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Original Article

Accumulation and decomposition of cultural residues of *Theobroma grandiflorum*, *Paullinia cupana*, *Bixa orellana* and forest in the southern region of Amazonas

Acúmulo e decomposição dos resíduos culturais de cupuaçu, guaraná, urucum e floresta na região sul do Amazonas

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Abstract

The litter deposited on the soil surface at various stages of decomposition is important for primary productivity that impacts the microbial communities and soil carbon storage. The objective of this study was to evaluate the accumulation and decomposition of cultural residues of *Theobroma grandiflorum* (Willd. ex. Spreng) Schum, *Paullinia cupana* (Mart.) Ducke, *Bixa orellana* L., and forest in the Amazon region. The study was carried out in the São Francisco settlement, Canutama in the south of Amazonas, in a randomized block experimental design, and the treatments consisted of four areas with different crops: 1 - *P. cupana*; 2 - *T. grandiflorum*; 3 - *B. orellana*; 4 - Native woodland area (forest), in time subdivided plots: 7, 15, 30, 60, 90, 120, 150, 180, 210, 240, 270, 300, and 330 days after the distribution of the bags in the field, all with four repetitions. To evaluate the contribution and fractions of litter, conical collectors were used in each area, and collections were performed monthly in the period from March 2020 to February 2021. The estimate of the decomposition rate of the litter was done by quantifying the loss of mass, using litter bags, which allow for a direct analysis of the rate of decay over time. The forest and *P. cupana* environments presented the highest litter production, and greater deposition when compared to environments cultivated with *T. grandiflorum* and *B. orellana*. The forest and *B. orellana* areas showed the highest speed of decomposition, while the opposite situation occurred under *T. grandiflorum* and *P. cupana* cultivation.

Keywords: amazonian crops, nutrient cycling, leaf fall, agroecosystems, litter.

Resumo

A serrapilheira depositada na superfície do solo, em vários estágios de decomposição tem importância na produtividade primária que impacta nas comunidades microbianas e estocagem de carbono no solo. Objetivou-se neste trabalho avaliar o acúmulo e decomposição dos resíduos culturais de cupuaçu, guaraná, urucum e floresta na região do Amazonas. O estudo foi realizado no assentamento São Francisco, Canutama no Sul do Amazonas, em delineamento experimental de blocos casualisados, sendo que os tratamentos constaram de quatro áreas com diferentes culturas: 1- Guaraná; 2 – Cupuaçu; 3 – Urucum; 4 – Área de mata nativa (floresta), em parcelas subdivididas no tempo: 07, 15, 30, 60, 90, 120, 150, 180, 210, 240, 270 e 300, 330 dias após a distribuição das sacolas no campo, todas com 04 repetições. Para avaliar o aporte e frações dá serapilheira, foram utilizados coletores cônicos em cada área, sendo as coletas realizadas mensalmente no período de março de 2020 a fevereiro de 2021. A estimativa da taxa de decomposição da serrapilheira foi realizada pela quantificação da perda de massa, utilizando-se litter bags, os quais permitem analisar de forma direta a taxa de decaimento ao longo do tempo. Os ambientes de floresta e guaraná apresentaram as maiores produções de serapilheira, e maior deposição quando comparados aos ambientes cultivados com cupuaçu e urucum. As áreas de floresta e urucum apresentaram a maior velocidade de decomposição, já a situação inversa ocorreu sob o cultivo do cupuaçu e guaraná.

Palavras-chave: culturas amazônicas, ciclagem de nutrientes, queda das folhas, agroecosssitemas, serrapilheira.

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1 Introduction

The litter consists of plant materials freshly deposited on the soil surface, such as: leaves, trunks, bark, sticks, flowers or inflorescences, fruits, seeds, among others (Cianciaruso et al., 2006). It can be defined as any type of biogenic material in various stages of decomposition, representing a potential source of energy for the consuming species (Pereira et al., 2016). In this sense, this component plays a role in maintaining nutrients in the ecosystem, while the process of litter deposition, including the annual rates of fall of waste material and the process of decomposition of this material should be studied and known, especially in the conditions of the tropics, where there is a large occurrence of soils with low levels of nutrients (Santana & Souto, 2011).

