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Biological properties of disturbed and undisturbed Cerrado *sensu stricto* from Northeast Brazil

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(With 2 figures)

Abstract

The aim of this study was to measure soil microbial biomass and soil surface fauna in undisturbed and disturbed Cerrado *sensu stricto* (Css) from Sete Cidades National Park, Northeast Brazil. The following sites were sampled under Cerrado *sensu stricto* (Css) at the park: undisturbed and disturbed Css (slash-and-burn agricultural practices). Total organic and microbial biomass C were higher in undisturbed than in disturbed sites in both seasons. However, microbial biomass C was higher in the wet than in the dry season. Soil respiration did not vary among sites but was higher in the wet than in the dry season. The densities of Araneae, Coleoptera, and Orthoptera were higher in the undisturbed site, whereas the densities of Formicidae were higher in the disturbed site. Non-metric multidimensional scaling analysis separated undisturbed from disturbed sites according to soil biological properties. Disturbance by agricultural practices, such as slash-and-burn, probably resulted in the deterioration of the biological properties of soil under native Cerrado *sensu stricto* in the Sete Cidades National Park.

Keywords: soil microbial biomass, soil fauna, sustainability, soil disturbance.

Propriedades biológicas de Cerrado *sensu stricto* preservado e não preservado do Nordeste do Brasil

Resumo

O objetivo do estudo foi avaliar as propriedades biológicas do solo em área de Cerrado *sensu stricto* preservadas e não preservadas do Parque Nacional de Sete Cidades, Nordeste do Brasil. Os seguintes sites sob Cerrado *sensu stricto* (Css) foram avaliados: preservado (UND) e não preservado (DIS). O C orgânico total e da biomassa microbiana foram maiores na área preservada do que na não preservada em ambas estações seca e chuvosa. Entretanto, o C da biomassa microbiana foi maior na estação chuvosa do que na seca. A respiração do solo não variou entre as áreas, mas foi maior na estação chuvosa. As densidades de Araneae, Coleoptera e Ortoptera foram maiores na área preservada, enquanto as densidades de Formicidae foram maiores na área não preservada. A analise de escalonamento não-métrico separou a área preservada da não-preservada de acordo com as propriedades biológicas. Os distúrbios no solo pelas atividades agrícolas, como corte-e-queima, resultaram na deterioração das propriedades biológicas do Cerrado nativo no Parque Nacional de Sete Cidades.

Palavras-chave: biomassa microbiana do solo, fauna do solo, sustentabilidade, distúrbio no solo.

1. Introduction

The Brazilian Cerrado is one of the ecosystems with the greatest biodiversity found in Brazil and comprises riparian forest, seasonal semideciduous forest, seasonal deciduous forest, and wet grasslands (Forzza et al., 2010). The ecosystem is the second largest Brazilian domain after the Amazonian (Gatti et al., 2014) and extends over all regions of Brazil.

In the northeast of Brazil, the Cerrado is concentrated in the states of Piauí and Maranhão with an area of 20 million ha (Felfili and Matos, 2010). In particular, in Piauí, the Brazilian government created the Sete Cidades National Park (PNSC), covering an area of 6,221 ha, aiming to study and protect the diversity of water, vegetation, and soil resources (IBDF, 1979). During the last ten years, geomorphological and quantitative surveys of vegetation and animals have been conducted (Digby et al. 1996; Cavalcanti and Mobin, 2001; Castro et al., 2002).

However, some areas under Cerrado around the PNSC are being converted to croplands through the practice of slash-and-burn. In this practice, the forest is cut manually by small farmers. The farmers burn the dried vegetation residues aiming to clear their land and subsequently establish crops (Farella et al., 2001). The nutrient-rich ashes resulting from the burnt forest biomass is used as a fertilizer and temporarily increases soil fertility (Fabian et al. 2005). This practice influences nutrient cycling patterns by modifying plant cover and biodiversity (Sankaran et al., 2005) and by directly altering chemical and biological properties of soil (Michelsen et al., 2004). Therefore, little is known about the soil biological properties in the protected areas of Cerrado, and how slash-and-burn practices affect soil properties at the PNSC.

