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INCREASES IN SOIL MESOFAUNA THROUGH TREE ESTABLISHMENT AND GRAZING DEFERMENT IN A DEGRADED AREA IN THE CAATINGA BIOME[1]

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ABSTRACT - Environmental degradation impacts negatively the diversity and quantity of invertebrates living in the soil, mainly in semiarid regions. Generally, a high diversity of invertebrates indicates good biofunctionality and sustainable use of the soil. We evaluated the effects of 14 years of grazing deferment and the presence of the native trees *Mimosa tenuiflora* and *Cnidoscolus quercifolius* on the soil mesofauna of a degraded Caatinga area, according to the χ^2 test, applied to assess the abundance of these microorganisms. The grazing deferment alone more than tripled the soil mesofauna. The abundance of the mesofauna under *M. tenuiflora* canopies increased by a factor of 3.17 and 3.41 in grazed and ungrazed areas, respectively, and under *C. quercifolius* canopies increased by a factor of 22.6 in the ungrazed area. The effect of *M. tenuiflora* in the grazed area was similar to 14 years of grazing deferment. The quantity of mesofauna under *C. quercifolius* canopies after 14 years of grazing deferment was 6.6-fold higher than that under *M. tenuiflora* canopies, under similar conditions. The grazing deferment and trees, especially *C. quercifolius*, increased the soil mesofauna; however, full recovery of such organisms in degraded Caatinga areas may need more than 14 years. Considering the current scenario of increasing environmental degradation, our findings regarding the relationships between soil mesofauna, grazing deferment and native trees are important to devise strategies and procedures for the recovery of degraded areas in the Caatinga biome.

Keywords: Environmental recovery. Acarina. Collembola. Jurema preta. Faveleira.

AUMENTO DA MESOFAUNA EDÁFICA RESULTANTE DO ESTABELECIMENTO DE ÁRVORES E EXCLUSÃO DE ANIMAIS EM UM SÍTIO DEGRADADO DE CAATINGA

RESUMO - A degradação ambiental impacta negativamente a diversidade e a quantidade dos invertebrados do solo, notadamente em regiões semiáridas. Geralmente, uma alta diversidade de invertebrados indica a biofuncionalidade e a sustentabilidade do uso do solo. Nós avaliamos o efeito de 14 anos de isolamento e da presença das árvores nativas *Mimosa tenuiflora* e *Cnidoscolus quercifolius* na mesofauna do solo de uma área degradada de Caatinga, de acordo com o teste do χ^2 aplicado aos dados de abundância desses microorganismos. O isolamento da área sozinho mais que triplicou a mesofauna do solo. A abundância da mesofauna sob a copa da *M. tenuiflora* aumentou 3,17 e 3,41 vezes na área com e sem pastejo, respectivamente, e sob a copa da *C. quercifolius* aumentou em 22.6 vezes na área sem pastejo. O efeito da *M. tenuiflora* na área pastejada foi similar ao de 14 anos de isolamento. A quantidade da mesofauna sob a copa de *C. quercifolius* após 14 anos de isolamento foi 6,6 vezes maior do que a observada sob a de *M. tenuiflora* em condições similares. O isolamento da área e árvores, especialmente *C. quercifolius*, aumentaram a quantidade da mesofauna do solo, porém, a recuperação total desses organismos em áreas degradadas de Caatinga pode necessitar de mais de 14 anos. Considerando o cenário atual de degradação ambiental crescente, nossos dados sobre as relações entre a mesofauna do solo, o isolamento de áreas e árvores nativas são importantes para delinear estratégias e procedimentos para a recuperação de áreas degradadas no bioma Caatinga.

Palavras-chave: Recuperação ambiental. Acarina. Collembola. Jurema preta. Faveleira.

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INTRODUCTION

Environmental degradation is observed worldwide in different intensities (SILVEIRA et al., 2015). In the Brazilian semiarid tropical region, high environmental degradation is mainly a result from inadequate human activities aggravated by regional soil and climate conditions. Since colonization in the 16th century, the economic cycles of the Brazilian semiarid tropical region have been based mainly on extraction of natural resources, extensive cattle raising, subsistence agriculture, and monocultures such as cotton (PEREIRA FILHO; SILVA; CÉZAR, 2013; ARAÚJO FILHO, 2013). These activities triggered environmental problems mainly by removing the vegetation and exposing the soil to solar radiation, winds, and rains (SOUSA et al., 2016). The overexploitation of soils, increases of degraded areas, and inappropriate use of water resources considerably reduced the biodiversity and impacted the quality of life of the human population in this region (SOUSA; NASCIMENTO, 2015).

