, Semiarid, Zea mays L.

RESUMO

O milho possui papel importante na agricultura, podendo ser utilizado tanto na alimentação humana como animal, produção de etanol, medicamentos e cola. No entanto, práticas de cultivo e manejo inadequado do solo tem levado à deterioração do solo. Com isso verifica-se a importância da cobertura vegetal e incorporação de matéria orgânica nesses solos cultivados. Objetivou-se com esse trabalho avaliar o efeito da bagana de Carnaúba dmantida no solo como cobertura morta e incorporada na macrofauna e no carbono orgânico do solo, no município de Itainópolis, no semiárido piauiense. As áreas estudadas foram: Área de milho com bagana de carnaúba como cobertura morta e incorporada ao solo; área de milho com solo descoberto e área de vegetação nativa preservada. A macrofauna epígea e edáfica foram coletadas, triadas e identificadas a

1 Trabalho de Iniciação Científica, Universidade Estadual do Piauí - UESPI.

2 Bolsista PIBIC-UESPI. Graduado em Engenharia Agronômica - UESPI, Picos, PI. E-mail: cassiosantos@aluno.uespi.br

3 Graduado em Engenharia Agronômica - UESPI, Picos, PI. E-mails: anaccarvalho@aluno.uespi.br; viniciusaraujo@aluno.uespi.br; rafaelnobre@aluno.uespi.br

4 Graduando em Engenharia Agronômica - UESPI, Picos, PI. E-mails: anakcosta@aluno.uespi.br; ronilsonveloso@aluno.uespi.br; lucilanunes@aluno.uespi.br; danielmsilva@aluno.uespi.br; mariamenezes@aluno.uespi.br; Irysrego@aluno.uespi.br

5 Orientador. Docente do curso de Engenharia Agronômica - UESPI, Picos, PI. E-mail: jefrejansouza@pcs.uespi.br

nível de ordem. Foram coletadas amostras de solo, para determinação do carbono orgânico do solo. A bagana de Carnaúba proporcionou melhoria na comunidade da macrofauna e nos teores de carbono orgânico do solo. O cultivo de milho sobre solo descoberto reduziu a uniformidade e diversidade da macrofauna epígea, a Riqueza e Abundância da macrofauna edáfica e os teores de carbono orgânico do solo. As variáveis Larva, Abundância, Riqueza, índices de Shannon e Pielou, e Carbono Orgânico do solo nas camadas 0,00-0,05 e 0,05-0,10 m foram selecionadas para futuros estudos do impacto do cultivo de milho na região.

***Palavras-chave*:** Carbono orgânico, Macrofauna, Semiárido, Zea mays L.

INTRODUCTION

Corn (*Zea Mays* L.) belonging to the Gramineae/Poaceae family is a plant native to Mexico (LOPES *et al.* 2019). This cereal is a source of carbohydrates, fats, proteins, vitamins and minerals, being used in human and animal food, in addition to being feedstock for the production of medicaments and biofuels (LANGNER *et al.* 2019; USDA 2021).

In the 2022/2023 harvest there was record production of 1.23 billion tons (CONAB 2023). However, the Northeast region recorded the lowest productivity, with 3785 kg ha^{-1}, much lower than the national average, which was around 5617 kg ha^{-1} (CONAB 2023).

This reduction in productivity rates is associated with factors such as climate, characterized by infrequent and low-intensity rainfall, and cultural practices and inadequate soil management, which has led to soil deterioration in this region, resulting in nutritional deficiencies (BIRTHAL *et al.* 2015; HERNÁNDEZ *et al.* 2015; BEN *et al.* 2019).

With this, is verified the importance of using alternative management practices that preserve and/or restore the productive capacity of the soil and the sustainability of production. (OLIVEIRA *et al.* 2017), such as the increase in organic matter.

Covering and incorporating of soil organic matter provide habitat and food for fauna, preserving and improving the diversity and richness of invertebrates. In addition, it increases infiltration and water retention in soil, improves soil aggregation, reduces erosion and loss of organic matter, and provides nutrients for plants (WU & WANG 2019; LUCERO *et al.* 2020). However, poorly managed soil negatively impacts in habitat, richness and diversity of soil fauna, which undermines ecosystem services fundamental to soil health and agricultural activity (JIANG *et al.* 2018; WU & WANG 2019; LUCERO *et al.* 2020). Among the impaired activities are aeration, aggregation and soil structuring, fragmentation and decomposition of organic matter, cation exchange capacity and nutrient cycling (DOMÍNGUEZ *et al.* 2018; LUCERO *et al.* 2020).