The accumulation of litter varies depending on the origin of the plant species, the forest cover, the successional stage, the age, the time of collection, the type of forest, and the location. The quality of the litter, on the other hand, is determined by the plant species (Vigulu et al., 2019), which in turn differentiate in contents of organic and inorganic compounds (soluble fractions, nutrients, lignin, cellulose, phenolic compounds, and carbon), which exert great influence on the regulation and nature of soil biota interactions (Rojas Molina et al., 2017).

The mechanism of decomposition is regulated by the communities of decomposer organisms (community size and diversity), the biochemical characteristics of the organic material (simple and complex sugars, amino acids and proteins) and the environmental conditions (climatic and edaphic factors) (Freschet et al., 2013). Regarding climatic factors, humidity and temperature stand out, because the increase of these, accelerate the action of decomposer communities in the soil (Gaxiola & Armesto, 2015).

In forest ecosystems, the production and decomposition of litter is the primary means of organic matter input and nutrient transfer as part of the biogeochemical cycle (Freire et al., 2020). In anthropized environments, with the introduction of cultivated species there is a breakdown of mechanisms involved in nutrient cycling, making the environment dependent on external inputs (Sales et al., 2021). In contrast, according to Silva et al. (2020) the tree component, present in agroforestry systems or crop-livestock-forest integration systems, absorb nutrients from the various soil layers and contribute organic material, generating beneficial impacts to the soil, contributing to the cycling of nutrients.

Regarding the decomposition of litter in the Amazon, works developed by Freire et al. (2020) in studies of decomposition in 'terra firme' environments in Western Amazon; Pereira et al. (2016) evaluating litter and nutrients in 'terra firme' tropical forest in the Amazon basin, as well as Bello et al. (2021) who studied decomposition in reforestation and forest systems found that the leaf fraction contributes the most to returning nutrients to the soil. For Tonin et al. (2017) the climatic components (high temperature and high atmospheric humidity) of the Amazon assume a determining role in the decomposition of the litter, enabling the development of vegetation without appearances of nutritional deficiencies even in soils with low natural fertility.

The study had as hypotheses: i) conversion of natural environments into agroecosystems (*P. cupana*, *T. grandiflorum*, and *B. orellana*) modifies the capacity for formation and accumulation of litter; and, ii) the temporal conditions interfere with the contribution and accumulation of litter in these environments in the Amazon. Thus, the objective of this study was to evaluate the accumulation and decomposition of cultural residues of *T. grandiflorum*, *P. cupana*, *B. orellana*, and forest in the southern region of Amazonas, Brazil.

2 Material and methods

2.1 Location and characterization of the study area

The study was conducted in the São Francisco settlement, located in the municipality of Canutama, in the southern region of Amazonas, on two properties, the first between the geographical coordinates 8º 13' 23" S and 64º 00' 50" W, and the second between 8º 13'25" S and 64º 00' 23" W, with an altitude of 59 and 63 m, respectively.

On these properties four areas were selected, three of which were under different crops: *Bixa orellana* L. ('urucum'), *Theobroma grandiflorum* (Willd. ex. Spreng) Schum ('cupuaçu'), *Paullinia cupana* (Mart.) Ducke ('guaraná'), and more native forest area (Figure 1).

2.2 Climate of the region

In terms of climate characterization, the region climate is Tropical Rainy, presenting a dry period of short duration. Average rainfall varies between 2,250 and 2,750 mm year^{-1}, with a rainy period between October and June. Average annual temperatures range between 25 and 27º C and relative air humidity between 85 and 90% (Alvares et al., 2013). According to the Instituto Nacional de Meteorologia the rainy season occurs between October and March and the dry season between June and August, with the rest of the months considered a transition period (Figure 2).

2.3 Soils of the region

The soil of the studied area was classified as 'Argissolo Vermelho-Amarelo Distrófico típico' (Santos et al., 2018), of loamy texture, which presents in the layer up to 0.40 m the granulometry of 279.3, 418.4, and 302.3 g kg^{-1} of sand, silt, and clay, respectively. The chemical analysis of the soil in the same layer showed: pH in water 4.0; 2.97 mg dm^{-3} of P available; 0.06 cmol$_c$ dm^{-3} of K^+; 0.61 cmol$_c$ dm^{-3} of Ca^{2+}; 0.17 cmol$_c$ dm^{-3} of Mg^{2+}; 8.5 cmol$_c$ dm^{-3} of H + Al; V = 10.76%; 2.05 g dm^{-3} of organic matter.

