ISSN 1807-1929
Revista Brasileira de Engenharia Agrícola e Ambiental
Brazilian Journal of Agricultural and Environmental Engineering
v.26, n.2, p.91-96, 2022
Campina Grande, PB – http://www.agriambi.com.br – http://www.scielo.br/rbeaa

DOI: http://dx.doi.org/10.1590/1807-1929/agriambi.v26n2p91-96

Litterfall decomposition of coffee shaded with *Tectona grandis* or in full sun[1]

Decomposição de serapilheira de cafeeiro sombreado com *Tectona grandis* ou a pleno sol

Nirvani S. Henrique[2*], Katia L. Maltoni[3] & Glaucia A. Faria[4]

[1] Research developed at Cacoal, RO, Brazil
[2] Instituto Federal de Educação, Ciência e Tecnologia do Rondônia, Câmpus Cacoal, Cacoal, RO, Brazil
[3] Universidade Estadual Paulista "Júlio de Mesquita Filho"/Faculdade de Engenharia/Departamento de Fitossanidade, Engenharia Rural e Solos, Ilha Solteira, SP, Brazil
[4] Universidade Estadual Paulista "Júlio de Mesquita Filho"/Faculdade de Engenharia/Departamento de Matemática, Ilha Solteira, SP, Brazil

HIGHLIGHTS:
The litterfall mass reduction was greater in shaded coffee compared to coffee in full sun.
N, Ca, Mg, and K stocks from litterfall decreased linearly with time.
Coffee cultivated in full sun had a greater stock of nitrogen, calcium, and magnesium in the litterfall.

ABSTRACT: Litterfall is an important source of soil nutrients, but its decomposition can be affected by the crop system used. The objective of this study was to evaluate litterfall decomposition and macronutrient stocks in coffee crop systems in shaded (SH_{CS}) environments and those in full sun (FS_{CS}). The experiment was conducted on a rural property in Cacoal, state of Rondônia, Brazil, in a 2 × 6 factorial scheme with two crop systems (SH_{CS} and FS_{CS}), and six litterfall decomposition evaluation times (0, 30, 60, 180, 300, and 360 days after the litterfall was returned to the soil (DAL)), with seven replicates. The constant of decomposition (k), half-life time ($t^{1/2}$) at 360 DAL, and phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), and nitrogen (N) concentrations of the remaining litterfall were determined at each evaluation time. The litterfall in the SH_{CS} had a greater weight loss and constant of decomposition and a lower half-life time at the last evaluation, and the weight loss increased as a function of decomposition time. The litterfall stocks of macronutrients N, P, K, Ca, and Mg showed a linear decrease throughout the decomposition time, and increases in sulfur stock were found at the last evaluation.

Key words: *Coffea canephora*, shading, sustainability, litter bag

RESUMO: A serapilheira é uma importante fonte de nutrientes para o solo e a sua decomposição pode ser influenciada pelos sistemas de uso do mesmo. Este estudo teve por objetivo avaliar a decomposição de serapilheira e seu estoque de macronutrientes em dois sistemas de cultivo do cafeeiro, sendo um sombreado (CS) e outro a pleno sol (CPS). O experimento foi realizado em uma propriedade rural do município de Cacoal, Estado de Rondônia, Brasil, em esquema fatorial 2 × 6, dois usos do solo (CS e CPS) e seis épocas de avaliação da decomposição da serapilheira (0, 30, 60, 180, 300 e 360 dias), com sete repetições. A decomposição de serapilheira foi avaliada aos 0, 30, 60, 180, 300 e 360 dias e, além disso, foi determinada a constante de decomposição (k) e o tempo de meia vida ($t^{1/2}$) aos 360 dias e os teores de fósforo (P), potássio (K), cálcio (Ca), magnésio (Mg), enxofre (S) e nitrogênio (N) da serapilheira remanescente em cada tempo de decomposição. No CS há maiores perda de massa e constante de decomposição, e menor tempo de meia vida da serapilheira ao final do período. A serapilheira apresenta perda de massa em função do tempo de decomposição. Os estoques de macronutrientes N, P, K, Ca e Mg reduziram-se de forma linear durante o tempo de decomposição e ocorreu incremento no estoque de enxofre ao final do período.