The lack of knowledge about soil biological properties is of concern because soil organisms play critical roles in essential ecosystem functions (Rodrigues et al., 2013). Microbial communities are responsible for much of the organic matter decomposition and nutrient cycling, influencing the chemical and physical properties of the soil, and consequently, its primary productivity (Pereira et al., 2013). These communities can be used as an efficient and dynamic indicator of soil quality (Araújo et al., 2014). In addition, soil surface fauna provide important information on ecosystem stability due to the strong dependency of these taxa on plant and soil diversity (Eisenhauer et al., 2013).

As slash-and-burn is being used at the edge of National Park, we hypothesized that this practice would affect the soil biological properties of the native Cerrado. Thus, the aim of this study was to evaluate the soil biological properties of the undisturbed and disturbed Cerrado *sensu stricto* from PNSC, Northeast Brazil.

2. Material and Methods

The study was conducted in the Seven Cities National Park (PNSC) (04º02'-08'S and 41°40'-45'W), located in the northeastern state of Piauí. The park covers an area of 6,221 ha. The climate is sub-humid and there are two distinct seasons (wet and dry) during the year, with the annual average temperatures at 25ºC. The area has an annual average rainfall of 1,558 mm distributed throughout February, March and April.

The following locations were sampled under Cerrado *strictu sensu* (Css) at the park: undisturbed Css (UND) belonging to the Long-Term Ecological Program (PELD-CNPq) from Brazilian government; and disturbed Css (DIS) site by slash-and-burn. The disturbed site was characterized by slash-and-burn practice of Cerrado *strictu sensu* and subsequent cultivation of maize or rice for one season. In this study, the last burning occurred on October 2012 and maize crop was planted in November 2012. The sites have about 1,000 m^2 and are homogeneous in terms of soil and slope. At each plot, we sampled eight subplots (50 m^2), which represented replicates (in each subplot we sampled three soil cores, at 0-20 cm depth which were mixed to make a composite sample per subplot), in March (wet season) and September (dry season) of 2013. All samples were immediately stored in sealed plastic bags in a cooler and transported on ice to the laboratory.

Soil pH was determined in a 1:2.5 soil/water extract. Exchangeable Al^{3+} was determined using extraction with 1 M KCl. Available P was extracted using Mehlich-1 extraction method (Tedesco et al., 1995). Total organic C (TOC) was determined by the wet combustion method using a mixture of potassium dichromate and sulfuric acid under heating (Yeomans and Bremner, 1988).

Soil microbial biomass C (MBC) was determined according to Vance et al. (1987) with extraction of C from fumigated and unfumigated soils by K_2SO_4. Moreover, we calculated the ratio between MBC and TOC, which is a common indicator for carbon availability.

Surface-active soil fauna were measured using pitfall traps, consisting of plastic containers of 10 cm height and 10 cm in diameter with 50% ethanol to about 1/3 of its volume. Each trap was buried leaving its opening at ground level, spaced twenty meters in the form of a transect towards the central part of each area, where it remained for seven days. Each site was fitted with a total of eight traps to capture some of the spatial heterogeneity. The soil fauna was identified and quantified with a binocular microscope and grouped to order or family level. Data were $\log_{10}$-tranformed to meet the requirements for parametric statistical tests. The means and standard deviations of these groups are nevertheless calculated. Only those four invertebrate groups were analyzed (Araneae, Coleoptera, Formicidae, Orthoptera) for which the sampling method was adequate (Araujo et al., 2015).

Soil chemical and microbiological properties were analyzed using the SPSS 11.0 for Windows software package. Means and standard deviations were calculated. Analysis of variance procedures (ANOVA) were used for comparing the differences between the sites (disturbed and undisturbed) and season (dry and wet). Least significant difference (LSD) analysis was performed and all differences reported in the text were tested and considered significant at $p<0.05$. Non-metric multidimensional scaling (NMS) with Sorensen distances was performed with the variables using multivariate ordination. NMS of CLPP was performed on normalized, transformed absorbance data. Ordination was performed using the PC-ORD v. 6.0 software.