The forest environment is characterized as a dense ombrophilous forest ('mata perenefólia'), whose vegetation is perennial, composed of dense and multi-stratified trees between 20 and 50 m high, with shrubby vegetation, formed by ferns, bromeliads, and palm trees (Veloso et al., 1991).

All areas under cultivation had the practice of fire to promote cleaning, and then the cultures were implanted.

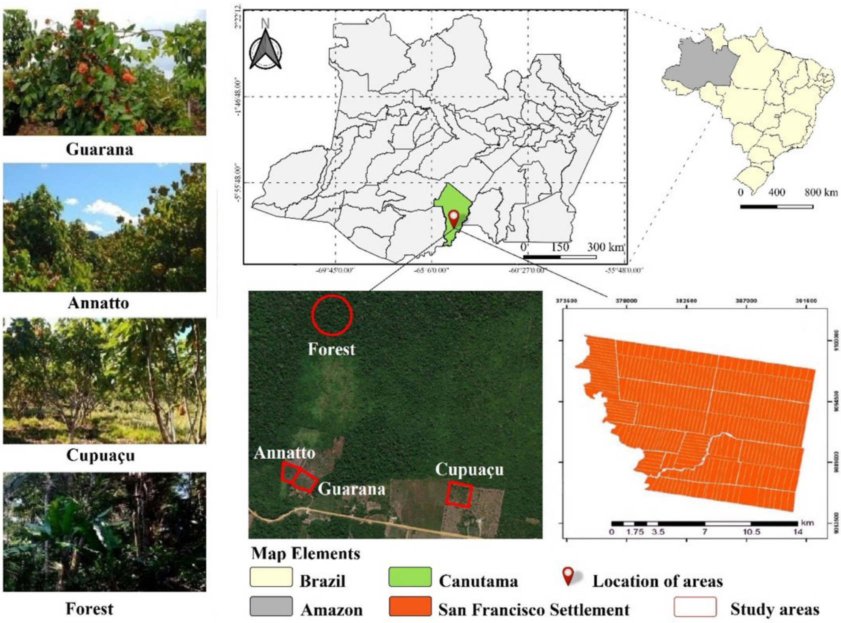

Figure 1. Location of the São Francisco settlement in the municipality of Canutama, southern Amazonas – AM, Brazil.

Fertilization and liming were not performed on the areas during the entire growing season.

The area with *T. grandiflorum* cultivation is 16 years old, with a spacing of 5 × 4 m (5 m between plants and 4 m between rows), presenting a productivity of 0.5 t ha^{-1} of pulp (average in Amazonas 4.5 t ha^{-1} of pulp), for weed control glyphosate herbicide is used. The area with *P. cupana* cultivation is 13 years old, with a spacing of 5 × 5 m (5 m between plants and 5 m between rows), presenting a productivity of 420 kg ha^{-1} of dry seed. The area with *B. orellana* cultivation is 6 years old, with a spacing of 5 × 4 m (5 m between plants and 4 m between rows), presenting a productivity of 642 kg ha^{-1} of seeds. Weed control in the *P. cupana* and *B. orellana* areas is done using motorized brush cutters.

2.4 Litter contribution evaluation

The contribution of litter was evaluated in each area of the study, with the aid of conical collectors with a total area of 0.21 m^2 and perimeter equal to 1.62 m, built with ¾" tube, made of polyethylene plastic material, with a 1 mm mesh and nylon mesh bottom, in order to allow the exit of water and avoid the loss of smaller material. These collectors were installed at a height of 30 cm above the ground, to prevent losses of litter by microorganisms and leaching losses.

Collections were conducted monthly during the period from March 2020 to February 2021. In the collectors, the litter was removed manually and packed in identified plastic bags. In the laboratory, the contents were dried for three days and separated into the fractions leaves, bark, and reproductive material. Each fraction was dried in an oven at 45 ºC until it reached constant mass and weighed on a precision balance. From these data, the monthly averages of the litter produced could be estimated.