In view of this, the use of carnauba bagana to protect the soil and increase organic matter in corn crops in the northeastern semi-arid region can be a promising alternative.

The municipality of Itainópolis in Picos-PI macro-region is a Carnauba producing region, from where the straw, stalk - caule, roots, wood and the dust of its straw are extracted, from which wax is

produced, a product in which the Brazil is the only exporter (ABRAÃO *et al.* 2021). This generates a byproduct known as Carnauba bagana. However, most of the time the bagana is discarded in nature, except in some local farmers where is used as mulch and incorporate in soil, usually in the cultivation of corn, commonly produced by family farmers in the region.

In this context, the objective of this study was to evaluate the effect of Carnauba bagana maintained on the soil as mulch and incorporated in macrofauna and soil organic carbon.

MATERIAL AND METHODS

LOCATION AND CHARACTERIZATION OF THE STUDY AREA

The work was carried out in the village of Várzea Grande, belonging to the municipality of Itainópolis-PI. The climate, according to the Köppen climate classification, is semiarid, very hot, characterized by scarce and irregular rainfall distribution, with high average temperatures around 30 °C and average anual rainfall of 696,6 mm (MEDEIROS *et al.* 2020).

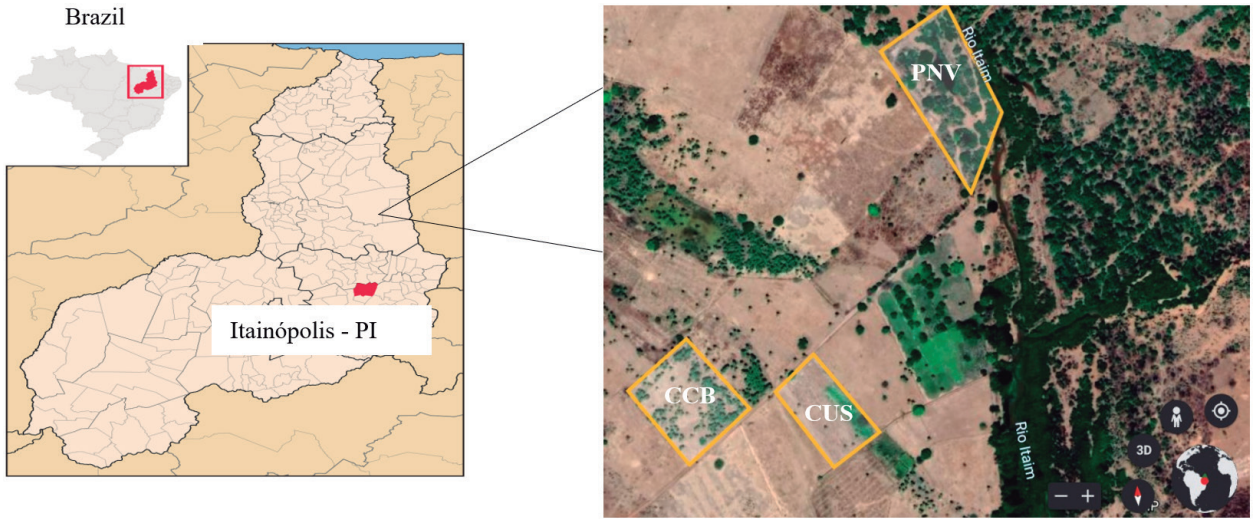
For this, three distinct areas were selected, but bordering and with similar topography and texture. Corn area with carnauba bagana (CCB) as mulch and incorporated into the soil; Corn area with uncovered soil (CUS) and an area of preserved native vegetation (PNV), considered as witness. The data referring to the characterization of the areas are presented in table 1 and figure 1.

Table 1- Characterization of the study áreas

Site	Area (ha)	Geographic coordinates	Altitude (m)	Land use history	Soil management
PNV	1.55	07° 21’ 8,1” S; 41° 32’ 55” O	185	· There are no reports of land use	· Unmanaged
CCB	1.14	07° 21’ 16”S; 41° 32’ 11” O	185	· About 20 years ago, Carnauba bagana is used as mulching and in the incorporation in corn cultivation.	· Manual planting, with spacing of 0.5 m x 0.80 m, after animal traction plowing, without harrowing; ·Without soil correction; · Without fertilization; · Rack crop; ·Cultural treatments: Manual weeding, with plant material maintained on the soil and incorporated, with the presence of animals in the area.
CUS	0.78	07° 21’ 16”S; 41° 32’ 12” O	185	· About 20 years ago, the site was deforested and prepared for corn planting without the use of vegetation cover.	· Manual planting, with spacing of 0.5 m x 0.80 m, after animal traction plowing, without harrowing; ·Without soil correction; · Without fertilization; · Rack crop; · Cultural treatments: Manual weeding.

