REVISTA VALE UninCor

A FREQUÊNCIA DO FOGO ALTERA AS PROPRIEDADES QUÍMICAS E BIOLÓGICAS DO SOLO?

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RESUMO

O fogo é uma perturbação de alto impacto no ecossistema e sua gravidade depende da frequência. Nossa hipótese é que a queima poderia afetar os parâmetros químicos e microbiológicos dos solos sujeitos a diferentes regimes de fogo. Estudamos três áreas de Plintossolos Pétricos concrecionários no Cerrado. As áreas avaliadas receberam os seguintes tratamentos: queimadas anualmente de 2014 a 2017, queimadas em 2014 e 2016 e nenhuma queimada no mesmo período. Três amostras de solo deformadas foram coletadas em cada local para determinar suas propriedades químicas, respiração microbiana do solo, biomassa microbiana do solo, quociente metabólico e conteúdo de carbono orgânico total. Os escores do eixo significativo foram utilizados para testar a hipótese nula de igualdade do tratamento por meio de testes de permutação. Os testes de permutação aplicados sugerem que o local frequentemente queimado mantém a menor fertilidade do solo, enquanto o local não queimado e o local queimado anualmente mantêm os níveis de fertilidade. Em relação à biomassa da microbiota e ao carbono do solo, nossos resultados sugerem uma gradiente em que os menores teores foram encontrados nos locais frequentemente queimados e os maiores teores nos locais queimados anualmente. Concluímos que os impactos do fogo dependem da sua frequência.

Palavras-chave: Microbiologia do solo. Fertilidade do solo. Fogo. Cerrado.

FIRE FREQUENCY CHANGES CHEMICAL AND BIOLOGICAL SOIL PROPERTIES?

ABSTRACT

Fire is a high-impact disturbance in the ecosystem, and its severity depends on the frequency. We hypothesized that burning could affect soils' chemical and microbiological parameters subject to different fire regimes. We studied three areas covered by concretionary petroferric Plinthosols in Cerrado. The assessed areas received the following treatments: burned annually from 2014 to 2017, burned in 2014 and 2016, and no fires during the same period. Three deformed soil samples were collected at each site to determine their chemical properties, soil microbial respiration, soil microbial biomass, metabolic quotient, and total organic carbon content. We also tested the significance of the PCA axis by permutation tests. The scores of the significant axis were used to test the null hypothesis of equality of the treatment by mensa of permutation tests. The permutation tests applied to PCA scores suggest that the frequently burned holds the minor soil fertility, while but not-burned and the biannual burned site save the same fertility levels. Concerning microbiota biomass and soil carbon, our results suggest a gradient in which the lowest content were found in frequently burned sites and the highest content in the biannualy burned ones. We concluded that fire impacts were dependent on their frequency.

Keywords: Soil microbiology. Soil fertility. Fire. Cerrado.

Recebido em: XX/XX/XXXX - Aprovado em: XX/XX/XXXX - Disponibilizado em: XX/XX/XXXX

1. INTRODUCTION

Fire is a high-intensity disturbance (CRAWLEY, 1998) that can shape vegetation forms and the whole ecology of ecosystems affected by him (BRADBURY et al., 2016; HOFFMANN et al., 2003), selecting traits that ensure some advantage in fire-prone ecosystems (LÜTTGE, 1997). In Brazil, the fire appears mainly associated with Amazonian burnings (SILVEIRA et al., 2022) and its effects on atmospheric carbon emission and the resulting contribution to the magnification of the greenhouse effect (NEPSTAD et al., 2008; SILVA et al., 2021). However, for grassland and Cerrados (Neotropical Savannas) ecologists, fire plays a critical ecological factor at the present time (COUTINHO 1977, COUTINHO 1978, HOFFMANN 2000, ABREU et al. 2021) and in the past (BEHLING, 1998; CASSINO et al., 2020; PINHEIRO and MONTEIRO, 2010).

The fire impact on the ecosystem depends on the amount of biomass fuel which affects the temperature at the soil surface or below, depending on a series of factors, like soil water and the heat conductivity of minerals (GOMES et al., 2020; CERTINI, 2005). As a rule, the higher the disturbance frequency, the higher its ecosystem impact (CRAWLEY, 1998), and the fire frequency seems to follow this rule (CERTINI, 2005). In general, fire can cause extreme ecosystem damage leading to nutrient and biomass loss, reducing biological richness, diminishing microfauna populations, and alterations in the soil's chemical and physical properties, ultimately leading to soil erosion (REDIN et al., 2011; Jiménez-Cisneros, 2014; CRAWLEY, 1998; VEGA et al., 2013; TILMAN, 1988; CERTINI, 2005). Strong microbial respiration reduction seems to indicate the bluntest fire effects, coupled with pH rising as a result of cations in the remaining ashes derived from burned organic materials (VEGA et al., 2013; CERTINI, 2005; ZALMAN et al., 2022).