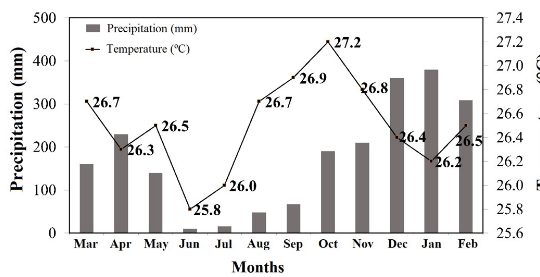

Figure 2. Cumulative temperature and rainfall over the period March 2020 to February 2021 at the study site. Source: Instituto Nacional de Meteorologia – INMET.

The production of litter was estimated according to Lopes et al. (2002), using the following Equation 1:

$$LP = MPL \times 10000 / Ca \tag{1}$$

where:

LP - litter production (Mg ha $^{-1}$ year^{-1});

MPL = monthly production of litter (Mg ha^{-1} month^{-1}); and,

Ca = collector area (m^2).

2.5 Assessment of litter decomposition

The litter decomposition rate was estimated through the quantification of the mass loss of the material, the methodology of decomposition bags (litter bags), developed by Santos and Whitford (1981), which allows the direct analysis of the decay rate at over time (Scorizar et al., 2012).

Fifty-two litter bags were randomly distributed in each study area, totaling 208, in order to simulate the natural fall of the litter-forming material. The litter bags were made of shading mesh with 4 mm mesh and dimensions

25 × 25 cm and 1.5 cm high. The litter bags were distributed near the conical collectors, facilitating their location and simulating the natural fall of litter-forming material.

In each litter bag 10 grams of the material collected in the conical collectors was inserted and dried in an oven at 45 ºC for 48 hours. The litter bags were collected at intervals of 07, 15, 30, 60, 90, 120, 150, 180, 210, 240, 270, 300, and 330 days after their installation, with four repetitions for each collection area.

After collection, the material contained in each litter bag was washed (to remove soil particles and possible organisms adhered to the leaves) and placed to dry in an air circulation oven at 45 ºC 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 ratio of final mass and initial mass, with the following Equation 2:

$$Remaining\ mass\ (\%) = (final\ mass / initial\ mass) \times 100 \quad (2)$$

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

$$X_t = X_0 \cdot e^{-kt} \quad (3)$$

where:
X_t - weight of remaining material after t days;
X_0 - weight of dry material originally placed in the bags at time zero (PI=10 g); and,
k - decomposition constant estimated by the equation.

Making a logarithmic transformation of Equation 3, we obtain a linear equation (Equation 4) of the weight of the remaining material as a function of time, whose linear coefficient a k is estimated by linear regression from field data collected periodically:

$$\ln X_t = -kt + \ln X_0 \quad (4)$$

Thus, through this exponential model, the value of the constant k was determined for each of the study areas, which indicates the greater or lesser speed of decomposition of the layer of litter accumulated on the ground. This model, as well as the curves that characterize the weight loss (decomposition) of the leaf litter, was elaborated with the aid of the Sigmaplot 12.1 software. The half-life ($T^{1/2}$) of this material will be calculated according to Rezende et al. (1999), by the Equation 5:

$$T^{1/2} = ln(2)/k \quad (5)$$

where:
k - decomposition constant estimated by the software mentioned above.

2.6 Statistical analysis

The statistical design used was randomized blocks with plots subdivided in time with four replications, then the results were submitted to the assumptions of equality of variance of residuals (homoscedasticity) from the Cochran test and the normality of the residuals, from the test of Shapiro-Wilk (at 5% probability). After this step, ANOVA analysis of variance was performed to check for statistical difference between the areas, using the Tukey test at 5% probability level. This comparison was performed by evaluating the overall average for a whole year of litter formation and also for formation within each month evaluated, all statistical analyses were performed in the computer program Statistical Package for Social Sciences (SPSS), version 12.5.

For a better presentation of the results, bar graphs, box plots and line dispersion were made for the formation of litter. In addition, regression analyses were performed for the decomposition of the leaf fraction as a function of time for each environment. The graphs and regression were made from the statistical software SigmaPlot 12.1 (Systat Software Inc., 2011).