Apparently lifeless soils usually contain a diverse community of organisms that is fundamental to plant development and maintenance of life on Earth (SILVA et al., 2012). These organisms are referred to as soil fauna, and correspond to the community of microorganisms and invertebrates that inhabit the soil throughout their entire life or during some stage of their biological cycle (BARETTA et al., 2011). They affect many processes in the soil, such as nutrient cycling, organic matter decomposition, and production of humus and complexes related to aggregation of soil particles and bioturbation (BROWN et al., 2015; BERNARDI et al., 2017). However, these organisms are affected by changes in the vegetation cover and soil structure (MANHAES; FRANCELINO, 2013), and their absolute and relative quantities are reliable bioindicators of the current environmental status (ROVEDDER et al., 2004; MELO et al., 2009; BERUDE et al., 2015). For example, overgrazing and cattle trampling degrade the soil by reducing its organic matter content, porosity, and water infiltration rate, and decrease plant cover and above ground biomass accumulation (GARCIA; NAHAS, 2007; ROVEDDER, et al., 2009; ARAÚJO et al., 2013; BERUDE et al., 2015), impacting directly the soil mesofauna, especially organisms that live close to the soil surface. However, protected old-growth forest (SOUTO et al., 2008), forest management practices such as selective cutting (MATOS; BARRETO-GARCIA; SCORIZA, 2019), and grazing carried out under adequate carrying capacity (GARCIA; NAHAS, 2007) have shown positive quantitative and qualitative effects on soil fauna population by providing litterfall and improving biomass accumulation and food, including animal excrements, which provide shelter and food for the soil microbiota.

The soil microbiota may also be affected by the presence of trees from different provenances, clones or hybrids. Gomes et al. (2022) found that provenances of *Spondias tuberosa* Arruda Cam. (OLIVEIRA et al., 2020) and clones of *Eucalyptus urophylla* × *E. grandis* and *E. grandis* × *E. camaldulensis* have different effects on soil fauna, and they attributed this result to differences in canopy diameter and to the quality and quantity of litterfall produced by each provenance or clone. Thus, factors such as canopy diameter and quality and quantity of litterfall produced by a tree should be considered when choosing a tree to recover degraded areas, since they can determine changes in biological processes and soil function, mainly in semiarid climate conditions (OLIVEIRA et al., 2020).

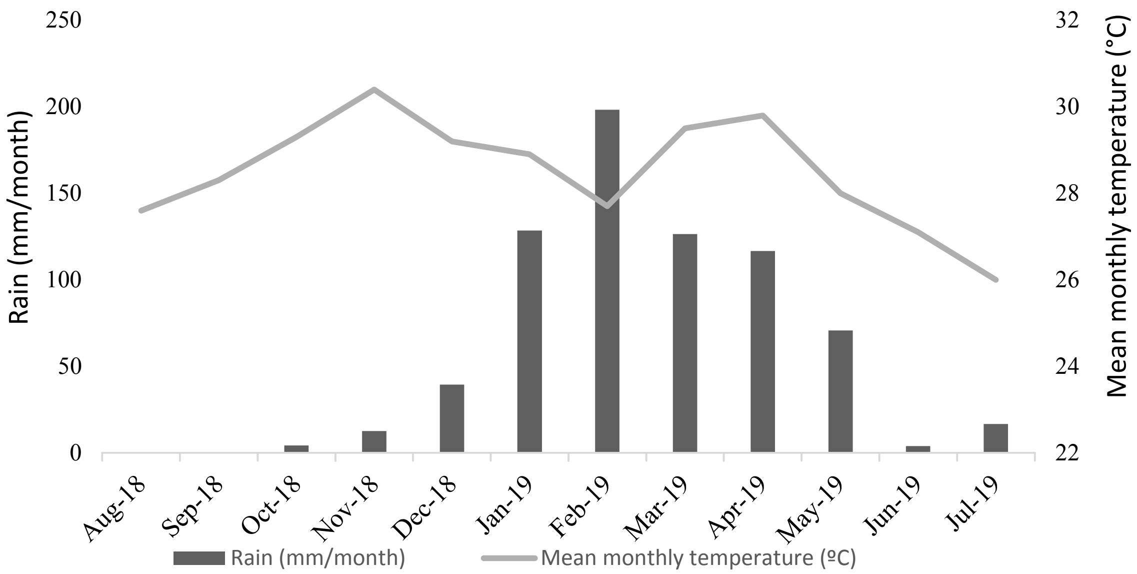
Soil fauna can be classified according to the feeding habits, mobility, role in the soil, and size of the composing organisms (BARETTA, et al., 2011). This last criterion is the most used and is based on body diameter (Ø). According to this classification, soil organisms with Ø<100 μm, 100 μm ≤ Ø < 2 mm, and 2 mm ≤ Ø ≤ 20 mm make up the soil microfauna, mesofauna, and macrofauna, respectively (SWIFT; HEAL; ANDERSON, 1979).

The soil mesofauna community is considered in studies on degraded areas because increases in density and diversity of organisms are directly related to the area recovery (BARETTA et al., 2011). This community depends on the vegetation cover, as it protects and helps the soil to absorb and retain water and provides shelter and nutrients for microorganisms (ROVEDDER et al., 2004). These organisms show negative phototropism and their populations decrease markedly under bare and compacted soils; thus, the lack of plant cover and the presence of unfavorable conditions to negative phototropism in the soil mean no shelter and food, starvation, desiccation caused by direct solar radiation, and ultimately, death of microorganisms (ARAÚJO et al., 2013). This is especially true for semiarid tropical regions such as those in the Northeast region of Brazil.