The organic matter, on the contrary, seems to reduce according to the severity of burning (VEGA et al., 2013). Although organic carbon tends to be reduced by the burning of organic matter (dead and alive), charred materials could increase the total amount of soil carbon, mainly in the presence of woody vegetation (ZALMAN et al., 2022).

The fire action decreases the amount of organic matter that constitutes the initial source of microorganisms' energy and, therefore, reduces the fungi population of the soil, consequently contributing to the loss of the productive capacity of the soil (CERTINI, 2005).

At first sight, burning offers some short-term benefits. Despite its high volatility, nitrogen shows some increase, mainly in ammonia form (ZALMAN et al., 2022), but is rapidly transformed into nitrate and subjected to leaching (CERTINI, 2005). There is a higher availability of nutrients, mainly potassium and calcium which do not volatilize and concentrates in the superficial layer (SIMON et al., 2016). Phosphorus does not volatilize as nitrogen, and its availability is increased with the rising pH linked to cation released by ashes (CERTINI, 2005). In fact, a long period of fire absence can cause phosphorus deprivation in plants, suggesting that fires can play an important role in the P cycle (Butler et al., 2018). However, despite an initial increase, nutrients tend to be diminished quickly (MACADAM, 1987).

In terms of physical properties, the burning of organic matter releases hydrophobic substances, which reduce water percolation and, as a result, soil water availability (CERTINI, 2005; MACDONALD AND HUFFMAN, 2004). The soil water controls subsurface water temperature during fires and the damage to soil biota (STOOF et al., 2013). Although mineralogical properties remain virtually the same, soil bulk density increase as the organic matter collapses, reducing the soil water retention, soil porosity, and hydraulic conductivity by clogging the soil pores with ashes and dispersed clay (CERTINI, 2005).

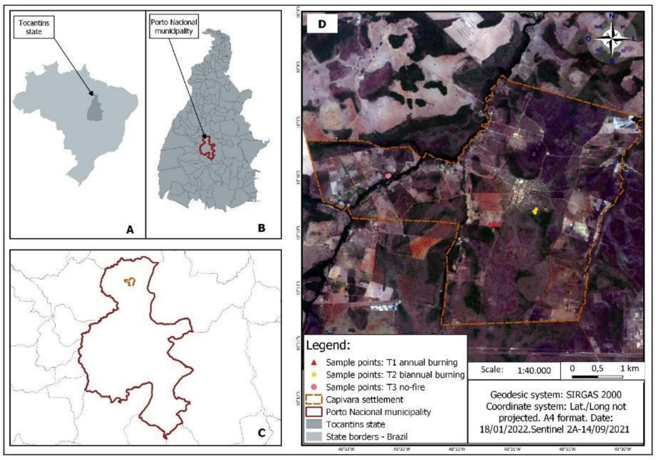
Despite the long history of evolution, which links natural fires to Cerrado, the current fire regime is more frequent and intense than the natural ones. They are mainly anthropic fires distributed mainly along dry seasons and causing significant damage to the environment and human health (GOMES et al., 2018). Besides, these fires have different intensities because the dryer the soil and the vegetation are at the end of the drought season, the greater the fire proportions and the damages they cause (RISSI et al., 2017).

As can be seen, there is a vast experience in the ecological literature dealing with the fire effects, much of which deals with vegetation aspects. The purpose of our study is to observe how fire affects soil chemistry and the measurable parameters of soil microbiological activities. We hypothesize that the effects of fire are more harmful when fires are more frequent. The novelty presented here concerns that this study was conducted in areas of the Cerrado with a predominance of Plinthosols, where petroplinthite can cause, even in low-frequency burning, effects as harmful as those of high-frequency burning. This suspicion is derived from the fact that petroplinthite is a material composed essentially of iron oxides, which exhibit excellent thermal conductivity.

