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ECOSYSTEMS

Decomposition of leaf litter in the Brazilian savanna on limestone and sandstone Neosols

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Abstract: Litter decomposition in the soil is an important stage of the nutrient cycling process that interferes with functioning of terrestrial ecosystems. Soil fertility and litter nutritional quality are fundamental factors that affect decomposition efficiency of plant residues. We evaluated decomposition in two areas of 'cerrado *sensu stricto*', each with a type of Neosol – limestone (eutrophic) and sandstone (dystrophic). In a rural area located in the municipality of Ituiutaba (MG, Brazil), 10 plots were randomly selected to install litter bags with 10 g of mixture of dry leaves that were used to estimate rate and time of leaf-litter decomposition from October/2015 to January/2016. Decomposition rate in the limestone cerrado was significantly higher than in the sandstone cerrado. This difference mustn't be explained by the edaphic texture between areas, since it was similar between them. But may be explained through aluminum absence and higher soil fertility in the limestone cerrado, especially phosphorus that is highly limiting in dystrophic cerrados like the sandstone cerrados, in which decay of decomposing leaf-litter was directly proportional to the levels of phosphorus. Limestone presence reduces aluminum toxicity and circumvent phosphorus limitation in the cerrado, favoring decomposition. Such influence is probably an important feature for limestone cerrados.

Key words: Calcium, carbonatic, decomposition, nutrient cycling, soil.

INTRODUCTION

The production, decomposition and release of nutrients from the litter deposited on the soil surface constitute different stages of the nutrient cycling process that interferes with the functioning of terrestrial ecosystems (Berg & McClaugherty 2014, Schilling et al. 2016). This natural process protects the soil against erosion, alters the structural quality of the soil, increases the water retention capacity and restores considerable amounts of nutrients to vegetation (Nardoto et al. 2006).

The litter decomposition in the soil is an important stage with specific functions, such as recycling of nutrients available for plant reabsorption (Nardoto et al. 2006), and promotion of CO_2 flow between soil, plant and air compartments (Schilling et al. 2016). The efficiency of decomposition is estimated by litter decay rates that are sensitive to changing conditions in the environment (Peña-Peña & Irmler 2016), such as humidity and temperature (Wall et al. 2008), levels of organic matter in the soil and carbon in the vegetation (Loss et al. 2013) and, especially, soil fertility and litter nutritional quality (Makkonen et al. 2012). Availability of each nutrient and their allocation by plants are related (Jobbagy & Jackson 2001) and, generally, higher soil fertility result in both higher litter's nutrients concentrations (Rossatto et al. 2015) and greater detritivores performance

(Seastadt 1984). In savanna ecosystems, the soils are commonly highly weathered (Bustamante et al. 2012), which can make it difficult the understanding of the plant activity (Jobbagy & Jackson 2004). Besides, these soils contain low cation and base exchange capacity (Solbrig 1996), presenting relative low fertility for plants and decompositors when compared to soils of ecosystems with more biomass productivity, as forests (Paiva et al. 2015).

In Brazil there is the cerrado, which although contains tropical grasslands and seasonal tropical forest, it is mostly understood by savannas (Batalha 2011), and so, it is also known as Brazilian savanna. One of the main savannic physiognomies of the cerrado is the "cerrado *sensu stricto", a* vegetation dominated by trees and interspersed shrubs, with abundant herbaceous strata (Oliveira & Marquis 2002), usually with soils exposed to sun, leaching and nutrients depletion processes (Silva et al. 2013), causing low leaf-nutrients concentration in plants (Rossatto & Franco 2017). This, in turn, may produce low litter nutritional quality (Kozovits et al. 2007), contributing to a slow decomposition rate in Cerrado (Scalon et al. 2017). However, studies on litter decomposition in Cerrado areas are scarce (Peña-Peña & Irmler 2016). The given dystrophic condition in the Cerrado mainly occurs on deep soils (Latosols) (Gottsberger & Silberbauer-Gottsberger 2006), in contrast to a smaller portion of cerrado formed on shallow soils with rock outcrops (Neosols), that can be poor or rich in nutrients (Reatto et al. 1998).