This study evaluated the effects of grazing deferment (14 years with no domestic ruminants) and establishment of *Mimosa tenuiflora* (Willd.) Poiret and *Cnidoscolus quercifolius* Pohl. on the soil mesofauna of a degraded area in the Caatinga biome. We hypothesized that: 1. overgrazing and lack of trees in areas in the Caatinga biome affect negatively soil mesofauna populations, 2. grazing deferment and tree planting should somehow amend environmental conditions, 3. these environment amendments could be detected by changes in the soil mesofauna, and 4. this positive effect increases over time. These hypotheses were confronted with literature data and tested, at least partially, by the data collected in this study.

MATERIAL AND METHODS

Data were collected in a degraded area in the Caatinga biome (07°05'0"S and 37°15'43"W) at the experimental station of the Núcleo de Pesquisas Para o Semiárido (NUPEÁRIDO) of the Federal University of Campina Grande (UFCG), Patos campus, at 6 km South from Patos, PB, Brazil. The region presents a BShw', hot and dry climate, according to the Köppen classification (ALVARES et al., 2013), mean annual air temperature of 25 °C, and annual rainfall depths ranging from 300 to 1500 mm (mean of approximately 700 mm); rainfalls are irregularly distributed over time and space, with higher depths from January to May. The mean monthly temperatures and rainfall depths in the experimental area from August 2018 to July 2019 ranged from 26.0 to 30.4 °C and totaled 717.7 mm, respectively; rainfall events were concentrated in the first six months of the year (Figure 1).



Source: INMET, 2019.

Figure 1. Mean monthly temperatures (ºC) and rainfall depths (mm) from August 2018 to July 2019 in Patos, PB, Brazil.

The study area has had almost no tree cover over the last 40 years due to logging and overgrazing by cattle, sheep, and goats. An area of 60 × 70 m was fenced and protected from grazing by domestic ruminant in 2005, i.e., the area had 13 to 14 years of grazing deferment until the data collection in 2018 and 2019. In addition to grazing deferment, 300 seedlings of *M. tenuiflora* and 300 seedlings of *C. quercifolius* were planted from 2005 to 2009 to re-establish the tree cover in experimental plots of 6 × 6 m or 12 × 12 m (FIGUEIREDO et al. 2012; SALES et al, 2019); 103 seedlings of *M. tenuiflora* and 91 seedlings of *C. quercifolius* survived and formed established adult trees. Outside the fenced area, the grazing was continued; sparse native adult trees, mainly *M. tenuiflora,* endured the grazing; no tree seedlings were found; and *Sida cordifolia* L. predominated in the herb stratum.

Qualitative (number of orders of organisms in the soil mesofauna) and quantitative (number of organisms from each order) data were collected in November 2018 from soil + litterfall samples collected under the canopies of seven *M. tenuiflora* and seven *C. quercifolius* trees in the 60 × 70 m protected area, and under the canopies of seven *M. tenuiflora* in the adjacent grazed area. In addition to these 21 sampling points, soil + litterfall samples were collected in areas under no direct effect of the tree canopies in both ungrazed (seven sampling points) and grazed (seven sampling points) areas, totaling 35 sampling points. This protocol was repeated on March 2019 and July 2019, totaling 105 sampling points. Different *M. tenuiflora* and *C. quercifolius* plants and sampling points with and without direct effect of tree canopies were chosen for each sampling time.

Soil + litterfall samples were collected using metal cylinders (4.8 cm diameter, 5.2 cm high, 18.1 cm^2, 94.1 cm^3), which were hammered on the upper end, on a wood board, until the entire cylinder was occupied. When the material was too dry, some water was added to the soil surface, mainly for samples collected in November 2018. Each cylinder with soil + litterfall sample was carefully placed in plastic bags, stored in a cooler to minimize water loss and death of the soil mesofauna, and taken to the laboratory (SOUTO et al., 2008).

The soil mesofauna was extracted following the protocol described by Berlese-Tullgren, with adaptations: the cylinders with soil + litterfall samples were placed on a nylon screen under 25-Watt incandescent lamps for 96 hours. A funnel under the nylon screen directed the soil mesofauna organisms that escaped from the sampled material in each cylinder into a glass recipient with 5 mL of 70% ethylic alcohol to preserve the microorganisms for identification.

