DECOMPOSITION OF LEAF LITTER IN THE BRAZILIAN CERRADO, CERRADÃO AND FOREST ENVIRONMENTS IN THE AMAZON, BRAZIL

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Resumo

Decomposição de serapilheira foliar em ambientes de cerrado, cerradão e floresta na Amazônia, Brasil. Os solos da região amazônica, apesar de estarem sob uma das florestas mais densas do mundo, são caracterizados, na sua maioria, pela baixa disponibilidade de nutrientes, sendo a serapilheira a principal via de entrada de nutrientes. O presente trabalho objetivou avaliar a decomposição da serapilheira em ambientes: floresta, cerrado e cerradão na Amazônia. A estimativa da taxa de decomposição da serapilheira foi feita pela análise de perda de massa utilizando-se *litter bags*. As coletas foram realizadas nos intervalos de 30, 60, 90, 120, 150, 180, 210, 240, 270 e 300 dias, com quatro repetições. Após coletado, o material contido em cada *litter bag* foi colocado para secar para a obtenção da massa seca. E assim, estimados o percentual de massa remanescente, as taxas de decomposição (k) e o tempo de meia-vida ($t_{1/2}$). Ao longo do período estudado, o ambiente de cerrado foi o que apresentou menor constante k (0,0017 g g^{-1} dia^{-1}) e consequentemente maior tempo de meia vida (407 dias). Dentre os ambientes avaliados, a floresta apresentou maior velocidade de decomposição e o cerrado a menor. Ficou evidenciado que o processo de decomposição para todos ambientes estudados ocorreu com maior intensidade no período chuvoso.

Palavras–chave: Ciclagem de nutrientes; Fertilização natural; Matéria orgânica.

Abstract

The soils of the Amazon region, despite being under one of the densest forests in the world, are mostly characterized by low nutrient availability, with litter being the main nutrient input route. The present work aimed to evaluate the litter decomposition in forest, C*errado* and C*erradão* environments in the Amazon. The litter decomposition rate was estimated by mass loss analysis using litter bags. The collections were performed at intervals of 30, 60, 90, 120, 150, 180, 210, 240, 270 and 300 days, with four replications. Once collected, the material contained in each litter bag was placed to dry to obtain the dry mass. And so, the remaining mass percentage, the decomposition rates (k) and the half-life time ($t_{1/2}$) are estimated. During the studied period, the C*errado* environment presented the lowest constant k (0.0017 g g^{-1} day^{-1}) and consequently longer half-life (407 days). The monthly deposition in C*errado* input ranged from Mgha^{-1}mother^1 (June to September). Among the evaluated environments, the forest presented the highest decomposition speed and C*errado* presented the lowest one. It was evidenced that the decomposition process for all studied environments occurred with greater intensity in the rainy season.

Keywords: Nutrient cycling; Natural fertilization; Organic matter.

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INTRODUCTION

Amazonian ecosystems are predominantly characterized by highly weathered and low fertility soils (Campos *et al.*, 2012b), with litter being the main input route for nutrients (SILVA *et al.*, 2009), as this controls the amount available that returns to the ground. This occurs due to nutrient cycling, which promotes the deposition and decomposition of plant material, enabling plant growth in soils with low nutritional contents. Thus, through the deposition of organic material and its decomposition, moderately high amounts of nutrients are made available for new annual plant growth (VIEIRA *et al.*, 2010)

Furthermore, the evaluation of litter accumulated on the soil can provide important information regarding its decomposition processes and even the biological activity in the forest soil. The amount of litter that remains on the ground is a result of the inflows and outflows of organic material, that is, how much remains in the soil, what was deposited as litter (ALMEIDA *et al.*, 2015).

Hereupon, several studies have highlighted the importance of litter for the conservation and natural maintenance of forests, which can be used to detect disturbances of natural and anthropogenic origins (MENEZES *et al.*, 2010; RIBEIRO *et al.*, 2017; PERES *et al.*, 2017; PERES *et al.*, 2017; *et al.*, 2021). In a context focused on nutrient cycling, litter decomposition rates and soil nutrient release have been studied in a wide variety of forests, with more than 1,000 studies carried out around the world, indicating its importance for forest maintenance (Prescott, 2005).

However, the Amazon region has a large extension and consequently a great diversity of vegetation features, making it difficult to characterize the nutrient cycling process via litter decomposition. However, with soil organic matter being one of the main responsible for the potential of nutrients available for plants in the Amazon, studies on litter decomposition are of great importance for understanding the natural soil fertilization process (LIEBSCH; MIKICH, 2008).