2. MATERIALS AND METHODS

The study areas are located in the Capivari settlement in Porto Nacional, Tocantins, in the Brazilian Northern Region (10°10'5.66"S and 48°31'26.61"W, 283 m; 10° 9'56.58"S and 48°30'56.37"W, 282 m; 10° 9'35.19" S and 48°32'33.01"W, 264 m, which represents from now on treatments 1, 2 and 3, respectively).

Figure 1. Localization of Tocantins State, in Brazil, and Porto Nacional municipality (A, B, and C). Capivari settlement and surveyed áreas were highlighted in D.



The climate is tropical, with a dry winter season (from May to October) and intense rainfall during the summer season (from November to April), a typical Cerrado Aw type (ALVARES et al., 2013).

The soils of the studied areas were classified as concretionary petroferric Plinthosols, according to Santos et al. (2018). All three sites were covered by native Cerrado vegetation. The first area, named T1 (as treatment 1), has soils with a sandy-clay-loam texture and annual burnings from 2014 to 2017. T2 has soils with a sandy-loam texture (with fires set in 2014 and 2016. Finally, T3 has soils with a clayey texture with no fire history from 2014 to 2017.

2.1 Samples collection and laboratory analysis

We collected the samples after burning the sites in August 2017. They were selected based on the knowledge about land use provided by neighbor farmers, besides the satellite images.

We collected three composed soil samples in each area (treatment) with a Dutch auger and mixed them to compose a 1 Kg superficial horizon (A horizon) sample. Then, we transferred the soil volume to a clean and unused polyethylene plastic bags, which were properly identified and transported to the laboratory for analysis.

The standard procedure for measuring microbiological parameters requires that the soil has moisture equivalent to a 60% of its field capacity (FC). Thus, we determined the soil´s field capacity, following Monteiro & Frighetto (2000) e Dionísio et al. (2016). This aspect is one of the most limiting factors of the microorganisms' activities and is highly variable between soils, mainly due to clay and organic matter levels.

We employed the methodology of soil respiration on a static system to determine soil microbial respiration (ALEF, 1995), as outlined by (DIONÍSIO et al., 2016). To determine the soil microbial biomass, we followed the methodology described by Anderson & Domsch (1980, as stated by DIONÍSIO et al. 2016). Finally, we calculated the metabolic quotient as the ratio between basal respiration and the microbial biomass carbon (ANDERSON and DOMSCH, 1980).

The soil chemical parameter was obtained through different lab methods, as follows. First, pH was measured in water in a 1:2.5 ratio with stirring for one minute and one hour as reaction time (TEIXEIRA et al., 2017). Next, the exchangeable cations were analyzed following Teixeira et al. (2017), extracting the Al^{3+}, Ca^{2+}, and Mg^{2+} cations by KCl 1mol.L-1 solution. Thus, the Ca^{2+} and Mg^{2+} content was obtained by atomic absorption spectrophotometry, and the exchangeable Al^{3+}, or exchangeable acidity, was determined by titration with NaOH 0,025 mol.L-1 solution in the presence of bromothymol blue indicator

(0.1%). Next, the Na+ and the K+ were extracted with the solution of Mehlich-1 and determined by flame emission photometry. The potential acidity (H+Al) was extracted with a buffered solution of calcium acetate 0.5 mol L-1 (pH 7.1-7.2) and defined by titration with a solution NaOH 0.025 mol.L-1 in the presence of 10 mg L-1 phenolphthalein indicator (Teixeira et al., 2017). After having the values of cation exchange capacity (CEC), we calculated the sum of extractable bases (S), exchangeable aluminum percentage (m), and base saturation percentage (V%). Finally, the granulometry was established by the pipette method (TEIXEIRA et al., 2017).

2.2 Statistical Analysis

Firstly, we divided the parameters into two matrices: one microbiological (Yb) and one chemical (Yc), composed of n observations and p descriptors or variables. We then used a principal component analysis (PCA) (LEGENDRE and LEGENDRE, 2012; MCCUNE et al., 2002) to reduce the data dimensionality, as well as to observe ordination patterns and correlations between the original descriptors (or variables) from both matrices. We checked the variance extracted by each principal component using eigenvalues λ_p, and their correlation with original descriptors using a correlation matrix. We tested the significance of the PCA axis by means of permutation tests.

We used permutation procedures to test the null hypothesis of equal means between the treatments (sites). We used the PCA1 scores instead of the original variables data since we admit that this axis collapses a major portion of data information from both matrices (chemical and microbiological). We assume that each treatment (site) represented the predictor variables.