CCB: Corn area with carnauba bagana; CUS: Corn area with uncovered soil; PNV: Preserved native vegetation

Figure 1 - Location of study areas. CCB: Corn area with carnauba bagana; CUS: Corn area with uncovered soil and PNV: Preserved native vegetation



SAMPLING OF THE EPIGEAL MACROFAUNA

In each area, a sampling unit with the same dimensions was determined (200m^2), providing the same evaluation condition. Subsequently, in the center of each sampling unit, a sampling mesh (grid) was established, where 10 traps were used, distributed in two rows, with a distance of 10 m between rows and 5 m between each trap. This ensured complete coverage of the sample unit in each studied area.

To collect the epigeal macrofauna, traps of the PROVID type were installed, which remained in the area for a period of 72 h, containing 200 mL of ethylic alcohol (70%) and neutral detergente, to preserve the insects (ANTONIOLLI *et al.* 2006). Subsequently, the traps were collected and taken to the Biology laboratory, State University of Piauí, Picos *Campus*, where the macrofauna it was separated and classified taxonomically at order level (ANDERSON & INGRAM 1993).

SAMPLING OF EDAPHIC MACROFAUNA

For the sampling of edaphic macrofauna, each sampling unit was subdivided into three homogeneous subunits, which represented the study area.

In the center of each subunit a monolith of 0.25 x 0.25 m (width x length) was collected, at a depth of 0.10 m. This totaled three samples per sampling unit, in each cultivation area. Subsequently, the soil monoliths were placed in polyethylene bags and transported to the Agronomy laboratory, State University of Piauí, Picos *Campus*, where the macrofauna it was separated and classified taxonomically at order level (ANDERSON & INGRAM 1993).

SAMPLING OF SOIL ORGANIC CARBON

In each sampling subunit, 10 simple samples were collected and formed a composite sample, in the 0.00-0.05m and 0.05-0.10 m layers, totaling three composite samples by cultivation area and layer. After collection, the soil samples were dried, crushed, packed and sent to the laboratory for analysis.

DETERMINATION OF EPIGEAL AND EDAPHIC MACROFAUNA

To determine the invertebrates, the following variables were calculated, according to Odum (1998): Relative frequency (percentage of each order identified in relation to the total, by study area), Abundance (total number of individuals of each order per area), Richness (number of orders per area) and the Shannon diversity and Pielou uniformity indexes.

Shannon diversity index was calculated by the formula:

$$Shannon = - \sum (pi \log pi) \quad (1)$$

Where, pi = ni/N; ni = abundance of each order, N = total abundance.

Pielou uniformity index was calculated by the formula: Pielou = Shannon/log Richness.

DETERMINATION OF SOIL ORGANIC CARBON

Soil organic carbon was extracted through the oxidation of organic matter by potassium dichromate ($K_2Cr_2O_7$) at 0.020 mol L^{-1} and determined by titration with ferrous ammonium sulphate at 0.005 mol L^{-1} (YEOMANS & BREMNER 1988).

STATISTICAL ANALYSIS

The data were submitted to analysis of variance using the F test ($P \leq 0.05$). Atributes means, when significant, were compared by the Tukey's test at 5% probability. Principal component analysis was also applied, with the aim of selecting the variables most sensitive to the effect of management, correlating the variables with each other and with the areas and management evaluated.

RESULTS AND DISCUSSION

Among the 10 taxonomic groups described, in relation to the epigean macrofauna, the Hymenopteras, Coleopteras and Orthopteras were more representative in the studied systems (Table 2).

Table 2 - Relative frequency (%) of taxonomic groups of epigeal invertebrate macrofauna under agricultural uses.

Group	CCB	CUS	PNV
	---------- (%) ----------		
Hymenoptera	17.90	74.04	30.74
Coleoptera	29.74	5.80	15.78
Orthoptera	26.35	6.35	9.09
Blattodea	7.78	2.54	34.23
Diptera	9.79	3.81	4.81
Araneae	2.37	3.63	4.01
Hemiptera	3.04	0.73	0.00
Homoptera	1.01	1.28	0.80
Lepidoptera	1.01	1.09	0.00
Thysanoptera	1.01	0.73	0.00
Larva	0.00	0.00	0.54
Total	100.00	100.00	100.00

CCB: Corn area with carnauba bagana; CUS: Corn area with uncovered soil and PNV: Preserved native vegetation.