The soil mesofauna organisms in each recipient were counted and classified by order using a 5x magnifying glass. The quantities of organisms were totaled by order according to the tree cover in the area: without grazing (no tree cover and tree cover of *M. tenuiflora* or *C. quercifolius*) or with grazing (no tree cover and tree cover of *M. tenuiflora*). The observed quantities in the five conditions were arranged according to the tree species and χ^2 grazing and tree cover conditions, and analyzed using tests (+Yates' correction) with one degree of freedom (SPIEGEL, 1981), according to Equation 1:

$$\chi^2_{Yates'corecction} = \sum \frac{[|f_0 - f_e| - 0.5]^2}{f_e} \quad (1)$$

where f_o and f_e is the observed and expected frequencies (i.e.: observed and expected quantities), respectively. The significance levels used were $p<0.05$, $p<0.01$, and $p<0.005$, indicated, respectively, by *, **, and ***.

The χ^2 test was applied to compare the total number of organisms extracted from the material in the 21 cylinders (7 sampling points × 3 dates) collected in areas under no effect of canopies of adult trees in the ungrazed area with the total number of organisms extracted from the material in the 21 cylinders (7 sampling points × 3 dates) collected in areas under no effect of canopies of adult trees in the grazed area. The results enabled to test the effect of grazing in areas under no direct effect of established trees.

The comparisons between other total number of organisms enabled to test the effect of grazing on the soil mesofauna under direct effect of *M. tenuiflora* canopies (Comparison 2), the effect of *M. tenuiflora* on the soil mesofauna in grazed (Comparison 3) and ungrazed areas (Comparison 4), the effect of *C. quercifolius* on the soil mesofauna in ungrazed areas (Comparison 5), and the difference between *C. quercifolius* and *M. tenuiflora* on the soil mesofauna of the ungrazed area (Comparison 6). Although one of the counting of soil mesofauna from the soil + litterfall samples collected under *C. quercifolius* canopies in the two last comparisons reached 301 organisms (soil + litterfall of one cylinder sampled in March 2019), this value was considered in the analyses to highlight the potential of *C. quercifolius* to improve soil microbiology. Furthermore, excluding this value from the analysis did not change the statistical conclusions. Other similar arrangements that enabled additional comparisons were performed and reported.

RESULTS AND DISCUSSION

The soil mesofauna extracted from soil + litterfall materials collected in the 105 sample points (1900 cm^2, 9880 cm^3) totaled 619 individuals from three orders: 499 Collembola (80.6% of the soil mesofauna), 118 Acarina (19.1%) and two Diplura (<1.0%). This quantity of taxonomic groups (orders) is three to four-fold lower than that reported by Santos et al. (2017) (9 orders) and Almeida, Souto, and Souto (2013) (13 orders), respectively, for a remnant of caatinga vegetation in Santana do Ipanema, AL, Brazil, and a 30-year-old preserved caatinga forest in Barra de Santa Rosa, PB, Brazil. These data indicate that the soil mesofauna order diversity was negatively and strongly affected by the removal of forest cover and overgrazing. In addition, 14 years of grazing deferment and natural recovery of vegetation, combined with planting and establishment of plants of two native tree species, were not enough to result in suitable conditions for the reestablishment of a diversified soil mesofauna community.

Plant soil cover in the area without grazing reached 100%, but herb and shrub communities were dominated by *Aristida adsencionis* Linn. and *Sida cordifolia* L., respectively, and the established trees of *M. tenuiflora* (103 adults and 190 regenerating) and *C. quercifolius* (91 adults and 7 regenerating). Rovedder et al. (2009) explain that a high plant cover level is important for soil microorganisms, mainly when plant diversity is high and can potentially create microhabitats with different nutrients and shelters suitable to diverse soil organism communities. However, abiotic factors, such as excessive or low water availability and high or low soil temperature may also depress soil fauna (PRIMAVESI, 2002). Thus, the low order diversity of the soil mesofauna reflected the incipient recovery of biotic and abiotic factors in the study area after 14 years of plant cover recovery and grazing deferment.

Collembola and Acarina individuals predominated (99.7%) in the soil mesofauna of the studied areas. Generally, Collembola and Acarina individuals are abundant and represented by many species in the soil mesofauna; organisms of these orders are rustic and responsible for important functions in the soil, such as organic matter comminution and decomposition (Collembola) and control of soil microbiota (mainly, Acarina). (MELO et al., 2009)

These orders predominated in the soil mesofauna of a preserved caatinga forest in Santa Terezinha, PB, Brazil (SOUTO et al., 2008). These authors explained that Acarina species are the most resistant and adapted meso-organisms to the adverse climate conditions of dry tropical regions (high temperatures, low rain depths, and long drought periods), denoting that they form relatively more stable populations throughout the year than Collembolla populations. These orders were also predominant in soil mesofauna under different provenances of *S. tuberosa* (OLIVEIRA et al., 2020). However, the relative quantity of Acarina and Collembola observed by Souto et al. (2008) and Oliveira et al. (2020) reached 70% to 80%, lower than the 99.7% predominance level of these orders observed in the present study, indicating low order diversity and high environmental degradation status of the experimental areas. Longer time and more environmental recovery seem to be necessary to support the presence of a soil mesofauna population with more orders.