3. Results

Soil chemical and biological properties differed between the undisturbed and disturbed sites in both wet and dry seasons (Table 1 and 2). The soil pH values and Ca content were lower in the undisturbed than the disturbed site. In contrast, the available P and exchangeable K did not differ between sites (Table 1).

TOC and MBC content were higher in the undisturbed than in the disturbed site in both seasons (Table 2). However, the MBC was higher in the wet than in the dry

season. Soil respiration did not vary among sites but was higher in the wet than in the dry season. Conversely, the metabolic quotient (qCO_2) was higher in the disturbed site in the wet season, whereas qCO_2 did not vary among sites in the dry season. The MBC-to-TOC ratio was higher in the undisturbed than in the disturbed site but did not vary between seasons.

Investigations of the soil surface fauna indicated that the densities of Araneae, Coleoptera, and Orthoptera were higher in the undisturbed site, whereas the density of Formicidae was higher in the disturbed site (Table 3). Seasonally, the densities of Coleoptera, Formicidae, and Orthoptera were higher in the wet season, whereas the density of Araneae was higher in the dry season.

The MNS of soil microbial biomass (Figure 1) and active fauna (Figure 2) explained 93% and 98% of variation, respectively, and separated undisturbed from disturbed sites according to soil properties. TOC, MBC, qmic, Araneae, Coleoptera, and Orthoptera were grouped with the undisturbed site and clustered with P and Al content. Soil respiration, qCO_2, and Formicidae were grouped with the disturbed site and clustered with soil pH and Na content.

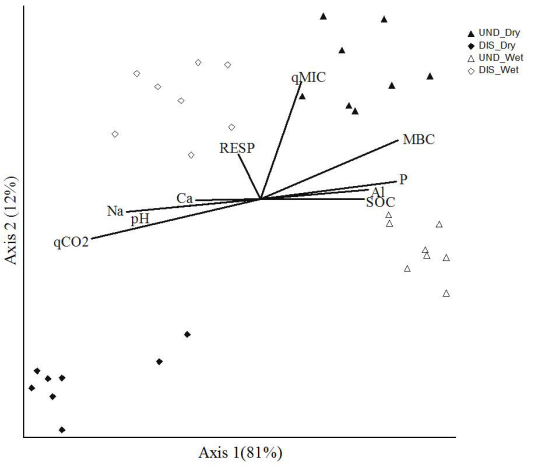

Figure 1. NMS based on microbial biomass and chemical properties of soil at undisturbed and disturbed Cerrado *sensu stricto* from Sete Cidades National Park, Brazil. pH – soil pH; P – available P; Ca – Exchangeable Ca; Na – Exchangeable Na; SOC – Soil organic C; MBC – Microbial biomass C; qMIC – Microbial quotient; RESP – Basal respiration; qCO_2 – Metabolic quotient.

Table 1. Soil pH, Ca, P and K content at undisturbed and disturbed Cerrado *sensu stricto* from Sete Cidades National Park, Brazil.

	pH (H_2O)		Ca ($cmol_c\ dm^{-3}$)		P ($mg\ dm^{-3}$)		K ($mg\ dm^{-3}$)	
	dry	Wet	dry	wet	dry	wet	dry	wet
Undistrubed	5.1 ± 0.5^{bA}	4.9 ± 0.3^{bA}	0.18 ± 0.07^{bA}	0.15 ± 0.06^{bA}	10.2 ± 1.9^{aA}	9.1 ± 1.5^{aA}	6.1 ± 1.3^{aA}	$5.0 + 1.7^{aA}$
Disturbed	5.8 ± 0.6^{aA}	5.5 ± 0.5^{aA}	0.78 ± 0.1^{aA}	0.73 ± 0.09^{aA}	2.3 ± 1.1^{bA}	2.3 ± 0.9^{bA}	2.7 ± 0.7^{bA}	$2.3 + 0.9^{bA}$

Mean ± standard error. Values followed by the same lower case letter, in each column, and capital letter, in each line, do not differ statistically from each other at $p < 0.05$.