The Hymenopteras group presented greater frequency in the Corn area with uncovered soil - CUS (74.04%), preserved native vegetation - PNV (30.74%) e Corn area with carnauba bagana - CCB (17.90%) (Table 2). This was due to the Formicidae family that stood out within the group, possibly by the high adaptation capacity in the different systems (MENEZES *et al.* 2009). This group stands out among the most important of soil fauna, due to its participation in the decomposition of organic matter and nutrient cycling as well as seed dispersal, soil structuring, predation, among others (BRITO *et al.* 2016; GUIMARÃES *et al.* 2021).

The second group with the highest representativeness among the systems was Coleoptera representing a relative frequency of 29.73% (CCB), 5.80% (CUS) and 15.77% (PNV) (Table 2).

The frequency of this group in the CCB was approximately twice the PNV and five times more than in CUS. This can be attributed to the adaptation of this group to the most regulated ecosystems (MARTINS *et al.* 2017), which shows a trend of good conservation of the

The Orthoptera group was the third most representative, with a relative frequency of 26.35%, 6.35% and 9.09% for the CCB, CUS and PNV systems, respectively (Table 2). This can be attributed to the ecological importance this order. These organisms are defoliators and make food base of many vertebrates and invertebrates, and therefore contribute directly the incorporation of organic matter in the soil (SANTOS JUNIOR *et al.* 2021).

There was a significant effect of areas for the Shannon and Pielou indices, while than for abundance and richness there was no significant difference (Table 3).

Table 3 - Resume of analysis of variance for Abundance, Richness and Shannon and Pielou indexes of taxonomic groups of epigeal invertebrate macrofauna under soil uses and management.

Variation sources	p value			
	Abundance	Richness	Shannon	Pielou
Area	0.053^{ns}	0.28^{ns}	0.03*	0.00*
CV (%)	56.00	18.15	28.18	24.06

*significant at the level of 5%; ns: not significant by F-test. CV - Coefficient of variation.

The CCB area obtained the highest Shannon and Pielou indexes, compared to the CUS area, without differing from the PNV (Table 4). This occurred, possibly due to the input of plant material in soil, making it possible to create a suitable habitat and, favoring the increase availability of food for invertebrate macrofauna (PEREIRA *et al.* 2015). According to NUNES *et al.* (2020) it is common to the increase the number of groups and individuals per group in the litter due to the greater availability of energy sources, which favor the reproduction of invertebrates. Similar results were found by ARAÚJO *et al.* (2021), where there was a significant effect of the area with the highest plant input, for the Shannon and Pielou indixes.

As for the relative frequency of taxonomic groups of edaphic macrofauna (Table 5), the Coleoptera group was the most present, being found in the three study áreas. Coleoptera are abundant in Brazilian soils and, although some families are considered pests in agricultural systems, some can contribute to the physical and chemical integrity of the soil (SILVA *et al.* 2012). These organisms act in the incorporation and decomposition of organic matter, being considered indicators of soil quality.

Table 4 - Shannon and Pielou indices of taxonomic groups of epigeal invertebrate macrofauna under soil uses and management.

Area	Shannon	Pielou
CCB	1.44 a	1.92 a
CUS	1.00 b	1.29 b
PNV	1.22 ab	1.76 a
CV (%)	28.18	24.06

CCB: Corn area with carnauba bagana; CUS: Corn area with uncovered soil and PNV: Preserved native vegetation. *Means followed by the same letter in the column do not differ by Tukey test at 5% probability of error. CV - Coefficient of variation.

Table 5 - Relative frequency (%) of taxonomic groups of edaphic invertebrate macrofauna under agricultural uses.

Group	CCB	CUS	PNV
	---------- (%) ----------		
Coleoptera	26.02	70.00	45.28
Larva	52.05	20.00	37.74
Blattodea	12.34	0.00	16.98
Hymenoptera	6.85	0.00	0.00
Araneae	0.00	10.00	0.00
Diplopoda	2.74	0.00	0.00
Total	**100.00**	**100.00**	**100.00**

CCB: Corn area with carnauba bagana; CUS: Corn area with uncovered soil and PNV: Preserved native vegetation.