Collembola predominated in March and July 2019, when the soil moisture was higher than in November 2018 (Figure 1), while only Acarina (three individuals) was extracted from soil + litterfall materials collected in November 2018, at the end of the hot dry season in the ungrazed area (Table 1). Although it may result from the soil mesofauna migration to soil layers deeper than 5.2 cm, the absence of Collembola and presence of Acarina in the collected material during the dry season denote the resistance of Acarina individuals to high temperature and low moisture conditions, which are conditions usually found in upper soil layers.

Table 1. Number of soil mesofauna individuals extracted from soil + litterfall materials collected in 7 sampling points (18.1 cm^2 of soil area and 94.1 cm^3 of collected soil + litterfall materials per sampling point), according to grazing and tree cover conditions and order, in November 2018, March 2019, and July 2019, in degraded areas in the Caatinga biome.

Grazing and tree cover conditions	Order	Nov 2018	Mar 2019	Jul 2019	Total
No grazing and effect of *Mimosa tenuiflora* canopies	Acarina	2	44	3	49
	Collembola	0	23	3	26
	Diplura	0	0	0	0
No grazing and effect of *Cnidoscolus quercifolius* canopies	Acarina	0	41	4	45
	Collembola	0	443	7	450
	Diplura	0	2	0	2
No grazing and no direct effect of tree canopies	Acarina	1	4	3	8
	Collembola	0	9	5	14
	Diplura	0	0	0	0
Sub-total (soil mesofauna extracted from the collected material under ungrazed conditions)					594
Grazing and effect of *M. tenuiflora* canopies	Acarina	0	10	3	13
	Collembola	0	6	0	6
	Diplura	0	0	0	0
Grazing and no direct effect of tree canopies	Acarina	0	2	1	3
	Collembola	0	3	0	3
	Diplura	0	0	0	0
Sub-total (soil mesofauna extracted from the collected material under grazed conditions)					25
Total		3	587	29	619

The quantities of the extracted soil mesofauna showed marked differences between collection times due to the different environmental conditions, reaching 589 individuals in March 2019 due to the rainfall depths in previous months: 128.4 mm in January, 198.2 mm in February, and 126.5 mm in March (Figure 1). The rainfall depth in May (70.7 mm), June (4.0 mm), and July (16.8 mm) 2019, were lower than those in January, February, and March 2019, explaining the decrease in quantity of extracted soil mesofauna from 589 to 27 individuals from March 2019 to July 2019. It also may explain the 3 individuals found in November 2018 due to the low or no rainfall in September (0.0 mm), October (4.4 mm), and November (2.6 mm) 2018. These data indicate that the rainfall level and soil moisture have positive effect on the soil microbiota abundance.

Contrastingly, increases in air temperature and direct solar radiation on the soil surface may explain the decreases in soil mesofauna population. These variables tend to increase during the dry season (August to December), as shown in Figure 1, affecting the field with marked decreases in soil cover by plant biomass; herbs do not survive, and senescent parts of herbs and trees decay or are consumed by microorganisms or ruminants, respectively. Thus, the quantity of the extracted soil mesofauna increased from 3 or zero (no soil mesofauna) in ungrazed and grazed areas, respectively, in November 2018 (Table 1), when air temperature peaked at the end of the dry season and most biomass covering the soil had decayed or was consumed by the animals, to 566 or 21 individuals in March 2019, in ungrazed or grazed areas, respectively, when environmental conditions (soil moisture due to rainfall and available biomass) were more favorable. The increase in soil mesofauna from November 2018 to July 2019 was less pronounced, but still significant. Similarly, soil mesofauna population increased in March and July 2019, compared to November 2018, due to the higher soil moisture and soil cover by well-developed and living herbs (March) or remains of senescent herb and tree parts (July), representing more food and shelter available for soil microorganisms, mainly in the ungrazed area.

Increases in soil mesofauna population in areas in the Caatinga biome during the rainy seasons of 2004 and 2005 were similar (SOUTO et al., 2008). Soil mesofauna population was higher in February and April, respectively, one month after the rainiest month of those years (January and March, respectively); it decreased as the dry season progressed. According to these authors, the increases in soil mesofauna population were due to the favorable soil microclimate conditions during the rainy season, such as reduction in soil temperature and increase in soil + litterfall moisture and food availability for soil organisms. They explained that these decreases in soil mesofauna populations may derive from adverse characteristics of the dry season, such as high temperatures (air and soil) and low soil moisture and food availability.

The total of 587 individuals found in March 2019 (Table 1) was affected by one sampling point, from which 301 Collembolas were extracted. It shows that great environmental differences in microbiota of soils are possible under different carrying capacity in degraded areas in the Caatinga biome. In the present case, it resulted mainly from the *C. quercifolius* canopy shadowing and the litterfall shelter and food provided by its senescent leaves.