In the western most part of the Amazon, there are different phytophysiognomies, from dense forests to natural fields in the southern region of Amazonas state and northern Rondônia state. A more detailed look is necessary because, despite the contribution of natural fertilization (nutrient cycling) of these soils, there are few studies related to litter decomposition in these environments. Therefore, the objective of this work was to evaluate litter decomposition in the forest, Cerrado and Cerradão environments in the Amazon.

MATERIAL AND METHODS

The study was carried out in three areas: Forest, Cerrado and Cerradão, which are located in the municipality of Humaitá, southern Amazonas state, on the banks of the road BR - 319, in an area belonging to the 54th Infantry Battalion of the Brazilian Army (Figure 1) , the three areas are approximately 1.5 km apart.
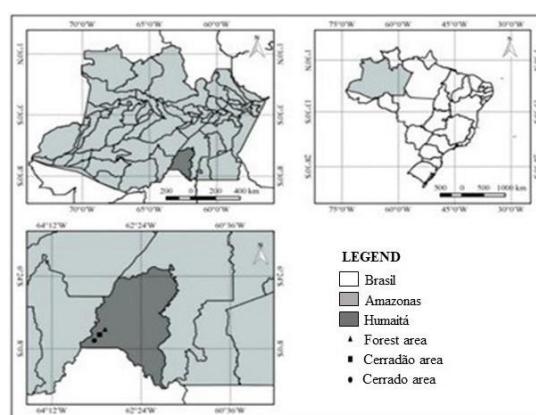

Figure 1. Location of the study areas. Map of Brazil, highlighting the state of Amazonas and the study areas in the map of the municipality of Humaitá – AM state.
Figura 1. Localização das áreas de estudo. Mapa do Brasil, destacando o Estado do Amazonas e as áreas de estudo no mapa do município de Humaitá – AM.

The forest is located in the highest and best draining areas of the landscape, functioning as a watershed, and presenting a dense forest physiography (CAMPOS *et al.*, 2012b). Cerrado exhibits a more uniform formation, composed of lower trees (CAMPOS *et al.*, 2012b), and suffers a lot from fire pressure in the dry period, which is a frequent event that influences the vegetation dynamics. According to Raw; Hay (1985), the origin of fire can be associated with natural, fortuitous (due to the degree of ignition) or accidental causes. The degree of ignition depends on several local, physical and even historical factors such as water deficit, duration of the dry period, vegetation structure and degree of intermittence of the event. The combination of these factors makes each area present different susceptibility to fire (Geraldinho *et al.*, 2010).

Finally, Cerradão presents a predominant physiognomy, the arboreal-shrubby component, it is a thinner and weaker forest, characterized by the presence of species that occur in Cerrado in the restricted sense and also by forest species, from the point of physiognomic view is a forest, but floristically it is more similar to a Cerrado (GALETTI *et al.*, 2010).

The source material of the soils in these regions comes from alluvial sediments, which chronologically originate from the Holocene. The soils have low natural fertility and are located in areas of flat, gently undulating relief. They are characterized by the presence of plinthite and/or concretions, are imperfectly drained and have excess water during a period of the year, which generally occurs at the time of highest rainfall in the region (BRASIL, 1978).

Regarding to climatic characterization, the climate of the region according to Köppen's classification belongs to group A (Tropical Rainy Weather) and climatic type Am (monsoon type rain), presenting a dry period of short duration, with average annual precipitation ranging between 2,200 and 2,800 mm (BRASIL, 1978). These high totals are the result of atmospheric circulation and the dynamics of the systems that act on the region, which, consequently, generate the convective rains that are common in the Amazon.

The annual averages of temperature vary around 25ºC and 27ºC and the relative humidity of the air varies between 85% and 90% (BRASIL, 1978). The rainy season occurs between October and March and the dry season occurs between June and August, considering the rest of the months as a transition period (Figure 2). The estimate of the litter decomposition rate was made by analyzing the loss of mass using litter bags, which allow the direct analysis of the rate of decay, through the loss of leaf mass throughout the experiment (SCORIZA *et al.*, 2012).
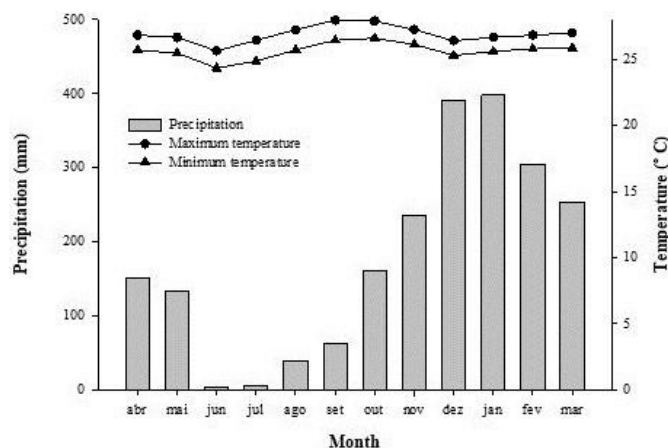