In general, the CCB area obtained a greater diversity of taxonomic groups in relation to CUS and PNV (Table 5). All areas studied there was presence of larvae, where the highest occurrences were in CCB (52.05%) and PNV (37,74%). Several invertebrates have a preference for depositing their larvae in environments with a greater accumulation of decomposing plant matter, so that they can develop (ROSA *et al.* 2015; ARAÚJO *et al.* 2021), which may explain the above results.

There was a significant effect of treatments for abundance, richness and soil organic carbon, in the 0.00-0.05 m and 0.05-0.10 m layers, and there was no significant effect for the Shannon and Pielou indexes (Table 6).

Table 6 - Resume of analysis of variance for Abundance, Richness and Shannon and Pielou indexes of taxonomic groups of edaphic invertebrate macrofauna and soil organic carbon under soil uses and management.

Variation sources	p value					
	Abundance	Richness	Shannon	Pielou	SOC 0-5	SOC 5-10
					----------g kg^{-1}----------	
Areas	0.008*	0.021*	0.156^{ns}	0.880^{ns}	0.000*	0.000*
CV (%)	36.18	24.85	28.37	19.02	5.03	9.05

*significant at the level of 5%; ns: not significant by F-test. SOC 0-5 and SOC 5-10 represent the content of soil organic carbon (SOC), in the 0.00-0.05 m and 0.05-0.10 m layers, respectively.

The highest means of Abundance and Richness of edaphic macrofauna were verified in CCB area, in comparison to CUS area, without differing from PNV area (Table 7). This may be related to the high increase in plant material present in CCB and PNV areas, which benefits the number of individuals (ARAÚJO *et al.* 2021). According to SALTON & TOMAZI (2014), plant residues on soil and incorporated improve soil porosity and aggregation, which favors the development of soil organisms.

Table 7 - Abundance and Richness of taxonomic groups of edaphic invertebrate macrofauna and soil organic carbon under soil uses and management

Area	Abundance	Richness	SOC 0-5	SOC 5-10
			----------g kg^{-1}----------	
CCB	25.67 a	4.00 a	15.87 a	15.35 a
CUS	3.33 b	1.67 b	10.66 b	8.37 b
PNV	17.67 a	3.33 ab	15.99 a	12.90 a
CV (%)	36.18	24.85	5.03	9.05

CCB: Corn area with carnauba bagana; CUS: Corn area with uncovered soil and PNV: Preserved native vegetation.
*Means followed by the same letter in the column do not differ by Tukey test at 5% probability of error.
CV - Coefficient of variation

For the SOC contents in the 0.00-0.05 and 0.05-0.10 m layers, the highest values were found in CCB and PNV systems (Table 7). The greater accumulation of SOC in the CCB area in relation CUS area can be explained by the high capacity for input of plant material by the straw, and by the decomposition of the material and by the non-revolving of the soil (CAMPOS *et al.* 2016;

SANTOS *et al.* 2019). In PNV, the greater accumulation of SOC can be explained by the non-revolving of the soil and litter and by the slow decomposition of plant residues (SALES *et al.* 2018; SANTOS *et al.* 2019).

Regarding the percentage of variation in principal component analysis, for edaphic macrofauna and soil organic carbon, principal component 1 (PC1) explained 69.40% and principal component 2 (PC2) explained 30.60% of the variability of the variables (Table 8).

The variables that explained with correlation highest were: Richness, Blattodea, Abundance, Shannon index, SOC 0-5, SOC 5-10, Larva, Pielou index and Coleoptera, with emphasis on Richness, Blattodea, Abundance, Shannon index, SOC 0-5, SOC 5-10, Larva and Pielou index that showed a correlation ≥ 0.9. This indicates these variables are more sensitive to the influence to management used in systems, and can be selected for monitoring in future studies.