According to Rovedder et al. (2001), soil mesofauna species are opportunistic and seasonal; Collembolas ones react promptly to changes in overall environmental conditions, especially in those connected to the soil. They reported that Collembolas are at the base of the food chain of many soil organisms and, thus, are considered efficient bioindicators. It indicates that grazing deferment and tree establishment, especially *C. quercifolius*, may accelerate the recovery of the soil biota in degraded areas in the Caatinga biome.

The soil mesofauna in November 2018 and March and July 2019 totaled 619 individuals (Table 1). This quantity, extracted from 105 sampling points, or an area of 0.19 m^2 ($105 \times 3.1416 \times 0.048^2 / 4$), corresponded to a mean density of 3.258 individuals m^{-2} of soil surface. However, this mean value was based on data collected under different conditions. For example, considering the 105 points, 21 (0.038 m^2) were in the ungrazed area under *C. quercifolius* canopies, with 497 (45+450+2) individuals, and 21 were in the grazed area without direct effect of tree canopies with 6 (3+3+0) individuals (Table 1). The 6 and 497 values represent mean densities of 158 and 13.079 individual m^{-2}, respectively, and show that soil mesofauna populations may be strongly affected by domestic ruminants and trees.

The density of soil mesofauna density reached 1,945 individuals m^{-2} in two degraded areas in the Caatinga biome with 3 years of grazing deferment and planted with *M. tenuiflora, C.* quercifolius, and *P. pyramidalis* (2-year-old plants) (PEREIRA, 2011). One of these areas is the same degraded area evaluated in the present study, and the other is at approximately 500 m from it. Their results indicate lower soil mesofauna recovery level compared to the current one, that showed a mean of 3,258 individuals m^{-2}. This difference is due to the difference in environmental recovery time, 2 to 3 and 14 years, respectively.

Soil mesofauna density may reach an average value of 4,318 individual m^{-2} (SOUTO et al., 2008), according to monthly collections for 1 year in a protected forest in Santa Terezinha, PB, Brazil. This quantity is approximately 33% higher than that found in the present study (3,258 individual m^{-2}). In addition, their monthly density results were directly and positively affected by rainfall depths, as observed in the degraded area in the present study. However, the main difference between these results and those found in the present study regarding soil mesofauna population is qualitative; they found presence of soil mesofauna species from 12 orders whereas three were found in the present study (Collembola, Acarina and Diplura) (Table 1). The higher quantitative and qualitative values reported by Souto et al. (2008) are due to the preserved environmental conditions of the forest cover, which had been protected from animal and human actions for more than 40 years, resulting in litterfall and organic matter accumulation on the forest ground, which favors the development of the soil mesofauna population. In addition, these results indicate that a qualitative (orders) is more difficult than a quantitative (soil mesofauna individuals m^{-2}) recover of the soil biota of degraded areas in the Caatinga biome.

Comparing soil mesofauna densities reported by different studies is interesting, but clearly determining the actual factors that could explain the quantitative and qualitative differences are difficult. This is not the case when comparing contiguous areas with easily perceived differences. For example, the comparison between the quantity of the soil mesofauna individuals extracted from soil + litterfall samples from ungrazed (22 individuals) and grazed (6 individuals) areas without direct effect of tree canopies (Table 2, Condition 1) shows the effect of a 14-year period of grazing deferment. According to the chi-square test applied to these quantities, the grazing deferment significantly ($p<0.05$) increased the quantity of the soil mesofauna by a factor of 3.7, corresponding to an increase in soil mesofauna population from 1,578,914 to 5,789,353 individuals ha^{-1}. This is due to the greater herb biomass (alive or dead) covering the soil and providing food and shelter to the soil biota and to the lower soil compaction in the ungrazed compared to the continuously grazed area, although no data on biomass accumulation or soil density were actually collected in the present study.

Excessive transit of heavy machinery and cattle trampling and biomass consumption impact negatively soil attributes by increasing density and decreasing porosity and water infiltration rate (ROVEDDER et al., 2009; ARAÚJO et al., 2013; BERUDE et al., 2015). These authors explain that the functioning and balance of soil mesofauna organisms, especially those close to the soil surface, are compromised by decreases in soil water availability and pore size, hindering soil organisms to move through spaces between soil particles when searching for food and protection, and increases the mortality rate of the soil mesofauna population.

However, grazing does not necessarily impact negatively soil biota; the use of adequate carrying capacity favors the soil community, as shown by Garcia and Nahas (2007), who explained that excreted feces by ruminants are source of partially digested, high-quality food to the soil biota and can increase populations of soil microorganisms. Indeed, the soil mesofauna population (4,615,285 individuals ha^{-1}) of an area under optimal carrying capacity (1 goat 6,400 m^{-2}) in the Caatinga biome (São João do Cariri, PB, Brazil) was similar to that found in soils of areas with no animal grazing (4,507,692 individuals ha^{-1}), whereas the soil mesofauna population decreases when the number of animals increased to 2 goat 6400 m^{-2} (2.600.000 individuals ha^{-1}) (ARAÚJO et al., 2013). These data indicate that the grazing pressure in the present study was above the carrying capacity of the area and counterbalanced the positive effects of the feces, probably due to the soil compaction and excessive consumption of herb biomass by ruminants, which depleted this important food source for soil mesofauna populations.