Figure 2. Total precipitation data from april 2018 to march 2019, obtained at the municipal weather station of Humaitá – AM state. Source: INMET. National Institute of Meteorology.
Figura 2. Dados de precipitação total de abril de 2018 a março de 2019, obtidos na estação climatológica do município de Humaitá – AM. Fonte: INMET. Instituto Nacional de Meteorologia.

Thirty (30) litter bags were randomly distributed in each study area (approximately 1 ha), close to where the conical collectors were installed (April 2018), simulating the natural fall of the litter-forming material. The litter bags consisted of a shading screen (50% shade) with 4 mm of mesh and dimensions of 25 x 25 cm and 1.5 cm in height. In each litter bag, 10 grams of material were inserted into the conical collectors after this material had been dried in an oven at 45ºC for 48 hours. Litter bags were collected monthly at intervals of 30, 60, 90, 120, 150, 180, 210, 240, 270 and 300 days after installation, with three repetitions for each collection.

After being collected, the material contained in each litter bag was cleaned with a brush (to remove soil particles and possible organisms adhering to the leaves) and placed to dry in an air circulation oven at 45ºC to obtain the dry mass. Afterwards, the material was weighed to obtain the remaining mass. The percentage of remaining mass (%R) was obtained by the relationship between the final mass and initial mass, with the following formula:

Remaining mass (%) = (final mass/initial mass) x 100

After calculating the remaining mass over the period, the decomposition constant K was estimated according to Asakawa (1993), using the following exponential model:

$$Xt = X0 \cdot e^{-kt}$$

Where: Xt is the weight of material remaining after t days.
X0 is the weight of dry material originally placed in the bags at time zero (PI=10g).
K is the decomposition constant estimated by the equation.

Through this exponential model, the constant k value was determined for each of the study areas, which indicates the rate of decomposition of the litter layer accumulated on the soil. This exponential model, as well as the curves that characterize the weight loss (decomposition) of leaf litter, were made with the aid of the SIGMPLOT program. The half-life time (T1/2) of this material was calculated according to Rezende *et al.* (1999), by the equation:

$$T1/2 = \ln(2) \, k$$

Where k is the decomposition constant estimated by the program mentioned above. After obtaining the data, when possible, they were compared using the Tukey t test at 5% probability, in order to verify which environment had the greatest decomposition and thus evaluate the factors to which this is linked.

RESULTS

Table 1 presents the data involving the half-life and the values of the decomposition constant that will be discussed throughout the material. During the study period, the Cerrado environment was the one with the lowest k constant (0.0017 g g-1 day-1) and consequently the longest half-life (407 days). Thus, presenting a lower decomposition rate, followed by Cerradão (0.0023 g g-1 day-1 and 301 days) and forest (0.0036 g g-1 day-1 and 192 days). Thus, it is possible to infer that Cerrado will require more time for the nutrients to be made available to the soil, requiring 407 days to decompose half of the leaf material.

Table 1. Values (n = 4) of litter decomposition constant (K) and half-life ($t^{1/2}$) in the different study areas.

Tabela 1. Valores (n= 4) de constante de decomposição (K) e tempo meia vida ($t^{1/2}$) da serapilheira nas diferentes áreas de estudo.

Areas	Constant K (g.g^{-1}.dia^{-1})	Half life (dias)	R²
Cerrado	0,0017	407	0,8712
Cerradão	0,0023	301	0,8998
Forest	0,0036	192	0,8372

n: number of repetitions.

Regarding the remnant mass, it is observed in Table 2, that Cerrado and forest differed significantly in the first 30 days after the installation of litter bags, with decomposition occurring with greater intensity in the forest area, which had a lower remnant percentage (89.4%), while in the Cerrado and Cerradão áreas, the remaining material was 97.7 and 95.6%, respectively. The rapid decomposition in the first 30 days in the forest may be related to greater loss of nutrients and better palativity of debris, which tend to be greater in the first month.

Table 2. Remaining leaf biomass of leaves (g) present in the *litter bags* at 0, 30, 60, 90, 120, 150, 180, 210, 240, 270, 300 days from may 2018 to february 2019 in *Cerrado, Cerradão* and forest areas in the Amazon, Brazil.

