Anais da Academia Brasileira de Ciências (2019) 91(4): e20190049
(Annals of the Brazilian Academy of Sciences)
Printed version ISSN 0001-3765 / Online version ISSN 1678-2690
http://dx.doi.org/10.1590/0001-3765201920190049
www.scielo.br/aabc | www.fb.com/aabcjournal

# Soil microbial C:N:P ratio across physiognomies of Brazilian Cerrado

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*Manuscript received on January 15, 2019; accepted for publication on July 25, 2019*

**How to cite:** ROCHA SMB, ANTUNES JEL, ARAUJO FF, MENDES LW, SOUSA RS AND ARAUJO ASF. 2019. Soil microbial C:N:P ratio across physiognomies of Brazilian Cerrado. An Acad Bras Cienc 91: e20190049. DOI. 10.1590/0001-3765201920190049.

**Abstract:** Different physiognomies across the Cerrado could influence the microbial C:N:P ratio in the soil since these physiognomies present different abundance and diversity of plant species. Thus, the aim of this study was to evaluate the microbial C:N:P ratio in soil across three different physiognomies of Cerrado in the Northeast, Brazil, namely campo graminóide (dominance of grasses), cerrado stricto sensu (dominance of grasses, shrubs, low trees, and woody stratum), and cerradão (dominance of woody stratum). Campo graminóide was characterized by lower values of total organic C, N, microbial C:P, N:P, and soil C:N. Cerrado stricto sensu presented average values for most of the measured parameters, while cerradão presented higher values of microbial C, N, P, organic C, N and soil C:P and C:N ratios. The principal component analysis showed that the samples grouped according to the sites, with a clear gradient from campo graminóide to cerradão. Therefore, the differences of vegetation across physiognomies of Cerrado influenced the soil microbial C:N:P ratio, where cerradão showed highest microbial C:N:P ratio than soil under campo graminóide.

**Key words:** Microbial biomass, soil quality, organic matter, tropical soil.

## INTRODUCTION

Soil organic matter (SOM) and microbial biomass (SMB) are suitable indicators of soil fertility in both native and managed ecosystems (Andrews et al. 2004, Jiménez et al. 2011). SOM presents the contents of C, N, and P that are important for biogeochemical cycles and also for plant growth (Liu et al. 2013). On the other hand, SMB is considered the living component of SOM being constituted by soil microorganisms (Sousa et al. 2015) and can be estimated by microbial biomass C (MBC), N (MBN) and P (MBP). Specifically, soil MBC varies from 1 to 7% of total organic C (TOC), while MBN and MBP vary from 1 to 5% of total N (TN) and P (TP) (Sparling 1992).

SMB presents importance on the biological process in soil, such as immobilization and mineralization of nutrients (Marinari et al. 2006). It means that SMB can act as the sink (immobilization) or the source (mineralization) of nutrients and it

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depends on the relationship between microbial C, N and P, expressed as the C:N:P ratio (Gnankambary et al. 2008). Thus, the C:N:P ratios are important for the understanding of microbial nutrient limitations in soils, since the microbial C:N:P ratio is a good indicator of nutrient status in soil. In native ecosystem, the C:N:P ratio is influenced by the type and structure of vegetation and soil environment (Cristina et al. 2010). Therefore, the knowledge about the microbial C:N:P ratios in native ecosystem is important to assess the soil nutrient status and ecological implications for vegetation.

As a native ecosystem, the Brazilian Cerrado is a biome with high plant diversity (Amaral et al. 2006) distributed in several physiognomies, such as grassland, shrubby and arboreal vegetation (Coutinho 1978). These physiognomies present different types and structures of vegetation that influence soil environmental conditions and, consequently, can affect the soil microbial biomass. Indeed, previous studies have found the highest MBC in shrubby and arboreal vegetation than in grassland (Mendes et al. 2012, Carvalho et al. 2018). In addition, some studies have observed the influence of these different physiognomies on the structure and diversity of soil microbial community (Araujo et al. 2018a, b, 2019).

However, the knowledge about the microbial C:N:P ratio across different physiognomies of Cerrado remains unclear. Also, part of the microbial biomass is threatened, mainly due to the conversion of native areas to agricultural fields. In this sense, the expansion of knowledge about microbial biomass is necessary to protect the native areas and regulate the use for agricultural purposes. Considering the different plant physiognomies found in Cerrado, we hypothesized that these plant physiognomies could influence the microbial biomass ratio in the soil due to their different abundance and diversity of plant species. Thus, the aim of this study was to evaluate the microbial C:N:P ratio in soil across different physiognomies of Cerrado in the Northeast, Brazil.