In order to test if same vegetation type in cerrado on eutrophic and dystrophic edaphic conditions differs in relation to decomposition efficiency, we evaluated the decomposition of two "cerrado *sensu stricto*" areas, one on limestone Neosol and another over sandstone Neosol. Such areas were classified, respectively, as eutrophic and dystrophic, and had the nutritional quality of the litter measured by Alves et al. (2018). Once the presence of limestone in the soil enhances the pH and the cation exchange capacity in the edaphic solution (Vitti et al. 2015), we evaluated whether the litter decay rates in the limestone are greater than in the expect that the nutrients will be more accessible to plant in "limestone cerrado" and, consequently, that leaf-litter decomposition will be higher than "sandstone cerrado". Furthermore, through this study, we ponder whether limestone may be a relevant feature to be considered in descriptions of cerrado ecosystems, since it is an uncommon edaphic type for formations of the "cerrado *sensu stricto*" and it may reflect in a distinctive decomposition.

MATERIALS AND METHODS

Experimental design

The study took place in two contiguous areas of "cerrado *sensu stricto*" (~50 ha each one) one in a limestone Neosol ("limestone cerrado") (19°03'438"S - 49°26'422"W) (hereafter called as area 1) and another one in an sandstone Neosol ("sandstone cerrado") (19°03'633"S - 49°26'075"W) (area 2). The edaphic fertility these areas were measured by Alves et al. (2018) and were classified, respectively, as eutrophic and dystrophic according to EMBRAPA (2006) criteria. More details about the soils of the study areas and content of nutrients in the leaf-litter can be found in Alves et al. (2018). Along the study areas, three 100 m transects separated by a distance of 50 m from each other were defined. Twenty contiguous plots (100 m²) were established along each transect, totalizing in 60 plots per area. From the 60 plots, 20 were randomly selected for soil analysis, sampled from 15 randomized points in each of them (0.2 m depth) from 15 randomized points in each plot of 100 m² per area (see Alves et al. 2018 for more experimental design details). Once the edaphic texture is also a factor that influences the decomposition (Berg & McClaugherty 2014), in this study, we evaluated the soil textural classes (coarse and fine sand, silt and clay) following the Embrapa's protocol (1997). The soil edaphic texture of each area was classified through mean values of all the soil samples for each soil class and Ribeiro's et al. (1999) criteria.

Considering that each litter component vary in relation to chemical composition and decomposition rate (Cianciaruso et al. 2006), and that leaves are the main litter component and with fast response to climatic variables (Liu et al. 2004), we standardize the use of only leaves (leaf-litter) in the method of litter-bags. We use such method, which despite having its limitations, allows us to compare treatments (e.g., sites) by statistical procedure and to infer trends characteristic of unconfined decomposing litter over time (Wider & Lang 1982). From the 20 plots of 100 m² used to collect and analyze the soil, we randomly selected 10 plots to set 10 litter-bags on the ground surface of each one, totalizing 100 litter-bags/area. Each bag was filled with 100 of mixture of dead leaves collected from the ground of the sampling plots. Such mixtures homogenized of leaf material from each plot were. All leaf material used on the bags was totally dried in an 85 ºC for 48 hours before placing litter-bags in the field. Even with the possible small impact on the day that litter from areas was collected for all litter-bags, the plots' soil was not unprotected from litter due to our removal.