3 Results

3.1 Litter contribution

The forest area showed the highest production of litter with 8.38 Mg ha^{-1} year^{-1}, statistically different from environments cultivated with *P. cupana*, *T. grandiflorum*, and *B. orellana*, which showed values of 5.63, 4.44, and 3.95 Mg ha^{-1} year^{-1}, respectively (Figure 3).

As for the monthly deposition, it appears that in the forest the contribution varied from 0.33 Mg ha^{-1} in January to 1.21 Mg ha^{-1} in October, in the area under *P. cupana* cultivation the values found were 0.30 and 0.98 Mg ha^{-1} in April and August, while in *T. grandiflorum*, the lowest value found was 0.08 Mg ha^{-1} in January and 0.87 Mg ha^{-1} in August. As for the *B. orellana*, the values found were 0.09 and 0.63 Mg ha^{-1} in the months of October and August (Figure 4).

The percentages of the leaf fractions showed the highest proportion in all areas studied. In relation to the areas studied, the forest area (77.8%) showed a lower value

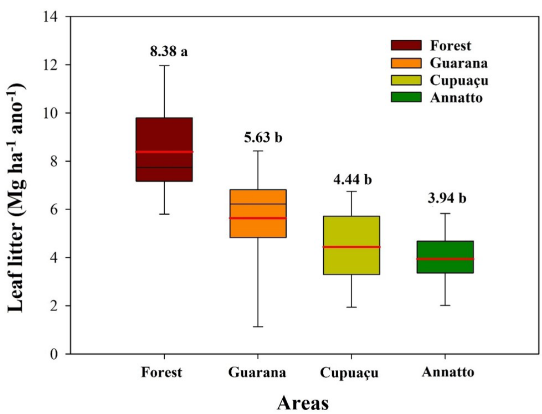

Figure 3. Annual production of litter in the different study areas. Equal letters do not differ by Tukey test at the 5% level. Red line represents the mean and black the median.

compared to the areas cultivated with *P. cupana* (86.7%), *B. orellana* (87.6%), and *T. grandiflorum* (87.9%), while the branch fractions showed a higher percentage in the forest and *B. orellana* areas. In the reproductive material fraction the highest percentage is found in the *P. cupana* and *T. grandiflorum* areas, probably due to the phenological behavior of these species (Figure 5).

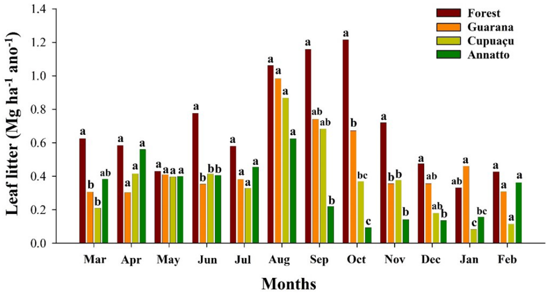

Figure 4. Monthly litter contribution in areas of forest, *P. cupana*, *T. grandiflorum*, and *B. orellana* in southern Amazonas, from March/2020 to February/2021. Equal letters in the column do not differ by Tukey test at the 5% probability level.

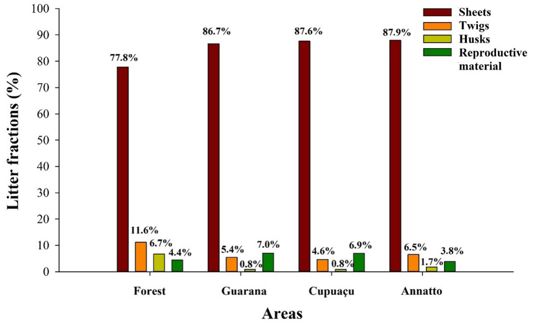

Figure 5. Percentage values of total deposition of the litter fractions in forest, *P. cupana*, *T. grandiflorum*, and *B. orellana* areas in southern Amazonas, from March/2020 to February/2021.

As for the temporal variation of the litter fractions, there was a greater deposition of leaf litter in the dry season during the month of August in the *B. orellana*, *T. grandiflorum*, and *P. cupana* areas, while in the forest area the period of greatest deposition was during the month of October (Figure 6).