## MATERIALS AND METHODS

This research was conducted in an area under preserved Cerrado inside the Parque Nacional de Sete Cidades (PNSC), located in the Piauí State (04°02’-08’S and 41°40’-45’W). In this region, the climate is sub-humid with two distinct seasons (wet and dry) and presents an annual average temperature of 25°C and rainfall of 1,558 mm, concentrated between February and April. The soil is classified as Fluvisol (FAO) and presents 926 g $kg^{-1}$ of sand, 39 g $kg^{-1}$ of silt, and 30 g $kg^{-1}$ of clay.

In this study, three preserved sites (about 1.000 $m^2$ each one) were evaluated across different physiognomies, namely campo graminóide (CG), cerrado stricto sensu (CSS), and cerradão (CD) (Table I). CG is characterized by the dominance of grasses, CSS is dominated by grasses, shrubs, short trees, and woody stratum; while CD is dominated by woody stratum.

Each site was divided into three transects (replications) where soil samples (500g) were collected at a depth of 0 - 20 cm (three points per transect) in May 2016 (rainy season). At each soil sampling, the soil temperature was measured for 5 minutes at 10 cm depth using a probe thermometer. A portion of the soil samples (300g) was stored in bags and kept at 4°C for microbial analysis, while another portion (200g) was air-dried, sieved through a 2-mm screen and homogenized for the chemical analyses.

Soil chemical properties (pH, P, K, Ca and Mg) were determined and measured using standard laboratory procedures (Embrapa 1999). 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 1998). Total N (TN) was determined by Kjeldahl digestion as described by Bremner (1996). Total P (TP) was determined by perchloric acid digestion according to Sommers and Nelson (1972).

**TABLE I**
**Vegetation indexes of the evaluated sites (Oliveira et al. 2007).**

| | campo graminóide | cerrado stricto sensu | cerradão |
|---|---|---|---|
| Plant richness* | 4.7 | 11 | 17 |
| Plant diversity** | 0.2 | 0.85 | 1.10 |
| Plant density*** | 4.7 | 27.1 | 35.0 |
| Vegetation**** | a | b | c |

* species/100 $m^2$; ** H/100 $m^2$; *** individual/100 $m^2$; **** species of plants present.
H – Shannon-Weaver index.
[a] *Andropogon fastigiatus; Aristida longifolia; Eragrostis maypurensis;*
[b] *Andropogon fastigiatus; Aristida longifolia; Terminalia fagifolia; Magonia pubescens; Hymenaea courbaril; Plathymenia reticulata; Qualea grandiflora; Combretum mellifluum; Lippia origanoides; Anacardium occidentale; Simarouba versicolor; Vatairea macrocarpa;*
[c] *Aspidosperma discolor; Parkia platycephala; Terminalia fagifolia; Piptadenia moniliformis; Plathymenia reticulata; Qualea parviflora; Anacardium occidentale; Copaifera coriacea; Thiloa glaucocarpa; Casearia grandiflora.*

The microbial biomass C (MBC) was determined by the chloroform fumigation-extraction method according to Vance et al. (1987); the microbial biomass N (MBN) was determined by the method of Brookes et al. (1985); and the microbial biomass P (MBP) was determined by a fumigation-extraction according to the method of Brookes et al. (1982). The extraction efficiency coefficients of 0.38, 0.45 and 0.40 were used to convert the difference in C, N and P between fumigated and unfumigated soil in MBC, MBN, and MBP, respectively. The analyses were conducted in triplicate and expressed as dry weight.

The data obtained were then compared between the treatments using a one-way analysis of variance (ANOVA), with the means being compared using least significant difference values calculated at the 5% level. Principal component analysis (PCA) biplot was used to visualize the differences between the treatments. First, the matrices were analyzed using Detrended Correspondence Analysis (DCA) to evaluate the gradient size of the species distribution, which indicated linearly distributed data (length of gradient < 3), suggesting the PCA as the best-fit mathematical model for the data. To test whether the sample clusters harbored significant differences among the treatments, we used the analysis of similarity ANOSIM. PCA plot was generated using Canoco 4.5 software (Biometrics, Wageningen, The Netherlands) and ANOSIM was calculated using Past 3 software (Hammer et al. 2001).