We performed five samplings from October/2015 to January/2016, corresponding to the wet season of the Cerrado (Bustamante et al. 2012), since the decomposition rate are very slow in "cerrado *sensu stricto*" (Peres et al. 1983) and the moisture increases the decomposition process (Mason 1980, Gurevitch et al. 2009), leading to a significant decay of the biomass of cerrado (Peña-Peña & Irmler 2016). The samplings consisted of the removal of litter-bags of nylon with mesh of 2 mm. We removed one pair of litter-bags per plot from each study area in the intervals of 15, 30, 60, 90 e 120 days (i.e. sampling periods). After the removal of the litter-bags in each sampling period, their leaves were again totally dried in an oven at 85ºC until constant weight and weighted with precision semi-analytical balance to access the average dry mass loss in each area along time of decomposition. Such average dry mass was calculated through the sum of the dry mass loss average of each litter-bag pair of each plot divided by the number of plots/area (n = 10). Since C:N ratio of the litter considerably influences decay rates (Peña-Peña & Irmler 2016), we used the nitrogen information from the same leaf-litter of Alves et al. (2018) and, this study, we extracted in the laboratory the organic carbon through the Yeomans & Bremner (1988) adapted technique, in order to estimate the mean C:N ratio during the total period of the experiment.

Statistical analysis

Besides the classification of the edaphic texture of each area, we verified if the two cerrado areas differed in soil texture (total sand - coarse and fine, silt and clay) through a Student's t test, since the data set met the normality and homoscedasticity assumption (Kolmogorov-Smirnov test, $p > 0.05$ and Levene's test, $p > 0.05$, respectively). In order to describe the leaves decomposition in each area, we applied the following exponential math equation: $Xt = X0.e^{-kt}$. Where Xt is the amount of remaining dry biomass (DB) after sampling period t (i.e. days); Xo is the initial amount of DB and *k* the constant of residual's decomposition (Thomas & Asakawa 1993). With the *k* value, we calculated the half-life time (T ½ life) of the remaining dry mass, using the formula T ½ = 0,693/*k* (Paul & Clark 1996). Such analysis of the decomposition was performed with software SigmaPlot (version 10) and fixed α = 0.05.

We tested simple correlations of Pearson or of Spearman (according to the parameterization of the data) between chemical attributes of soil fertility described in Alves et al. (2018) and total variation of the dry mass decay in the same plots of the litter-bags. Additionally, the same statistical procedure was performed between total mean of the C:N ratio and the total variation of dry mass decay of the litter-bags in the plots of each area. In the case that we attested that the behavior of one variable was significantly correlated with the behavior of another variable, we tested the premises of parameterization, transformed the data if necessary and performed simple linear regression between same variables, as indicated by Volpato & Barreto (2016). For all of these analyzes, we adopted α = 0.05.

RESULTS

Differences and similarities were observed between the "limestone cerrado" (area 1) and the "sandstone cerrado" (area 2) regarding the analyzes performed. Through the mean values for each textural soil class and the Ribeiro's et al. (1999) criteria, the soil in both areas was classified as medium texture (< 350 $g.kg^{-1}$ of clay and > 150 $g.kg^{-1}$ of sand). Furthermore, textural classes were also similar between areas (total sand: t = -1.53, df = 38, p = 0.13; silt: t = 1.39, df = 38, p = 0.17; and clay: t = 0.05, df = 38, p = 0.96). The dry leaf-mass significantly decreased along the sampling periods of decomposition evaluation in both areas. The decomposition in area 1 was higher than in area 2 (Figure 1, Table I). The mean C:N ratio along the 120 days of experiment in area 1 and area 2 were 265.34 and 277.84, respectively. However, the total average of the leaf-litter C:N ratio not correlated with the total variation of dry mass loss in the litter-bags both in the area 1 (Pearson's correlation, r^2 = 0.12, df = 8, p = 0.31) and in the area 2 (Pearson's correlation, r^2 = 0.04, df = 8, p = 0.56).