The negative effect of grazing on soil mesofauna under the direct effect of *M. tenuiflora* canopies was also evident (<0.005) (Table 2, Condition 2), and corroborates the data found for Condition 1. Thus, grazing deferment was important to recover the soil mesofauna population under *M. tenuiflora* canopies, increasing soil mesofauna by a factor of 3.95.

This significant positive effect of *M. tenuiflora* canopies was significant in both conditions, with (Condition 3, $p<0.05$) and without (Condition 4, $p<0.005$) animals grazing, by a factor of 3.17 and 3.41, equivalently to increases from 6 to 19 and from 22 to 75 extracted individuals, respectively. However, the presence of *M. tenuiflora* alone in the grazed area was not enough to recover the soil mesofauna to the levels observed in the area without grazing (19 and 75 in conditions 3 and 4, respectively). In both grazed and ungrazed conditions, the positive effect of *M. tenuiflora* on the soil mesofauna was probably due to the shading and litterfall accumulation in the area covered by the tree canopies, as reported elsewhere (e.g.: ROVEDDER et al., 2009).

Considering the lowest and highest values of Conditions 3 and 4, 1,578,914 and 19,736.430 individuals ha^{-1} respectively (Table 2), 14 years of grazing deferment and establishment of *M. tenuiflora* trees can result in a 12-fold increase in mesofauna abundance in degraded areas in the Caatinga biome. In addition, the comparison of intermediary values (4,999,896 and 5,789,353 individuals ha^{-1}) shows that the effect of *M. tenuiflora* canopies on the soil mesofauna abundance in the degraded area continuously grazed (actually, overgrazed) for more than 40 years was equivalent to 14 years of grazing deferment.

Contrastingly, negative effects of tree removal and continuous grazing for more than 40 years on soil mesofauna due to deficient herb and tree strata (SOUTO et al., 2008) were evidenced by the predominance of only Sida shrub species and largely spaced adult *M. tenuiflora* trees characterized by the lack of seedlings of any tree species. This result indicates a high level of soil degradation, which is connected to direct solar radiation, high temperature, and low moisture on the soil surface layer.

Cnidocscolus quercifolius had a positive effect ($p<0.005$) on the soil mesofauna in the ungrazed area (Table 2, Condition 5), increasing its population from 5,789,353 to 130,786,742 individuals ha^{-1}, outside and under the tree canopies. This positive effect of *C. quercifolius* on the ungrazed area showed to be almost 7-fold that observed for *M. tenuiflora* ($p<0.005$) (Table 2, condition 6). Soil mesofauna density under *C. quercifolius* can be even higher when considering only the data of March 2019 (Table 1), when the collected 41+443+2=486 individuals corresponded to a density of 895,027,624 individuals ha^{-1}, mostly from the Collembola order.

Table 2. Quantity (Y) of soil mesofauna individuals extracted from soil + litterfall materials collected using 21 4.8-cm Θ cylinders; corrected chi-square value ($\chi^2_{correctYates}$); estimated Y per hectare (X); and Y_{max} to Y_{min} ratio (Q), according to the grazing pressure, canopy effect, and presence of native trees in a degraded area in the Caatinga biome.

Condition 1: Effect of grazing without direct effect of tree canopies					
Y (individuals in 21 cylinders)		$\chi^2_{correctYates}$	X (individuals ha^{-1})		Q
No grazing	Grazing		No grazing	Grazing	
22	6	8.04***	5,789,353	1,578,914	3.67
Condition 2: Effect of grazing under direct effect of *Mimosa tenuiflora* canopies					
Y (individuals in 21 cylinders)		$\chi^2_{correctYates}$	X (individuals ha^{-1})		Q
No grazing	Grazing		No grazing	Grazing	
75	19	32.14***	19,736,430	4,999,896	3.95
Condition 3: Effect of *M. tenuiflora* canopies in grazed area					
Y (individuals in 21 cylinders)		$\chi^2_{correctYates}$	X (individuals ha^{-1})		Q
Direct tree canopy effect	No direct tree canopy effect		Direct tree canopy effect	No direct tree canopy effect	
19	6	5.76*	4,999,896	1,578,914	3.17
Condition 4: Effect of *M. tenuiflora* canopies in ungrazed area					
Y (individuals in 21 cylinders)		$\chi^2_{correctYates}$	X (individuals ha^{-1})		Q
Direct tree canopy effect	No direct tree canopy effect		Direct tree canopy effect	No direct tree canopy effect	
75	22	27.88***	19,736,430	5,789,353	3.41
Condition 5: Effect of *Cnidoscolus quercifolius* canopies in ungrazed area					
Y (individuals in 21 cylinders)		$\chi^2_{correctYates}$	X (individuals ha^{-1})		Q
Direct tree canopy effect	No direct tree canopy effect		Direct tree canopy effect	No direct tree canopy effect	
497	22	432.90***	130,786,742	5,789,353	22.59
Condition 6: Effect of *C. quercifolius* compared to *M. tenuiflora* canopies in ungrazed area					
Y (individuals in 21 cylinders)		$\chi^2_{correctYates}$	X (individuals ha^{-1})		Q
Direct effect of *C. quercifolius* canopies	Direct effect of *M. tenuiflora* canopies		Direct effect of *C. quercifolius* canopies	Direct effect of *M. tenuiflora* canopies	
497	75	308.86***	130,786,742	19,736,430	6.63