We use the Vegan package (OKSANEN et al., 2015) and the R programming (R Development Core Team, 2013) to conduct all statistical procedures and the graphic representation of the results. PCA permutation tests used the PCAtest package (CAMARGO, 2022).

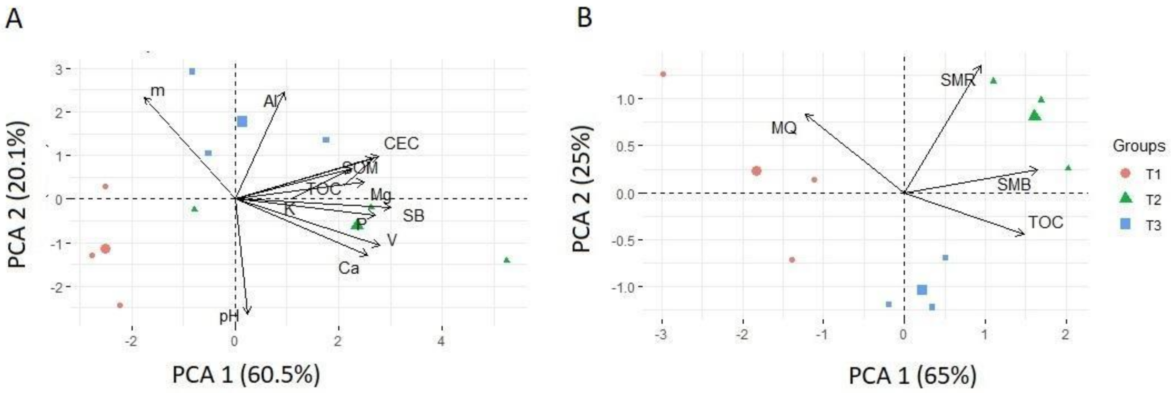
3. RESULTS

The first principal component accounts for nearly 60% of the total dataset variance, suggesting that it should represent the major segregating axis. Moreover, this is the only significant axis in the permutation test ($p=0.001$).

As can be seen in figure 2A, axis 1 seems to perform an organic matter/fertility gradient. All correlation coefficients between PCA 1 and the exchangeable bases are higher than 0.7, as well as the fertility parameters (S and V%), the organic matter indicators (SOM and TOC), and the cation capacity exchange (CEC). According to the results of permutations tests, all the variable loadings (correlations) on PCA 1 are significant. All the others axis were not significant.

In the ordination diagram depicted in Figure 2A, we can observe treatment 1 samples (soil with fire history for four consecutive years) in the left end of the fertility gradient determined by PCA 1 ordination. Treatment 1 differs from T2 ($p=0.049$) and T3 ($p=0.046$), but both latter do not ($p=0.15$). In fact, Treatment 1 seems to be in a somewhat tight cluster, while the other two groups of observations (treatment 2 and 3) are slightly difficult to distinguish (figure 2A). Thus, sites 2 and 3 (biannual burning and no-burning, respectively) are equivalent and show higher fertility than site 1, which was frequently burned.

Figure 2 – Ordination diagram resulted from the application of the principal components analysis (PCA) on data of soil chemical attributes (A) and soil microbiological attributes (B): m = exchangeable aluminum percentage; Al = Aluminum; CEC = cation exchange capacity; SOM = Soil Organic Matter; TOC = Total Organic Carbon; Mg – Magnesium; SB = sum of extractable bases; K = Potassium; V = base saturation percentage; Ca – Calcium. The fourth and bigger point of each treatment represents the centroid of each group. Only the first PCA axis was significant in both cases according to permutation tests.



As described for the matrix of soil chemical descriptors, the resulting PCA ordination in figure 2B shows that the first axis retained 65% of the total variance. According to permutation tests (p=0.01), it is the only significant axis, which means it performs a good representation of actual data. Only the soil microbial biomass (SMB) and the total organic carbon (TOC) showed significant loadings on PCA1. Thus, axis 1 appears to be a gradient of microbial biomass and organic carbon that discriminate T2 (biannual burnings) at the right extreme, and T1, at the left one.

Treatment 1 differs from the other sites (T2, p=0.048 and T3, p=0.047), and the permutation test showed that T2 differs from T3 (p=0.045). Thus, site 2 (biannual burning) showed higher organic carbon and microbial biomass content, while the worst levels of both parameters were found in annually burned site 1.