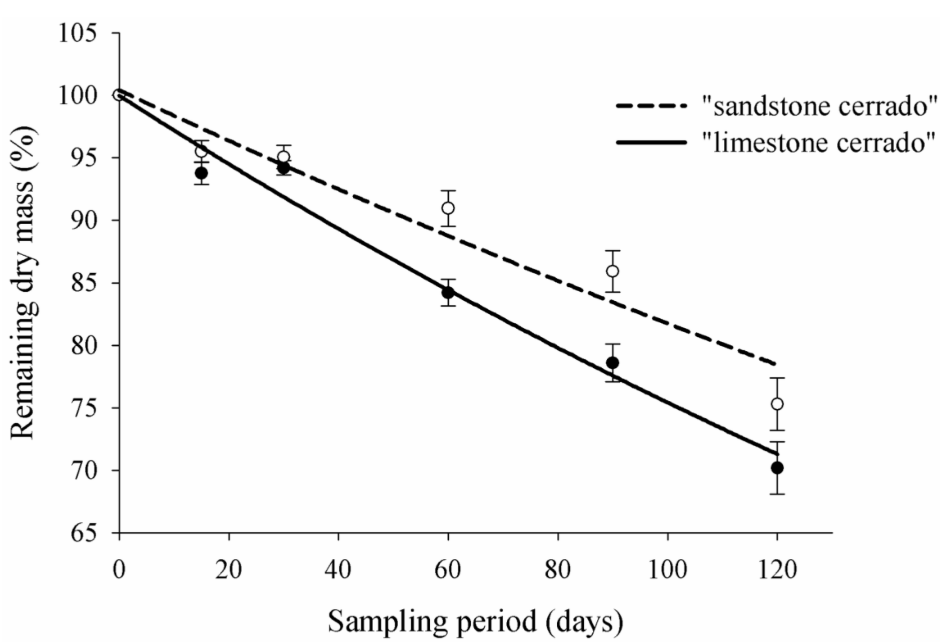

Figure 1. Decomposition of the leaves in the "limestone cerrado" and the "sandstone cerrado" with *X* ± EP. This figure was elaborated in the SigmaPlot (version 10).

In area 1 there was no correlation between total averages of the soil chemical attributes (macronutrients, pH and organic matter) described by Alves et al. (2018) and total variation of dry mass decay of the litter-bags (Table II). In area 2 also there was no correlation between total averages these soil chemical attributes and total variation of dry mass decay of the litter-bags, with exception of phosphorus (P) (Table II). In this case, the variation of the P content in the soil correlated with the variation of the dry weight of the decomposing litter in area 2 (Table II). Moreover, in the subsequent simple linear regression, the dry matter losses were higher where the phosphorus contents in the soil were higher, being that the behavior between the two variables was adjusted in a straight line (Figure 2).

DISCUSSION

In accordance with Villalobos-Vega et al. (2011), the dry mass decay follows an exponential rate along time, a pattern also found in our study, with the significant reduction of plant material in decomposition. The decomposition in area 1 was faster than in area 2 probably because the soil of the "limestone cerrado" contains insignificant levels of aluminum and higher levels of pH, organic matter and macronutrients (P, K, Ca and Mg) in relation to the "sandstone cerrado" soil, mirroring in the contents of macronutrients of leaf-litter from area 1 that, in general, are higher than in area 2 (Alves et al. 2018).

The soil texture influences the availability of water in the soil for microorganisms (Coleman et al. 2004) and, thus, may influence a decomposition. However, mean texture was the same between areas and the difference of decomposition rate shouldn't be explained by the edaphic texture. This indicate that the presence of limestone may influence the decomposition in a chemical level (i.e. nutrients). Within all the macronutrients, we highlight the Ca, which was

Table I. Constant decomposition rate (*k*), half-life (T ½) and coefficient of determination (r^2) of the relationship analysis between leaves of the "limestone cerrado" and "sandstone cerrado".

Areas	Remaining material		
	K	T ½	r^2
	g^{-g}-1	days	
"limestone cerrado"	0,0028	247,5	0,99**
"sandstone cerrado"	0,0021	330	0,97**

** indicate significant differences at α <0.01 for the dry mass decay in the evaluated time.

Table II. Simple correlations between the total averages of chemical attributes of the soil and the total variation of the dry mass decay in the "limestone cerrado" and "sandstone cerrado".