A greater variation of the branch fraction is observed in the forest area (Figure 6) during the months of March to August, probably associated with the decrease of precipitation (March/2020) with the arrival of the dry period (August/2020) in the Amazon region (Figure 2).

In relation to the contribution of reproductive material, it is observed that this was high in *P. cupana* compared to the other environments. The largest contributions occurred in the dry season, reaching the maximum production value in October. While in *T. grandiflorum* and *B. orellana*, the highest contribution of this fraction was observed in August, respectively, dry period in the study region. Even so, it is observed for all areas, that production occurred throughout the year, however, the quantities were variable (Figure 6), it is noteworthy that it is linked to the flowering season of the cultivated crop species.

When analyzing the bark fraction, the highest production was observed in November in the forest and *B. orellana* areas, while in *T. grandiflorum* the highest production was observed in September, and in *P. cupana* the highest production was estimated in August (Figure 6).

3.2 Decomposition of leaf litter

The values of the decomposition constant (k) and half-life of the litter from each of the study environments are presented in Table 1. Over the period studied, the *T. grandiflorum* and *P. cupana* areas had the lowest value of the k constant (0.001 g g^{-1} day^{-1}) and consequently the

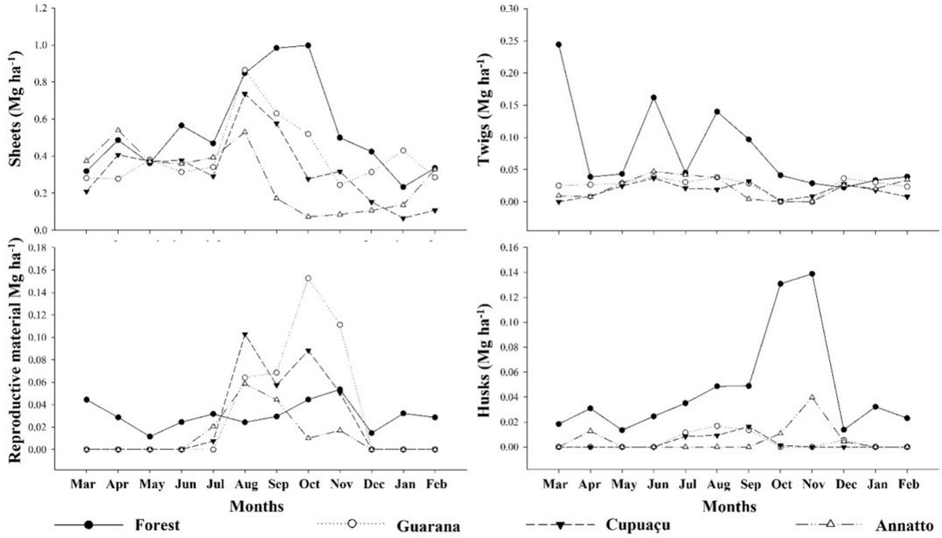

Figure 6. Monthly average of leaf, twig, reproductive material and bark fraction in the different study areas in southern Amazonas, in the period from March/2020 to February/2021.

Table 1. Decomposition constant (k), half-life time ($T^{1/2}$) in days, exponential regression analysis and coefficient of determination of dry mass of litter in forest, *P. cupana*, *T. grandiflorum*, and *B. orellana* environments (Figure 7), Canutama, Amazonas, Brazil, 2020.

Environments	Decomposition of the remaining mass			
	k (g g^{-1} day^{-1})	$T^{1/2}$ (Days)	Equation (Figure 7)	R^2
Forest	0.003	231	$Y=104.86e^{-0.0026X}$	0.80
P. cupana	0.001	693	$Y=99.52e^{-0.0009X}$	0.96
T. grandiflorum	0.001	693	$Y=99.16e^{-0.0009X}$	0.96
B. orellana	0.002	346	$Y=100.09e^{-0.0027X}$	0.96

longest half-life (693 days), and therefore the slowest rate of decomposition, followed by the *B. orellana* (0.002 g g^{-1} day^{-1} and 346 days) and forest (0.003 g^{-1} day^{-1} and 231 days) areas.