4. DISCUSSION

Our results suggest that virtually all fertility and some microbiological parameters seem to be affected by recurrent fire episodes. It includes the soil carbon and the soil organic matter (SOM), but it appears that the burnings frequency does not affect the acidity and the aluminum-related parameters, which sounds a little bit strange since changes in pH (resulting probably from exchangeable bases leaching) leads to a higher exchangeable Al content (BRADY and WEIL, 1999). Thus, our results suggest that the higher fire impact was related to T1, where repeated burning has decreased nutrient availability and lowered the total microbial biomass, which may or may not be linked with reducing organic carbon.

In fact, repeated fires might reduce the organic matter content and the nitrogen content (POURREZa et al., 2014; VEGA et al., 2013; ZALMAN et al., 2022) and, consequently, impact the microbial soil activity once their metabolism is based on carbon and also resulting in deploying nutrients such as nitrogen and phosphorous, reflecting directly on soil fertility (MAILLARD et al., 2019).

However, the higher soil fertility of the biannual burned site, which does not differ from the chemical properties of the non-burned site, seems to reflect the effects of mobilization of nutrients by burning that could be equivalent to rapid cycling. This higher fertility, however, may be short-lived, and a long time of recurrence could lead to the reduction of fertility, perhaps at a slower pace (REDIN et al., 2011; CERTINI, 2005).

The lower microbial biomass of T1 seems to result from the high mortality of soil microbiota (ALVES et al., 2011; VEGA et al., 2013; SOUSA, 2014) induced by the high frequency of fires. It showed the lowest values of microbial biomass, which may result from their incapacity to recover in short intervals between the fires. Indeed, temperatures may achieve spikes that completely sterilize the soil layer at 5 cm depth (DOOLEY and TRESEDER, 2012). A sequence of fires could reduce the soil microbiota resilience to the point that makes it difficult to return to the original conditions.

Burning effects are expected to be restricted to the first centimeters of the soil top (ARAÚJO and RIBEIRO, 2005; REDIN et al., 2011). Still, the high amount of iron oxide gravels in Plintosols (petroplinthita) may amplify the temperature effect at depth.

Furthermore, a low level of SOM may provoke a synergetic effect in diminishing microbial biomass. Low levels of SOM may reflect the low quantity and quality of plant litter available to the microbiota decomposition, reducing their ability to use the organic C (SILVA et al. 2009). There is sufficient evidence that fires are devastating to organic carbon. It alters the carbon cycle, contributes to greenhouse gas emissions, and also provokes the loss of many benefits to the soil, affecting the environmental functionality (CHERUBIN et al., 2015).

Some authors noticed that occasional fires do not affect microbial activity, but repeated fires may bring severe damage to the fungal community (POURREZA et al., 2014). Thus, the reduction of soil organic carbon could be involved in the process since microorganisms depend on this element for metabolic processes (VEGA et al., 2013). The higher content of organic carbon, on the contrary hand, could favor the microbiota in sites 2 and 3, and the release of nutrients provoked by less frequent burning could result in the maintenance of plant biomass, which could contribute to adding more and more charred materials (ZALMAN et al., 2022). Finally, it seems reasonable that fires are a stress-promoting disturbance among the soil microbial population (D'ANDRÉA et al., 2002) and, maximized by burning SOM and hampering carbon additions, maximized by high consumption levels of organic carbon of the soil.

However, our result also suggests that occasional fires may benefit microbial biomass (temporarily, at least). The higher soil microbial biomass SMB values for treatment 2 can be seen as a result of the rapid availability of soil nutrients such as Ca, Mg, and K, stimulating the activity and increasing soil microbial biomass. The prompt availability of nutrients leads to a rapid increase in soil microbial biomass shortly after the burning and a subsequent slight decrease after depleting the sources of energy to the microorganisms (NARDOTO and BUSTAMANTE, 2003).

These results parallel the theory of intermediary disturbance (CONNELL, 1978), naturally considering the differences between our case and the theory idea linked to biodiversity, not to aspects of soil microbiota activity. However, we found no theoretical basis for discussion on our data. Naturally, we are aware of the small number of samples in our study and the danger involving generalizations made based on our data, but it fits very well with the results of others studies.

5. CONCLUSION

Our data seem to confirm the hypothesis that fire frequency is the main factor affecting fertility and microbiological parameters. High fire frequency has led to decreasing fertility, microbial biomass, and total soil carbon content, creating undesirable negative

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