## RESULTS

The results of soil and microbial properties are shown in Table II. Soil pH, K content and temperature did not vary between sites, while soil moisture and P content increased from campo graminóide to cerradão. The values of TOC, TN, MBC, MBN and MBP also increased from campo graminóide to cerradão. Campo graminóide presented the lowest value of TP than cerrado stricto sensu and cerradão.

The values of soil C:N and microbial biomass C:N were higher in cerrado stricto sensu than in campo graminóide and cerradão (Table III). On the other hand, the values of soil C:P and N:P were higher in cerradão than cerrado stricto sensu and campo graminóide. Similarly, microbial biomass C:P and N:P presented the highest values in cerradão and lowest in campo graminóide (Table III).

The microbial indices were different across sites (Table IV). MBC:TOC ratio were higher in campo graminóide and cerrado stricto sensu than cerradão, while MBN:TN ratio did not vary across sites. On the other hand, MBP:TP ratio was higher in cerradão than cerrado stricto sensu and campo graminóide.

The PCA analysis based on the soil and microbial C:N:P across different Cerrado physiognomies explained more than 99% of the data variation (Figure 1). The analysis showed that the samples grouped according to the treatment,

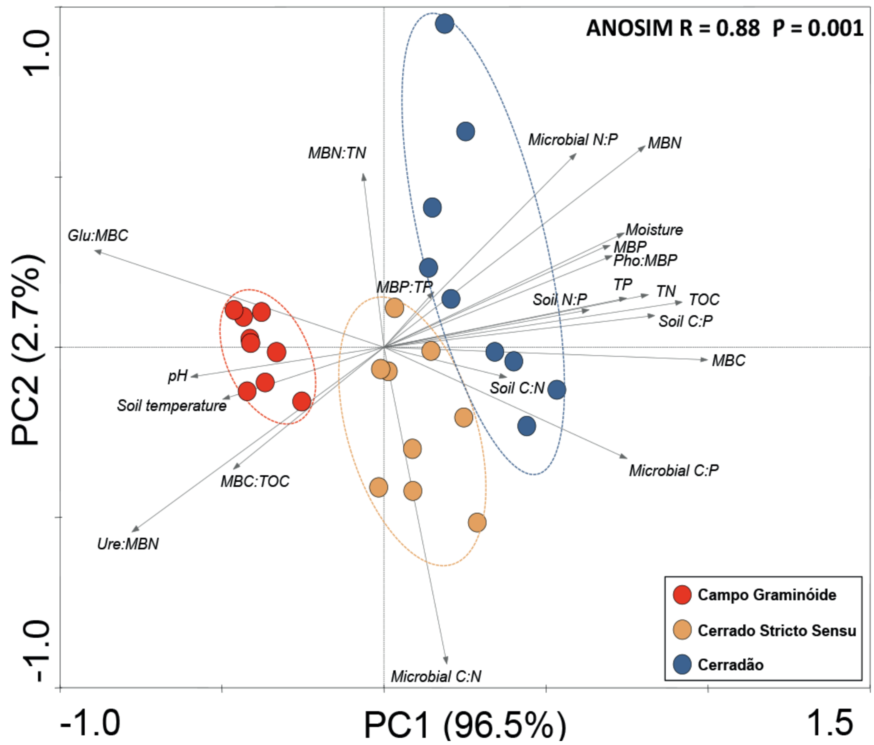


**Figure 1** - Principal component analysis (PCA) based on the soil and microbial C:N:P across different Cerrado physiognomies.