Tabela 2. Biomassa foliar remanescente das folhas (g) presentes nos *litter bags* aos 0, 30, 60, 90, 120, 150, 180, 210, 240, 270, 300 dias no período de maio de 2018 a fevereiro de 2019 em áreas de Cerrado, Cerradão e floresta na Amazônia, Brasil.

Period (days)	Decomposition Cerrado	Decomposition Cerradão	Decomposition Forest
0	100% a	100% a	100% a
30	97% a	95% ab	89% b
60	96% a	95% a	85% b
90	97% a	95% a	86% a
120	93% a	9,0% a	85% a
150	90% a	85% ab	79% b
180	84% a	79% a	74% a
210	82% a	74% a	62% b
240	70% a	66% a	49% a
270	60% a	55% a	35% b
300	65% a	49% b	30% c

The means were compared with each other by the Tukey test; means followed by the same letter on the line do not differ from each other by the Tukey test at 5% probability.

It is also noted that over the months the forest presented the lowest percentage of remaining mass, differing significantly from the other areas at 60, 210, 270 and 300 days. However, Cerrado and Cerradão did not differ significantly from each other, except at 300 days of evaluation (Table 2). In the forest, the leaf material decomposition process occurred with greater intensity after 240 days of study (January), with a loss of 14%. While for Cerrado and Cerradão, the greatest losses were registered at 270 days of study (February), with losses of 10 and 11% respectively. During this period, the highest rainfall in the region was recorded (Figure 2). At the end of the experiment, the forest decomposed 70% of its initial total mass (10 g), while Cerrado and Cerradão decomposed, respectively, 35 and 50% of the mass (10 g) (Table 2).

In Figure 3, the curves that simulate the leaf litter decomposition model in the different environments studied are presented, obtained by adjusting the negative exponential model, which had regression indices between 0.8372 and 0.8998. The exponential model proved to be adequate to explain the mass loss pattern of the litter leaf fraction for the three environments. The decomposition curves, obtained by adjusting the model (Figure 3), show a more accentuated pattern of mass loss for the forest, in relation to Cerrado and Cerradão, and it is possible to

identify a small slope of its curve, which indicates that the forest decomposition process is more accelerated in relation to the other studied areas.
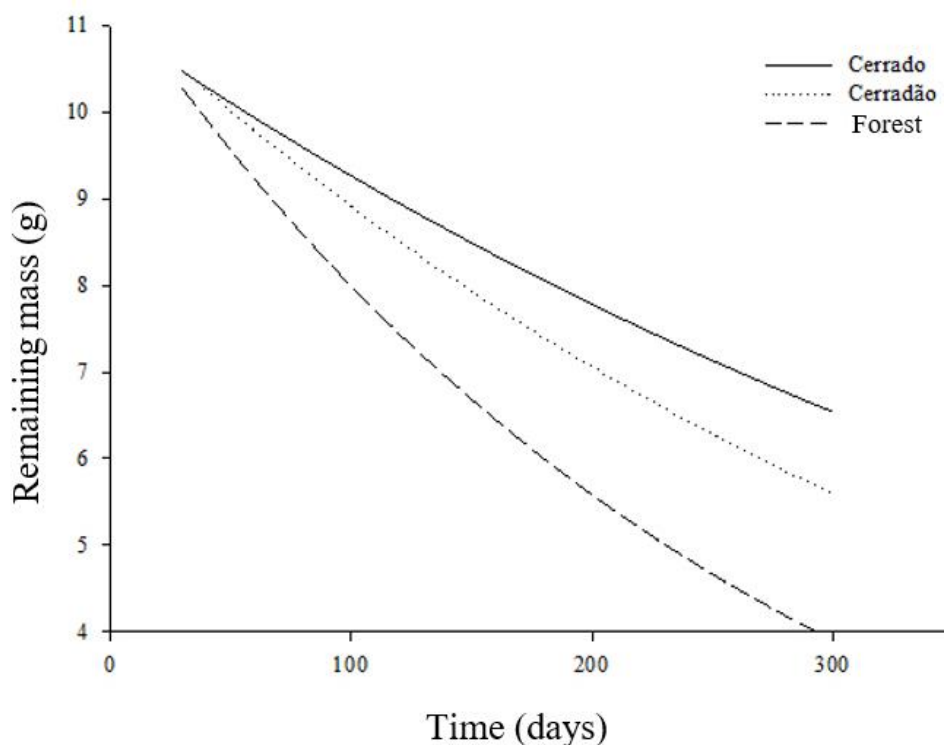

Figure 3. Litter decomposition curve in C*errado, Cerradão* and forest environments in the Amazon - Brazil.
Figura 3. Curva de decomposição da serapilheira em ambientes de Cerrado, Cerradão e floresta na Amazônia-Brasil.