The abundance of soil mesofauna was higher under *C. quercifolius* than under *M. tenuiflora* canopies in similar soil, climate, and grazing conditions to the present study (PEREIRA, 2011); most of this author`s samples (soil + litterfall) came from the same area used for the present study. The data reported by Pereira (2011) were based on 35 sampling points (4.8 cm Θ and 5.2 cm high metal cylinders) for each tree species, collected from November 2008 to October 2010, after 1-to-2 years of grazing deferment and tree planting. Correcting to 21 sampling points, the data reported by Pereira (2011) are equivalent to 30, 26, and 57 soil mesofauna individuals in 21 cylinders for soil + litterfall materials collected outside and under the direct effect of *M. tenuiflora* and *C. quercifolius* canopies, respectively. The respective quantities in the present study were 22, 75, and 497 individuals (Table 2).

The data in the last two sentences of the previous paragraphs indicate that: 1) 1-to-2 and 14 years of grazing deferment have similar effect on the quantitative recovery of soil mesofauna (30 vs. 22 individuals); 2) canopies of 1-to-2-year-old *M. tenuiflora* trees have no effect on soil mesofauna up to 2 years after grazing deferment (26 vs. 30 individuals), whereas young *C. quercifolius* showed the potential to practically duplicate soil mesofauna (57 vs. 30 individuals); 3) *C. quercifolius* is more beneficial to soil mesofauna than *M. tenuiflora*, and this difference increases from 1-to-2 (57 vs. 26 individuals) to 14 years (497 vs. 75 individuals) of grazing deferment, and 4) *M. tenuiflora* and *C. quercifolius* can increase 3- and 22-fold the soil mesofauna (75/22 and 497/22, respectively) after 14 years of grazing deferment.

Considering that Collembola reproduction is fast, mainly when grown under adequate soil moisture and organic matter contents (ANTONIOLLI et al., 2013), these 4 indications imply that the pronounced peak of soil mesofauna population under *C. quercifolius* canopies observed in March 2019 was due to the favorable soil moisture and air temperature during this time of the year (Figure 1); under these conditions, herbs develop and constitute an abundant source of food and shelter. Additionally, the senesced leaves of *C. quercifolius* may have contributed to the soil mesofauna population peak, as they are large and rich in protein (19%) and highly degradable due to the low (47%) fiber contents (DRUMOND; SALVIANO; CAVALCANTI, 2007) and provide proper food to soil microorganisms (ROVEDDER et al., 2004). The strong effect of *C. quercifolius* on the soil mesofauna certainly resulted from this species denser canopy with wider leaves than the observed for *M. tenuiflora*. Moreover, the crude protein content and digestibility of *M. tenuiflora* biomass is lower than that reported for *C. quercifolius* (CORDÃO et al., 2013). It results in a higher soil protection and better shelter and food source provided by *C. quercifolius* when compared to *M. tenuiflora* leaves in tree canopies and after senescence.

Soil mesofauna is a reliable bioindicator of environmental status. The quantitative reestablishment of this community in degraded areas in the Caatinga biome are probably partial, even after 14 years of grazing deferment and development of the native trees *M. tenuiflora* and, especially, *C. quercifolius*, although both management practices can significantly increase soil mesofauna. Considering the current increases in environmental degradation, these findings regarding the relationships between soil mesofauna, grazing deferment, and native trees can assist in devising useful strategies and procedures for the recovery of degraded areas in the Caatinga biome.

CONCLUSIONS

The 14 years of grazing deferment more than tripled the soil mesofauna of the evaluated degraded area in the Caatinga biome. The presence of adult trees of *Mimosa tenuiflora* and *Cnidoscolus quercifolius* was beneficial, under grazed and ungrazed conditions, and resulted in up to 22.6-fold increases in soil mesofauna abundance in the area directly affected by their canopies. The direct effect of *M. tenuiflora* canopies on the abundance of soil mesofauna in the grazed area was similar to that of the 14-year period of grazing deferment. The quantity of these soil organisms under direct effect of *C. quercifolius* canopies after 14 years of grazing deferment and tree planting was 6.6-fold higher than that under direct effect of *M. tenuiflora* canopies, under similar conditions. The grazing deferment and planting of *M. tenuiflora* and, specially, *C. quercifolius* trees significantly increased the soil mesofauna of the evaluated degraded area in the Caatinga biome.

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