**TABLE II**
**Soil chemical parameters and microbial properties.**

| | campo graminóide | cerrado stricto sensu | cerradão |
|---|---|---|---|
| pH | 4.97$^{a}$ ±0.5 | 4.85$^{a}$ ±0.7 | 4.79$^{a}$ ±0.7 |
| P (mg kg$^{-1}$) | 3.57$^{b}$ ±0.4 | 4.87$^{a}$ ±0.7 | 4.81$^{a}$ ±0.5 |
| K (cmol$_{c}$ kg$^{-1}$) | 1.33$^{a}$ ±0.2 | 1.86$^{a}$ ±0.3 | 1.80$^{a}$ ±0.3 |
| Moisture | 8.47$^{c}$ ±0.8 | 9.90$^{b}$ ±1.0 | 12.07$^{a}$ ±1.4 |
| Temperature | 27$^{a}$ ±1.9 | 26$^{a}$ ±1.8 | 26$^{a}$ ±2.1 |
| TOC (g kg$^{-1}$) | 3.31$^{c}$ ±0.3 | 6.44$^{b}$ ±0.5 | 8.47$^{a}$ ±0.9 |
| TN (g kg$^{-1}$) | 0.35$^{c}$ ±0.1 | 0.50$^{b}$ ±0.1 | 0.78$^{a}$ ±0.2 |
| TP (g kg$^{-1}$) | 0.036$^{b}$ ±0.008 | 0.049$^{a}$ ±0.01 | 0.048$^{a}$ ±0.01 |
| MBC (mg kg$^{-1}$) | 113$^{c}$ ±9.3 | 198$^{b}$ ±13.4 | 228$^{a}$ ±15.7 |
| MBN (mg kg$^{-1}$) | 28$^{c}$ ±2.7 | 41$^{b}$ ±5.8 | 60$^{a}$ ±6.1 |
| MBP (mg kg$^{-1}$) | 10$^{c}$ ±0.8 | 12$^{b}$ ±1.1 | 15$^{a}$ ±1.5 |

TOC – Total Organic C; TN – Total N; TP – Total P; MBC – Microbial Biomass C; MBN – Microbial Biomass N; MBP – Microbial Biomass P. Different lower case letters in each line refer to significant differences between physiognomies ($P < 0.05$).

with a clear gradient from campo graminóide to cerradão (ANOSIM R = 0.88, P = 0.001). In general, samples from the cerradão presented the highest values for the most of the variables, while samples from the campo graminóide presented higher values of pH and soil temperature.

## DISCUSSION

The results showed that all sites presented low soil pH and confirm that soil under cerrado is usually acid (Reatto et al. 2008). The pH has been considered the main driver of microbial

**TABLE III**
**C:N:P ratios in soil and microbial biomass across the Cerrado gradient.**

| | C:N | C:P | N:P |
|---|---|---|---|
| *Soil* | | | |
| campo graminóide | $9.5^{c} \pm 0.6$ | $93.4^{c} \pm 8.1$ | $9.8^{b} \pm 0.7$ |
| cerrado stricto sensu | $13.2^{a} \pm 0.9$ | $133.3^{b} \pm 9.6$ | $10.3^{b} \pm 1.3$ |
| cerradão | $11.0^{b} \pm 0.7$ | $177.1^{a} \pm 12.5$ | $16.5^{a} \pm 1.5$ |
| *Microbial biomass* | | | |
| campo graminóide | $4.0^{b} \pm 0.3$ | $10.8^{b} \pm 0.8$ | $2.6^{b} \pm 0.3$ |
| cerrado stricto sensu | $4.9^{a} \pm 0.5$ | $15.6^{a} \pm 1.1$ | $3.2^{a} \pm 0.5$ |
| cerradão | $3.8^{b} \pm 0.2$ | $14.6^{a} \pm 1.0$ | $3.8^{a} \pm 0.6$ |

Different lower case letters in each line refer to significant differences between physiognomies ($P < 0.05$).

**TABLE IV**
**Microbial indices.**

| | campo graminóide | cerrado stricto sensu | cerradão |
|---|---|---|---|
| MBC:TOC | $3.21^{a} \pm 0.7$ | $3.08^{a} \pm 0.5$ | $2.74^{b} \pm 0.8$ |
| MBN:TN | $8.16^{a} \pm 0.9$ | $8.34^{a} \pm 0.8$ | $7.98^{a} \pm 0.6$ |
| MBP:TP | $2.97^{b} \pm 0.3$ | $2.66^{b} \pm 0.4$ | $3.32^{a} \pm 0.3$ |

TOC – Total Organic C; TN – Total N; TP – Total P; MBC – Microbial Biomass C; MBN – Microbial Biomass N; MBP – Microbial Biomass P. Different lower case letters in each line refer to significant differences between physiognomies ($P < 0.05$).

communities (Fierer and Jackson 2006). However, the soil pH did not present significant correlation with microbial biomass in our study because there was no variation in soil pH across the gradient of Cerrado. It corroborates the study of Xu et al. (2013), which did not find the influence of pH on microbial biomass across different biomes in the world. However, soil moisture varied between sites and it may have contributed for differences in the content of soil microbial biomass. Indeed, higher soil moisture found in cerradão influenced the soil microbial biomass probably due to the increase of the available organic matter (Eaton and Chassot 2012). Other factors may have influenced the higher microbial biomass observed in cerradão, such as higher plant diversity (Oliveira et al. 2007), a factor that influences this parameter (Lamb et al. 2011). Previous studies in these sites have also shown that both plant diversity and litter influenced the microbial diversity, i.e. archaeal, bacterial and fungi diversities increased from campo graminóide to cerradão (Araujo et al. 2017a, b, 2018).