Table 2. Total organic C (TOC), microbial biomass C (MBC), soil respiration (CO_2), metabolic quotient (qCO_2), and ratio between soil microbial biomass C and total organic carbon content (MBC-to-TOC) at undisturbed and disturbed Cerrado *sensu stricto* from Sete Cidades National Park, Brazil.

Site	TOC ($g\ kg^{-1}$)		MBC ($mg\ C\ kg^{-1}$)		Soil respiration ($mgCO_2\ kg^{-1}d^{-1}$)		qCO_2		MBC-to-TOC (%)	
	wet	dry	wet	dry	wet	dry	wet	dry	wet	dry
Undisturbed	6.1 ± 1.4^{aA}	5.3 ± 1.6^{aA}	141 ± 15.8^{aA}	81 ± 13.9^{aB}	3.3 ± 0.8^{aA}	2.0 ± 0.9^{aB}	0.03 ± 0.01^{bA}	0.01 ± 0.01^{aB}	4.1 ± 1.2^{aA}	3.8 ± 1.3^{aA}
Disturbed	4.4 ± 1.2^{bA}	3.6 ± 1.7^{bA}	81 ± 19.4^{bA}	62 ± 12.8^{bB}	3.4 ± 0.6^{aA}	1.9 ± 0.4^{aB}	0.05 ± 0.01^{aA}	0.02 ± 0.01^{aB}	2.8 ± 0.9^{bA}	2.4 ± 0.8^{bA}

Mean ± standard error. Values followed by the same lower case letter, in each column, and capital letter, in each line, do not differ statistically from each other at $p < 0.05$.

Table 3. Soil surface fauna (Araneae, Coleoptera, Formicidae and Orthoptera) at undisturbed and disturbed Cerrado *sensu stricto* from Sete Cidades National Park, Brazil.

	Araneae		Coleoptera		Formicidae		Orthoptera	
			Mean density of individual per trap					
	wet	Dry	wet	dry	wet	dry	wet	dry
Undisturbed	6.9 ± 1.3^{aA}	6.6 ± 2.1^{aA}	45.1 ± 7.3^{aA}	30.5 ± 9.6^{aB}	31.3 ± 5.4^{bA}	20.5 ± 3.2^{bB}	11.7 ± 2.1^{aA}	7.4 ± 1.9^{aB}
Disturbed	3.1 ± 0.9^{bA}	2.9 ± 1.1^{bA}	18.9 ± 5.9^{bA}	4.2 ± 1.4^{bB}	59.3 ± 9.2^{aA}	48.5 ± 7.1^{aB}	7.3 ± 1.5^{bA}	3.0 ± 0.8^{bB}

Mean ± standard error. Values followed by the same lower case letter, in each column, and capital letter, in each line, do not differ statistically from each other at $p < 0.05$.

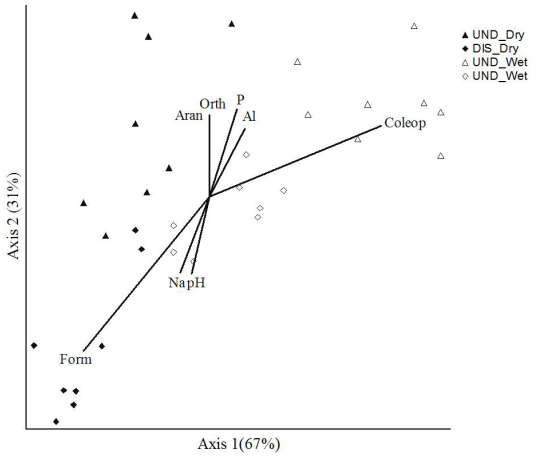

Figure 2. NMS based on soil surface fauna and chemical properties of soil at undisturbed and disturbed Cerrado *sensu stricto* from Sete Cidades National Park, Brazil. pH – soil pH; P – available P; Ca – Exchangeable Ca; Na – Exchangeable Na.