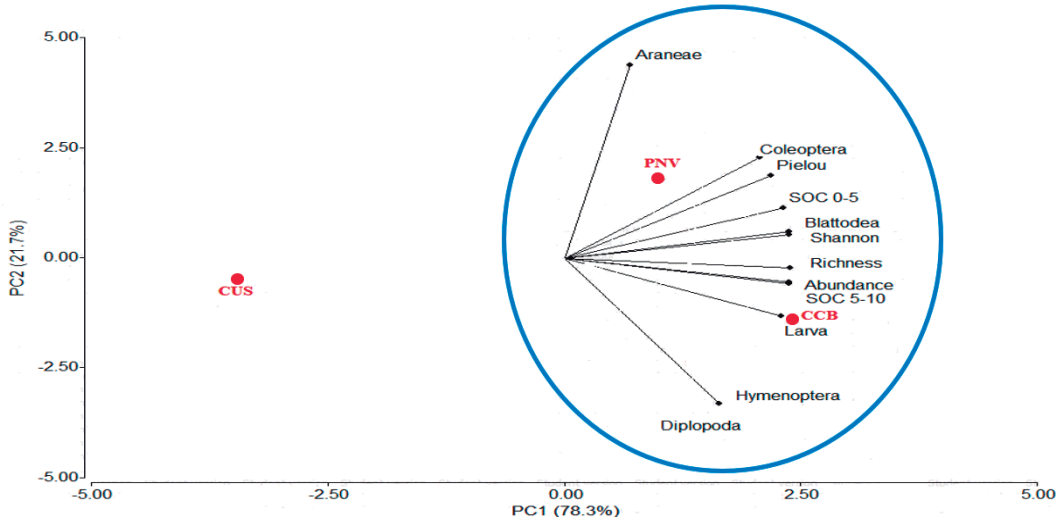
Table 8 - Correlation between each principal component and edaphic macrofauna and soil organic carbon in areas under agricultural use in the semi-arid region of Piauí.

Variables	PC1	PC2
Richness	1.00*	-0.05
Blattodea	0.99*	0.12
Abundance	0.99*	-0.13
Shannon	0.99*	0.13
SOC 0-5	0.97*	0.25
SOC 5-10	0.99*	0.12
Larva	0.96*	-0.29
Pielou	0.91*	0.41
Coleoptera	0.87*	0.50
Hymenoptera	0.69	-0.73*
Diplopoda	0.69	-0.73*
Araneae	0.29	0.96*
Absolute variance (%)	**78.30**	**21.70**
Cumulated variance (%)	**78.30**	**100.00**

PC: Principal component *Values ≥ |0.70| are significant.

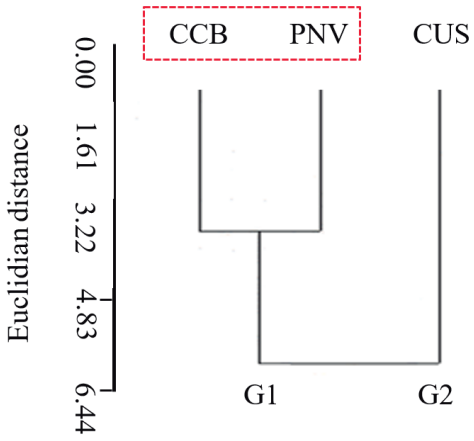
Figure 2 shows that all variables were strongly associated with the CCB and PNV areas, and that none of these groups associated with the CUS area. This points to a positive influence of the organic matter present in these areas for these organisms. Environments that favor a greater accumulation of organic matter tend to have a greater number of invertebrate fauna, because they act in the conservation of biodiversity (LIMA *et al.* 2019).

Figure 2 - Graphical representation of principal component analysis between study areas and taxonomic groups of edaphic macrofauna and soil organic carbon in the semi-arid region of Piauí. CCB: Corn area with carnauba bagana; CUS: Corn area with uncovered soil and PNV: Preserved native vegetation. SOC 0-5 and SOC 5-10 represent the content of organic carbon in the soil (COS), in the layers 0.00-0.05 m and 0.05-0.10 m, respectively



In cluster analysis, two distinct groups (G1 and G2) were formed between the systems (Figure 3). Group 1 was formed by CCB and PNV and group 2 was formed by CUS. This again shows the similarity between the CCB and PNV, a fact that again highlights the importance of vegetation cover and of the input of organic matter.

Figure 3 - Dendrogram of similarity constructed from the averages of edaphic macrofauna and soil organic carbono, in the different areas under study in the semi-arid region of Piauí. CCB: Corn area with carnauba bagana; CUS: Corn area with uncovered soil and PNV: Preserved native vegetation



CONCLUSIONS

Carnauba bagana improved the macrofauna community and soil organic carbon content.

The cultivation of corn on uncovered soil reduced the uniformity and diversity of the epigeal macrofauna, the Wealth and Abundance of the edaphic macrofauna and the soil organic carbon content.

The variables Larva, Abundance, Richness, Shannon and Pielou indixes, and COS in the 0.00-0.05 and 0.05- 0.10 m layers were selected for future studies of the impact of corn cultivation in the region.

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