The higher amount of plant litter found in cerradão may also have contributed to the increase of soil organic C, N and P, influencing the amount of nutrient source to the microorganisms. These different characteristics found between sites, mainly between cerrado and cerradão, also contributed to shape the structure and diversity of soil microbial community (Araujo et al. 2017a, b, 2018). Nardoto et al. (2006) estimated the input of plant litter in these areas and found that campo graminóide presented about 1 ton $ha^{-1}$ $y^{-1}$, cerrado stricto sensu 2.1 ton $ha^{-1}$ $y^{-1}$ and cerradão 7 ton $ha^{-1}$ $y^{-1}$. Thus, this contribution of plant litter influenced in the highest content of soil organic C, N and P found in cerradão and cerrado stricto sensu as compared with campo graminóide. The values of microbial biomass C, N, and P observed in this study are in agreement with previous studies in Brazilian soil which ranged from 72 to 797 mg $kg^{-1}$ for microbial C (Matsuoka et al. 2003, Sampaio et al. 2008), from 11 to 104 mg $kg^{-1}$ for microbial N (Hungria et al. 2009, Santos et al. 2004) and from 4 to 60 mg $kg^{-1}$ for microbial P (Rheinheimer et al. 2000).

Cerradão, as forest formation, presented higher C:P and N:P ratios and it may be the result of more plant litter content, as discussed before. Other studies have also shown higher C:P and N:P in the forest than the grassland environment (Chen et al. 2000, Ouyang et al. 2017). It corroborates a previous study that found a decrease of 33% in microbial C:P ratio from forest to grassland environment (Chen et al. 2000). It also confirms that changes in vegetation status influence the microbial C:N:P ratios. For microbial C:N ratio, the result shows that higher value found in cerrado stricto sensu may also indicate a higher presence of fungi than bacteria in this site as compared with the others sites (Araujo et al. 2017a, b).

In this study, the values of microbial C:N, C:P and N:P ratios are in agreement with the range reported for soil that are microbial C:N of 2.2 to 14.1 (Smith and Paul 1990), microbial C:P of 5.0 to 276 (Joergensen et al. 1995) and microbial N:P of 1.0 to 4.2 (Balota et al. 2003). This difference in microbial biomass ratios between the sites may be related with the different composition of the microbial community (Araujo et al. 2017a, b, 2018) and microbial C, N, and P that were influenced by the characteristic of each site. Thus, as campo graminóide presented lower plant diversity, organic matter inputs, and P content, these characteristics contributed to the lowest microbial C, N and P contents. Since the microbial biomass ratios are indicators of C, N and P availability in the soil (Balota and Auler 2011), the lowest microbial C:N and C:P found in campo graminóide may suggest a high potential of mineralization, while highest microbial C:N and C:P found in cerradão suggest a process of immobilization of N and P (Paul 2006). Therefore, soils from cerrado stricto sensu and cerradão present more ability for storage C, N, and P with slow releasing to plants. Ecologically, these results confirm that soils from cerrado stricto sensu and cerradão present more abundance of fungi than soil from campo graminoide (Araujo et al. 2017b).

The ratios of microbial C:N:P found in all evaluated sites were lower than the ratios found by Heuck et al. (2015) and Tischer et al. (2014), that were 39:4:1 and 32:3:1, respectively. The values are also below the mean found in forest soils that was 74:9:1 (Cleveland and Liptzin 2007). On the other hand, the values of microbial C:N:P ratios are closer to the values found by Balota et al. (2003) in soils from Brazilian Cerrado, which was 18:2:1. The lower values of microbial C:N:P ratio found in this study may be related to the high microbial P found in all sites as compared with microbial C and N.

The values of soil C:N ratio did not differ between cerrado stricto sensu and cerradão, while it was lowest in campo graminóide. Soil C:P and C:N ratios were higher in cerradão than other sites. The ratios between C, N, and P are indicators of nutrient dynamic in soil (Fazhu et al. 2015). According to Paul (2006), C:N ratio higher than 25 indicates the accumulation of organic matter. In this study, the values of C:N ratios were below 25, indicating mineralization of the organic matter. However, cerradão presented higher C:N ratio than campo graminóide, indicating that this site accumulates more organic matter than campo graminóide. Similarly, the values of C:P were lower than 200, also indicating net mineralization (Paul 2006). The values of soil C:N, C:P and N:P found in this study are similar to a previous study which reported ranges from 9.9 to 25.5; 54.5 to 459.8; and 1.91 to 30.9 for C:N, C:P and N:P, respectively (Fazhu et al. 2015).