4. Discussion

Soils under Cerrado are usually acidic and show low levels of exchangeable Ca (Ruggiero et al., 2002). Therefore, the higher values found for soil pH and Ca content in the disturbed site are probably due to the slash-and-burn practice that contributes to increasing Ca content and consequently soil pH (Beliveau et al., 2014). The increase in Ca content is related to the carbonization of plant biomass resulting in the production of calcite ($CaCO_3$) (Yuan et al., 2011). In addition, soil pH may also increase due to incorporation of alkaline ash from slash-and-burn practices (Kopecky et al., 2012). The similar P and K concentrations at all sites may be associated with the presence of organic residues at the undisturbed site or the slash-and-burn practice at the disturbed site (Tabi et al., 2013).

The higher TOC content in undisturbed Cerrado *sensu stricto* indicates that the presence of plant litter contributes to an increase in organic C, whereas soil disturbance through the slash-and-burn practice promotes a strong decrease in TOC content (Tabi et al., 2013; Leite et al., 2014). The decrease in organic C can have a major impact on soil, leading to an overall decline in soil quality due the reduction in available water capacity, nutrient status, and soil structure (Kimble et al., 2001).

Soil microbial biomass is an important indicator of soil quality and also a sensitive early indicator of soil change (Zhang and Fang, 2007). Soil microbial biomass C differed seasonally, and this pattern may be attributed to different soil humidity (Silva et al., 2012) or temperature (Rodrigues et al., 2015). During both seasons, the undisturbed Cerrado *sensu stricto* showed higher soil microbial biomass. This difference may be attributed to a more diverse quantity of litter under the native vegetation, which is able to support a larger microbial biomass (Nsabimana et al. 2004).

Soil respiration was higher during the wet season, possibly because of activation of soil biological activity by soil moisture. However, for the disturbed site, the qCO_2 was higher. This difference may be a signal of stress on soil microbial biomass by the disturbance. For the MBC-to-TOC ratio, an index indicating the availability of organic matter in soils (Santos et al., 2012), the results showed that the more stable soil microbial biomass under undisturbed Cerrado *sensu stricto* contributed to a higher MBC-to-TOC ratio during both seasons.

Soil surface fauna showed different patterns in the undisturbed and disturbed sites. Aranaea, Coleoptera, and Orthoptera were lower in the disturbed sites, possibly due to the loss of vegetation cover after slash-and-burn. This practice results in the loss of an adequate habitat for arthropods. In contrast, Formicidae were more abundant in disturbed soil. This result suggests that this agricultural practice degraded the habitat for litter-dwelling species and at the same time, created an open and dry habitat that favored the Formicidae (Graham et al., 2004). A similar finding was found by Luz et al. (2013), who reported a higher frequency of Formicidae in managed areas than in native forests in Northeast Brazil.

The NMS analyses of the soil biological and chemical properties revealed distinct trends for each site, indicating a strong relationship among biological properties and soil conditions. The undisturbed Cerrado in both seasons clustered together was characterized by higher microbial biomass C and densities of all soil fauna compared to the other site. These data may indicate that undisturbed soil presents greater availability of source of plant litter and organic residues for soil biota. In contrast, the disturbed Cerrado had a high respiratory quotient, which can be indicative of stress due to limited availability of resources.

5. Conclusion

Disturbance by agricultural practices, such as slash-and-burn, likely resulted in the deterioration of the biological properties of soil under native Cerrado *sensu stricto* in the PNSC. The removal of vegetation by slash-and-burn practices promoted a decrease in soil microbial biomass and surface fauna in the preserved site. These declines are sufficient to result in soil degradation and loss of biodiversity in the long-term. Therefore, policies of protection and conservation of native Cerrado in PNSC should be implemented to avoid further soil degradation and loss of soil biodiversity.

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