Areas	Macronutrients	Results of the Pearson simple correlations with df = 8	
		r^2-value	p-value
"limestone cerrado"	P	0,05	0,53
	K	0,07	0,46
	Ca	-0,06	0,85
	Mg	0,05	0,53
	M.O.	0,07	0,83
	pH	9,37 e-006	0,99
"sandstone cerrado"	P	0,46	0,03*
	K	0,38	0,27
	Ca	-0,03	0,92
	Mg	0,01	0,78
	M.O.	0,09	0,38
	pH	0,04	0,55

* indicate significant correlation at p < 0.05. Notations: degrees of freedom (df), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), organic matter (M.O.), pH = hydrogen potential.

the one that differed more in the soil and leaf-litter between areas, being its concentrations higher in area 1 (Alves et al. 2018). The Ca, when not being a limiting factor, may contribute to the augmentation of the degradation rate of the lignin by the micro-decomposing community (Berg & McClaugherty 2014). These differences in Ca, together with the higher efficiency of decomposition in area 1 found in our study, may support the negative relation between nutritious quality of the vegetal material and decomposition time (Dahlgren et al. 2003, Moretti et al. 2007). On the other hand, considering the lack of significant correlations tested between the areas, the calcium and almost all other soil fertility attributes described by Alves et al. (2018) may not, in isolation, explain the greater decomposition found in the "limestone cerrado". Additionally, contrary to expectations, the C:N ratios in the leaf-litter of the areas did not explain the difference in decomposition found between the areas. This may be explained by the fact that N is highly mobile and lost in savanna areas, including by burning (Miranda et al. 2002), which can affect an effective use of this macronutrient in the decomposition. Thus, it is more plausible to suggest that in the natural environment it is the set of the chemical attributes in interaction in the eutrophic soil of the area 1 that attracts more decompositors and favors decomposition, when compared to the dystrophic soil of the area 2.

However, still with respect to soil and decomposition differences between areas, it is reasonable to assume interference relation between phosphorus and the decomposition. From our results of simple regression in area 2, it was observed that the variation in the phosphorus content explains 46% of the variation in the decaying dry mass, so that the variables vary linearly and inversely proportional (Figure 2). That is, where there is more P content in the soil, it influences a greater decay of leaf-litter. Indeed, the dystrophic cerrados are highly limited P (Kozovits et al. 2007), so that the P is a limiting factor for decomposition in the "sandstone cerrado", but not in the