The ratio of MBC:TOC is an indicator of the potential mineralization of organic matter (Hedo et al. 2014). As reported before, the highest MBC:TOC found in campo graminóide confirms that this site presents more mineralization, leading to less accumulation of organic matter than cerrado stricto sensu and cerradão. On the other hand, the highest of MBP:TP ratio in cerradão may represent conservation of P in soil, thus increasing the soil fertility in this site.

Finally, the result of PCA showed a clear separation of physiognomies according to the variables and confirms that the type and structure of vegetation influence the soil properties. Therefore, soil pH, temperature, and MBC:TOC ratio are more correlated with campo graminóide. On the other hand, MBC, MBN, TOC, TN, TP, microbial N:P and C:P ratios, and soil C:N, C:P, and N:P ratios are correlated with cerradão. Our analysis also revealed that the cerrado stricto sensu presents an intermediate position between campo graminóide and cerradão, revealing a gradient of physiognomies. Together, our data revealed that each physiognomy influences differently the pattern of soil microbial biomass.

## CONCLUSIONS

The differences in the physiognomies of cerrado, i.e. across a gradient from grassland to arboreal vegetation, influenced the soil microbial biomass ratio. Therefore, campo graminóide presented lower soil microbial biomass compared to cerradão. This result indicates that the preserved Brazilian cerrado, such as cerradão with rich and diverse vegetation, presents higher soil microbial C:N and C:P ratios than soil under campo graminóide. Our results indicate that cerradão presents a higher capacity of accumulating soil organic matter and maintaining soil fertility.

## ACKNOWLEDGMENTS

The authors thank Fundação de Amparo a Pesquisa do Estado do Piauí (grant 004/2012) and Conselho Nacional de Desenvolvimento Científico e Tecnológico - CNPq (Grant 201005/2014-0) for financial support. Sandra M.B. Rocha and Jadson E.L. Antunes are supported by scholarship from Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES-Brazil). Ademir S.F. Araujo and Marcia V.B. Figueiredo are supported by CNPq.

## AUTHOR CONTRIBUTIONS

SMBR carried out the research as part of her master's degree and contributed to write the paper, prepared the tables and figures and interpreted the results. JELA, FFA and RSS performed data analysis, interpreted results and give suggestions for improving the paper. LWM carried out the statistical analysis, discussed the results and revised all paper. ASFA was the supervisor of the project, and contributed to the experimental design, data analysis, writing and revision of the manuscript, as well as the correspondence with the editors and reviewers.

## REFERENCES

AMARAL AG, PEREIRA FFO AND MUNHOZ CBR. 2006. Fitossociologia de uma área de cerrado rupestre na fazenda sucupira, Brasília - DF. Cerne 12: 350-359.

ANDREWS SS, KARLEN DL AND CAMBARDELLA CA. 2004. The soil management assement framework: A quantitative soil quality evaluation method. Soil Sci Soc Am J 68: 1945-1962.

ARAUJO ASF, BEZERRA WM, SANTOS VM, NUNES LAPL, LYRA MCCP, FIGUEIREDO MVB AND MELO VMM. 2017b. Fungal diversity in soil across a gradient of preserved Brazilian Cerrado. J Microbiol 55: 273-279.

ARAUJO ASF, BEZERRA WM, SANTOS VM, ROCHA SMB, CARVALHO NS, LYRA MCCP, FIGUEIREDO MVB, LOPES ACA AND MELO VMM. 2017a. Distinct bacterial communities across a gradient of vegetation from a preserved Brazilian Cerrado. Anto van Lee 110: 457-469.

ARAUJO ASF, MENDES LW, BEZERRA WM, NUNES LAPL, LYRA MCCP, FIGUEIREDO MVB AND MELO VMM. 2018. Archaea diversity in vegetation gradients from the Brazilian Cerrado. Braz J Microbiol 49: 522-528.

BALOTA EL AND AULER PAM. 2011. Soil microbial biomass under different management and tillage systems of permanent intercropped cover species in an orange orchard. Braz J Soil Sci 35: 1873-1883.