For the regression models, the correlation coefficients were significant (0.845, 0.913, 0.944, and 0.643, for the forest, *P. cupana*, *T. grandiflorum*, and *B. orellana* areas, respectively), with model fits showing R-squared above 0.713, except for the *B. orellana* area, which obtained a value slightly below. In the independence of the residuals of the model with the reference one, they presented a Durbin-Watson between 0.996 and 2.374. Thus, the linear regression model showed significant (p-value < 0.05), which is an indication of robustness of analysis in determining the constant k (decomposition rate).

The regression plots of the remaining mass as a function of time for each study area, are presented, in Figure 7. They show that mass loss is faster for forest and *B. orellana* compared to *P. cupana* and *T. grandiflorum*.

Pearson correlation was significant for precipitation, and not significant for temperature in all environments studied, confirming the antagonistic effect of precipitation on the remaining mass of litter. The highest correlation values for precipitation were observed in the forest (-0.714) and *T. grandiflorum* (-0.662) areas, however, the *P. cupana* (-0.590) and *B. orellana* (-0.614) areas showed the lowest values.

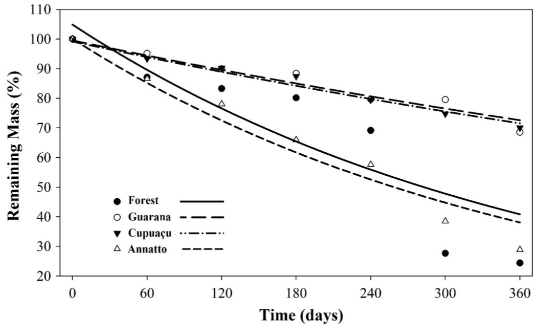

Figure 7. Litter decomposition curve in forest, *P. cupana*, *T. grandiflorum*, and *B. orellana* environments, Canutama, Amazonas, Brazil, 2020.

4 Discussion

4.1 Litter contribution

The variations in the deposition of the litter can be justified by different species and crop ages (Castro et al., 2022). Sales et al. (2020) evaluating litter formation in the southern Amazon region, observed a value of 12.58 Mg ha^{-1} year^{-1} in a forest area. These higher values of litter observed in forest areas are due to the greater canopy closure, variability, plant densification, and the water regime that provides greater natural pruning (Correia et al., 2016; Villa et al., 2016).

When evaluating the seasonality of the production of litter, we noticed a higher production in the months of August to October, with the highest levels observed in the forest area and the lowest in the *B. orellana* area, a period that coincided with the months with the lowest accumulation of monthly rainfall, which occurred from June to September 2020 (Figure 2). This higher production of litter may be related to the development cycle of the crops and the seasons of the year, with this period coinciding with the reproductive season of the crops (Figure 6). Camargo et al. (2015), evaluating the effect of seasonal inundation variation on litter production in an alluvial forest of the middle Rio Xingu (Amazon basin, Brazil) observed a positive correlation between precipitation and litter accumulation.

In studies developed by Correia et al. (2016) and Sales et al. (2020) also observed higher productions of litter occur in the period from August to October that corresponds to the dry season, they attributed this behavior to a physiological response of plants to water stress, in which they release their leaves to reduce water loss by transpiration. Brasil et al. (2017) and Holanda et al. (2017) observed the existence of two patterns for the annual production of litter in Brazilian ecosystems, the first being related to a greater deposition in the dry period of the year, occurring in Amazon ecosystems, in mesophytic and cerrado forests, the second consists of a greater deposition in the rainy season, common in restingas and Atlantic Forest.

Sales et al. (2021) studying litter formation in the Amazon in areas of cerrado, 'cerradão' and forest, also observed that the fraction with the highest proportion is the leaf. These results corroborate Pimentel et al. (2021), who also observed a greater participation of the leaf in the composition of biomass, and related this behavior to the high rate of transpiration of these organs that, when they suffer some stress are discarded by the plants, in order to mitigate permanent damage. However, in the leaf is where it concentrates most of the nutrients provided by the litter (Alves et al., 2017), being fundamental for nutrient cycling in Amazon environments.