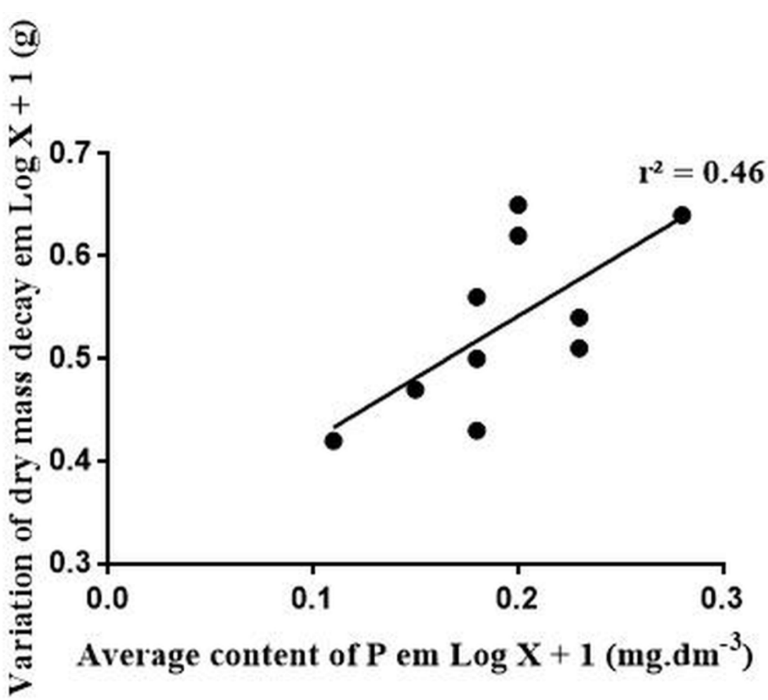

Figure 2. Simple linear regression between total average of P in soil and total variation of dry mass decay in litter-bags considering the 120 evaluation days in the "sandstone cerrado" ($F_{1,8}$ = 6.87, df = 8, p = 0.03).

"limestone cerrado" where the proportion of this macronutrient is greater.

Comparisons of decomposition rate *(k)* and half-life (T ½) of the remaining dry mass with other studies in the Cerrado were not feasible since decomposition is only evaluated with leaves of specific plant species or family (Silva & Vasconcelos 2011, Villalobos-Vega et al. 2011). On the other hand, it is reasonable to carefully discuss the differences in light of other studies with decomposition in plant assemblages of "cerrado" on Latosols that also used litter bags and presented an exponential decay of dry mass within a specific interval of time. There are studies on decomposition efficiency in areas of "cerrado" on Latosols evaluated for a few more months or up to a year (Cianciaruso et al. 2006, Kozovits et al. 2007, Valenti et al. 2008, Freitas et al. 2012, Oliveira et al. 2017). Although it does not claim that decomposition in our areas is higher in relation to the studies of other areas that evaluated the mass rate decay at longer time intervals, we can, in a relative sense, that the "limestone cerrado" presented dry mass rate decay similar to that found by Freitas et al. (2012) and Valenti et al. (2008). Besides, the "limestone cerrado" presented half of decay found by Oliveira et al. (2017), and also an explained variation (decay) of the dry mass (r^2 estimated) higher than from Cianciaruso et al. (2006). The differences in the dry mass decay may result from differences edaphic fertility, since that available quantity of nutrients in the soil tends to limit the leaf level processes (Scalon et al. 2017). According to Oliveira et al. (2017), plants of "cerrado" that live in environments with low nutrient availability are highly efficient in the use and conservation of nutrients, which can influence dead tissues to have low nutrients concentrations (Haridasan 2005). Besides that, the low relative concentrations of P that occur in dystrophic Latosols contribute to lower content of P and slower dry mass decay (Kozovits et al. 2007, Jacobson & Bustamante 2014).

We conclude that the natural occurrence of limestone outcrop, by favoring higher nutrients contents in the soil and in leaf mass, promotes higher efficiency in leaf-litter decomposition, when compared to sandstone outcrop. This same difference may occur to other "cerrados" on dystrophic Latosols, but this must be evaluated with more detailed studies. Moreover, we reinforce the importance of more studies characterizing "cerrados" on Neosols in the region of "Triângulo Mineiro", especially on those with evident influence of limestone.

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Vinícius N. Alves and Marcelo H.O. Pinheiro participated of the study conception. Vinícius N. Alves, Marcelo H.O. Pinheiro and Danila G. Bertin participated of the theoretic fundamentations. Vinícius N. Alves, Marcelo H.O. Pinheiro and Danila G. Bertin performed the field work. Vinícius N. Alves, Danila G. Bertin, Douglas S. Santos, Beno Wendling and Regina M.Q. Lana performed the laboratory analyses. Vinícius N. Alves and José L.R. Torres performed the statistical analyses. Marcelo H.O. Pinheiro, Beno Wendling and Regina M.Q. Lana participated of the study resources. Marcelo H.O. Pinheiro participated of the study supervision. Vinícius N. Alves wrote the original draft. Marcelo H.O. Pinheiro, Vinícius N. Alves, Danila G. Bertin, Douglas S. Santos, José L.R. Torres, Regina M.Q. Lana and Beno Wendling participated of the review & editing. All authors approved the final version of the manuscript.