BALOTA EL, COLOZZI-FILHO A, ANDRADE DS AND DICK RP. 2003. Microbial biomass in soils under different tillage and crop rotation systems. Biol Fert Soils 38: 15-20.

BREMNER JM. 1996. Nitrogen total. In: Sparks DL (Ed), Methods of Soil Analysis, Part 3: Chemical Methods; Soil

Science Society of America: Madison, Wisconsin, p.1085-1121.

BROOKES PC, LANDMAN A, PRUDEN G AND JENKINSON DS. 1985. Chloroform fumigation and the release of soil nitrogen: A rapid direct extraction method to measure microbial biomass nitrogen in soil. Soil Biol Biochem 17: 837-842.

BROOKES PC, POWLSON DS AND JENKINSON DS. 1982. Measurement of microbial biomass phosphorus in the soil. Soil Biol Biochem 14: 319-329.

CARVALHO NS, ROCHA SMB, SANTOS VM, ARAUJO FF AND ARAÚJO ASF. 2018. Soil microbial biomass across a gradient of preserved native Cerrado. Floram 25: e20170536.

CHEN GC, HE ZL AND HUANG CY. 2000. Microbial biomass phosphorus and its significance in predicting phosphorus availability in red soils. Commun Soil Sci Plan 31: 655-667.

CLEVELAND C AND LIPTZIN D. 2007. C:N:P stoichiometry in soil: is there a ‘Redfield ratio’ for the microbial biomass? Biogeochemistry 85: 235-252.

COUTINHO LM. 1978. O conceito de Cerrado. Rev Bras Bot 1: 17-23.

CRISTINA A, TEODORO M AND LUIS VG. 2010. Microbial C, N and P in soils of Mediterranean oak forests: influence of season, canopy cover and soil depth. Biogeochemistry 101: 77-92.

EATON W AND CHASSOT O. 2012. Characterization of soil ecosystems in Costa Rica using microbial community metrics. Trop Ecol 53: 25-36.

EMBRAPA - EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA. 1999. Manual de análises químicas de solos, plantas e fertilizantes. Embrapa, Brasília.

FAZHU Z, JIAO S AND CHENGJIE R. 2015. Land use change influences soil C, N, and P stoichiometry under “Grain-to-Green Program” in China. Sci Rep 5: 10195.

FIERER N AND JACKSON RB. 2006. The diversity and biogeography of soil bacterial communities. Proc Natl Acad Sci USA 103: 626-631.

GNANKAMBARY Z, ILSTEDT U, NYBERG G, HIEN V AND MALMER A. 2008. Nitrogen and phosphorus limitation of soil microbial respiration in two tropical agroforestry parklands in the south-Sudanese zone of Burkina Faso: The effects of tree canopy and fertilization. Soil Biol Biochem 40: 350-359.

HAMMER Ø, HARPER DAT AND RYAN PD. 2001. Past: Paleontological Statistics Software package for education and data analysis. Palaeontol Electron 4: 9.

HEDO J, LUCAS-BORJA ME, WIC C, ABELLÁN MA AND LAS HERAS J. 2014. Soil respiration, microbial biomass and ratios (metabolic quotient and MBC/TOC) as quality soil indicators in burnt and unburnt Aleppo pine forest soils. J For 1: 20-28.

HEUCK C, WEIG A AND SPOHN M. 2015. Soil microbial biomass C:N:P stoichiometry and microbial use of organic phosphorus. Soil Biol Biochem 85: 119-129.

HUNGRIA M, FRANCHINI JC, BRANDÃO-JUNIOR O, KASCHUK G AND SOUZA RA. 2009. Soil microbial activity and crop sustainability in a long-term experiment with three soil-tillage and two crop-rotation systems. App Soil Ecol 42: 288-296.

JIMÉNEZ JJ, LORENZ K AND LAL R. 2011. Organic carbon and nitrogen in soil particle–size under dry tropical forests from Guanacaste, Costa Rica – implications for within site soil organic stabilization. Catena 86: 178-191.

JOERGENSEN RG, KUBLER H, MEYER B AND WOLTERS V. 1995. Microbial biomass phosphorus in soils of beech (*Fagus sylvatica*) forests. Biol Fert Soils 19: 215-219.

LAMB EG, KENNEDY N AND SICILIANO SD. 2011. Effects of plant species richness and evenness on soil microbial community diversity and function. Pl Soil 338: 483-495.

LIU ZP, SHAO MA AND WANG YQ. 2013. Spatial patterns of soil total nitrogen and soil total phosphorus across the entire Loess Plateau region of China. Geoderma 197: 67-78.