In relation to the other fractions of the litter, the high production of branches in the intense rainy period probably occurred due to the greater presence of storms and windstorms and the higher amount of water absorbed by the plants in this period, causing the branches to have greater weight and friction, resulting in their breakage (Konig et al., 2002). For the reproductive fractions, according to Holanda et al. (2017) the deposition of reproductive material of the species studied, are linked to the time of the reproductive cycle adopted by the species for their reproduction and only as a function of microclimate variations. However, in order to have better explanations, it is necessary to monitor the phenological behavior of the species during the collection phase, aiming to obtain data that can help explain the results obtained, and even determine the isolated influence of each species for a certain event that occurred in the production process (Nascimento et al., 2013).

4.2 Decomposition of leaf litter

The litter performs several ecosystem functions, among which the cycling of nutrients is a key factor for the maintenance of forests and crops in tropical regions. Litter decomposition processes are influenced by several factors, among them are microbial diversity and population, degree of lignification of the leaves present (Yin et al., 2022), soil temperature and moisture, enzymatic activities (Liu et al., 2022), nutritional composition of the litter (C:N ratio) (Dawoe et al., 2010), and the interactions among these factors (Prieto et al., 2019). Thus, the higher rate of decomposition observed in the forest and *B. orellana* cultivation environments can be attributed to the greater vegetation cover that these areas have, which maintains greater moisture (Table 2) in the environment (Cotrufo et al., 2010) and with this greater population and microbial diversity especially in the forest environment.

The lower decomposition rates observed in the *T. grandiflorum* and *P. cupana* areas can be attributed to lower moisture of the litter, related to high C:N ratio associated with high lignin concentrations (Walela et al., 2014; Li et al., 2022). Longer decomposition time is not an indication of malfunctioning agricultural systems, because the longer material remains on the soil surface, the greater its accumulation and surface coverage will be, providing soil protection (Assis et al., 2020) and providing long-term nutrients (Bai et al., 2022).

Table 2. Pearson correlation between remaining mass, temperature, and humidity for each environment studied as a function of time.

Remaining mass	Temperature	Rainfall
Forest	0.133^{ns}	-0.714**
P. cupana	-0.024^{ns}	-0.590*
T. grandiflorum	0.044^{ns}	-0.662**
B. orellana	-0.019^{ns}	-0.614*

**Correlation is significant at the 0.01 level; *Correlation is significant at the 0.05 level; ^{ns} Not significant.

Observing the data in Table 1, the K values noted in this study are considered low, when compared to the study by Waring & Schlesinger (1985), who observed accelerated rates of litter decomposition in tropical forest ecosystems, with k values greater than 1.00. In their work Pereira et al. (2008), Giácomo et al. (2012) and Pedro (2017), studying the input and decomposition of litter, found values of 0.040, 0.0023, and 0.0030 for k, respectively, these values being close to those found in the forest and *B. orellana* environments. According to César (1993), differences in the decomposition rate of litter between different stages can be attributed to the type of relief conditions, vegetation cover, quality of the material, edaphic macrofauna, and to environmental conditions such as temperature and humidity.

These low values of decomposition in the studied areas in relation to other studies, may be related to the higher lignin content present in the leaves (Yin et al., 2022). Although precipitation has a greater weight in the decomposition of the leaf fraction of the litter (Table 2), in general, it may be contributing to the loss of available nitrogen by leaching, thus decreasing the C:N ratio and thus the decomposition rate (Li et al., 2022).

The decomposition process over time follows the exponential decay model (Figure 7), indicating that decomposition is not constant over time, since it is linked to several physical, chemical, and environmental factors of the material itself (Castro et al., 2016), among these factors, increased precipitation (Table 2) and N deposition significantly promotes the decomposition rate of the litter (Li et al., 2022).

5 Conclusions

The areas evaluated showed the highest accumulation of litter in the following increasing order: *B. orellana*, *T. grandiflorum*, *P. cupana*, and forest.

Regarding the fractions of the plant, the leaf had the largest share, followed by twigs, reproductive material, and bark.

The greatest contribution of the deposited fractions of leaves, twigs, reproductive material occurred in the dry period between the months of August and November.

The decomposition of the residues occurred in greater proportion in the following order: forest, *B. orellana*, *T. grandiflorum*, and *P. cupana*.

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