DISCUSSION

According to Barbosa *et al.* (2017), the longer the half-life, the longer it takes for the leaf material to decompose, so Cerrado will be the environment with the longest decomposition process. The values of K observed in this study can be considered low because, according to Waring and Schlesinger (1985), the litter decomposition rates are considered fast if the decomposition coefficients in the condition of dynamic equilibrium (K) are greater than 1.0. For Fernandes and Matricardi (2015), a value for constant K above 1.15 suggests a rapid reuse of nutrients by the vegetation.

However, it is noted that in the literature there is a large number of studies that point values lower than 1. This fact reflects the great variability of nutrient cycling strategies in tropical systems and the impossibility of defining standards for them. Giácomo *et al.* (2012), studying the contribution and decomposition of litter in Cerradão, found values of 0.040 for K, which is different from the one found in the present study (Table 1). Differences in litter decomposition rate between different physiognomies can be attributed to the type of vegetation cover, material quality, soil fauna activity and environmental conditions, especially temperature and humidity (Santana, Souto, 2011). As the composition and quality of the material change over time (CIANCIARUSO *et al.*, 2006). Thus, the more attractive and palatable the substrate, the greater and more efficient the action of the decomposing community on it.

The litter decomposition process can be divided into two stages, in the first stage, the soluble elements and non-lignified carbohydrates are rapidly degraded, while in the second stage, which involves lignified carbohydrates and lignin itself, it generates a gradual decline in the decomposition rate (Bauer *et al.*, 2017). Between 30 and 120 days of evaluation of the litter decomposition estimate, a low reduction in dry matter was observed (Table 2), this fact may be related to the permanence of compounds more resistant to microbial attack, after the rapid initial decomposition of the fraction more easily decomposed (SILVA *et al.*, 2014). This slow decomposition may also be due to the mechanism of adsorption, stabilization of metabolites and a drop in soil biomass.

In addition, this interval corresponds to the dry period in the study regions. In the dry period, the decomposition is slower due to a decrease in soil moisture (water deficit) and consequently a reduction in the

amount of soil organisms, which in turn are essential in nutrient cycling (ZARDO, 2010). The decomposition process occurred with greater intensity from 150 days after the installation of litter bags (Table 2), that is, times when rainfall was higher (Figure 2).

According to Pereira *et al.* (2013), the rainy season provides very favorable moisture conditions for an intense activity of decomposers, both micro-decomposers and macro-arthropods, which remove litter and which seem to be more affected by adverse moisture conditions during the dry season or part of it, as well as seasonal variations can cause changes in the decomposition rates of the material, which justifies the results observed in the present study. Therefore, the period with the lowest occurrence of rainfall negatively influenced the microbiological activity of the soil, decreasing the rate of decomposition of plant material.

The decomposition in Cerrado and Cerradão was more intense in this study (Table 2) than that one recorded by Silva *et al.* (2007) in a Cerrado restricted sense in the Federal District (32% of the initial mass) and Cianciaruso *et al.* (2006) in a Cerradão in São Paulo (43% of the initial mass). The fact that the decomposition process over time follows an exponential-type curve indicates that decomposition is not constant over time, since it is linked to various environmental and chemical-physical factors of the material itself (CIANCIARUSO *et al.*, 2006) Such as: vegetation type, latitude, altitude, temperature, precipitation, light availability, day length, evapotranspiration, relief, general stage, water availability, soil nutrient stock, biota diversity (macro and micro), diversity of plant material, litter chemical quality (lignin and polyphenol content, C/N, C/P ratio, lignin/N, polyphenols/N and lignin + polyphenols/N), nutrient concentration and atmospheric CO_2 concentration and deposition of nitrogen.

As the climate conditions of the three areas studied are similar, it is suggested that the greatest loss of dry matter verified in the forest is related to the quantity and quality of leaf material deposited in the soil, or even to the characteristics of the decomposing population (BARBOSA *et al.*, 2017), as shown in figure 3.

CONCLUSIONS

- Among the evaluated environments, the forest presented a decomposition rate twice as fast as that one of Cerrado, showing that Cerrado will require more time for nutrients to be made available to the soil;
- It was evidenced that the decomposition process for all studied environments occurred with greater intensity in the rainy season, that is, from 150 days after the installation of litter bags.

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