MARINARI S, MANCINELLI R, CAMPIGLIA E AND GREGO S. 2006. Chemical and biological indicators of soil quality in organic and conventional farming systems in Central Italy. Ecol Indic 6: 701-711.

MATSUOKA M, MENDES IC AND LOUREIRO MF. 2003. Biomassa microbiana e atividade enzimática em solos sob vegetação nativa e sistemas agrícolas anuais e perenes na Região de Primavera do Leste (MT). Braz J Soil Sci 27: 425-433.

MENDES IC, FERNANDES MF, CHAER GM AND JUNIOR FBR. 2012. Biological functioning of Brazilian Cerrado soils under different vegetation types. Pl Soil 359: 183-195.

NARDOTO GB, BUSTAMANTE MMC, PINTO AS AND KLINK CA. 2006. Nutrient use efficiency at ecosystem and species level in savanna areas of Central Brazil and impacts of fire. J Trop Ecol 22: 191-201.

OLIVEIRA MEA, MARTINS FR, CASTRO AAJF AND SANTOS JR. 2007. Classes de cobertura vegetal do Parque Nacional de Sete Cidades (transição campo-floresta) utilizando imagens TM/Landsat, NE do Brasil. In: Simpósio Brasileiro de Sensoriamento Remoto, 13. Florianópolis. Anais (Proceedings) 13: 1775-1783.

OUYANG S, XIANG W, GOU M, LEI P, CHEN L, DENG X AND ZHAO Z. 2017. Variations in soil carbon, nitrogen, phosphorus and stoichiometry along forest succession in southern China. Biogeoscience e408: 1-27.

PAUL EA. 2006. Soil microbiology, ecology, and biochemistry, 3rd ed., Academic press, London.

REATTO A, CORREIA JR, SPERA ST AND MARTINS ES. 2008. Solos do Bioma Cerrado: aspectos pedológicos. In: Sano SM, Almeida SP and Ribeiro JF (Eds), Cerrado: Ecologia e Flora. Planaltina: Embrapa, p. 109-149.

RHEINHEIMER RS, ANGHINONI I AND CONTE E. 2000. Fósforo da biomassa microbiana em solos sob diferentes sistemas de manejo. Braz J Soil Sci 24: 589-597.

SAMPAIO DB, ARAÚJO ASF AND SANTOS VB. 2008. Avaliação de indicadores biológicos de qualidade do solo sob sistemas de cultivo convencional e orgânico de frutas. Ci Agrotec 32: 353-359.

SANTOS VB, CASTILHOS DD, CASTILHOS RMV, PAULETTO EA, GOMES AS AND SILVA DG. 2004. Biomassa, atividade microbiana e teores de carbono e nitrogênio totais de um planossolo sob diferentes sistemas de manejo Rev Bras Agro 10: 333-338.

SMITH JL AND PAUL EA. 1990. The significance of microbial biomass estimations. In: Bollag JM and Stozky G (Eds), Soil biochemistry. New York, Marcel Decker, p. 357-396.

SOMMERS LE AND NELSON DW. 1972. Determination of Total Phosphorus in Soils: A Rapid Perchloric Acid Digestion Procedure. Soil Sci Soc Am J 36: 902-904.

SOUSA RF, BRASIL EPF, FIGUEIREDO CC AND LEANDRO WM. 2015. Soil microbial biomass and activity in wetlands located in preserved and disturbed environments in the Cerrado biome. Biosci J 31: 1049-1061.

SPARLING GP. 1992. Ratio of microbial biomass carbon to soil organic carbon as a sensitive indicator of changes in soil organic matter. Austr J Soil Res 30: 195-207.

TISCHER A, POTTHAST K AND HAMER U. 2014. Land-use and soil depth affect resource and microbial stoichiometry in a tropical mountain rainforest region of southern Ecuador. Oecologia 175: 375-393.

VANCE ED, BROOKES PC AND JENKINSON DS. 1987. An extraction method for measuring soil microbial biomass. C Soil Biol Biochem 19: 703-707.

XU X, THORNTON PE AND POS WM. 2013. A global analysis of soil microbial biomass carbon, nitrogen and phosphorus in terrestrial ecosystems. Global Ecol Biogeogr 22: 737-749.

YEOMANS JC AND BREMNER JM. 1998. A rapid and precise method for routine determimation of organic carbon in soil. Comm Soil Sci Pl Anal 19: 467-1476.