Palavras-chave: *Coffea canephora*, sombreamento, sustentabilidade, bolsas de decomposição

• Ref. 248322 – Received 03 Feb, 2021
* Corresponding author - E-mail: nirvani.henrique@ifro.edu.br
• Accepted 01 Aug, 2021 • Published 01 Sept, 2021
Edited by: Walter Esfrain Pereira

Introduction

Coffee is mainly grown in Brazil in a monoculture system (DaMatta et al., 2017), however the planting of trees on coffee farms has been increasing, since the conservation of natural resources is an existing concern in the agricultural sector (Gomes et al., 2015). In Brazil and worldwide, combining coffee crops with tree species is a conventional technique that has been studied as a method of sustainability and protection of crops against adverse environmental effects (Guimarães et al., 2015).

The intercropping of coffee crops with arboreal species results in several benefits to the soil, such as reduced soil erosion and increased litterfall production (Rodrigues et al., 2015), which provides nutrient cycling from the decomposition of these plant residues and improves soil microbiological activity (Urbano et al., 2018; Garlet et al., 2019).

The use of decomposition bags or litter bags is common for the evaluation of litterfall degradation, whereby the decomposition of material is quantified by the difference between the initial and final weights after a previously defined exposure time (Inkotte et al., 2019).

The weight of the decomposed plant residues obtained is then used to calculate the constant of decomposition as a function of the exposure time (Thomas & Asakawa, 1993), and to calculate the half-life time, which is, the time required for the decomposition of 50% of the litterfall (Rezende et al., 1999).

It is hypothesized that litterfall decomposition occurs faster under a shaded coffee system because of the favorable microclimate for microbial activity. In this context, the objective of this study was to evaluate litterfall decomposition and macronutrient stocks in soils under two coffee crop systems, shaded (SH_{CS}), and full sun (FS_{CS}).

Material and Methods

The experiment was conducted in a rural property in the municipality of Cacoal, state of Rondônia, Brazil (11°26'19" S, 61°26'50" W, and 238 m altitude). The most common soil in the region is Ultisol of medium to clayey texture, which was assigned to the soil of the experimental area as it had similar characteristics.

The region presents mean air temperatures between 24 and 26 °C, and mean annual rainfall of 1400 to 2600 mm, with June to October as the driest period (Alvares et al., 2013). During the study period (April 2018 to April 2019), the averages of precipitation and temperature were 2560 mm and 26.2 °C, respectively (INMET, 2019).

Two areas, side by side, were defined at the site selected for the experiment, each with differently managed coffee crops: an agroforestry system with coffee and teak plants, the shaded coffee system (SH_{CS}), and a monoculture of coffee plants grown in full sun (FS_{CS}).

The coffee plants (*Coffea canephora* from the botanical variety conilon, propagated from seeds of unknown genetic origin) under the SH_{CS} were planted in 1996 with a spacing of 3 m between rows and 2 m between plants. The coffee crop was intercropped with teak trees (*Tectona grandis*), which were introduced at every two planting rows at the time of coffee planting, with a spacing of 6 m between rows and 4 m between plants. The teak trees were not pruned or thinned. In the SHcs, fertilization, phytosanitary control, irrigation, and pruning were not performed. The only management practice carried out in the SH_{CS} area was weed control, using a brush cutter (annually).

The coffee plants under the FS_{CS} were also planted in 1996, with a spacing of 3 m between rows and 2.5 m between plants. Soil mineral fertilizer was applied annually, using nitrogen (48 kg ha^{-1} of N), phosphorus (12 kg ha^{-1} of P_2O_5), and potassium (48 kg ha^{-1} of K_2O), with the doses recommended based on soil analysis.

In the FS_{CS} area, along with annual brush cutting, the glyphosate herbicide was used for weed control (2 L ha^{-1}, twice a year). The coffee crops in this area were irrigated using a sprinkler system for seven days in late July, with a daily water depth of 6.3 mm, to induce flowering. The branches were manually pruned after the annual coffee harvests, and the buds were manually removed during the rainy period.

The area of each coffee crop system was divided into four homogeneous clusters, each with dimensions of 24 × 27 m. Each cluster was divided into a grid (8 × 9 m) displaying nine sampler points, of which seven were randomly selected to represent the replicates. Thus, each treatment was represented by four clusters with seven replicates, totaling 28 replicates for each treatment.

In March 2018, five litterfall samples were collected, one for each period of evaluation (May 2018, 30 days; June 2018, 60 days; October 2018, 180 days; March 2019, 300 days; and April 2019, 360 days), for 140 samples per cultivation system, and 280 samples in total. All litter bags were returned to the soil in April 2018, and 30 days later (May 2018) the evaluation period began.

The collection was conducted using a frame with internal measures of 0.25 × 0.25 m. All plant residues (leaves, branches, and reproductive structures) found in the area within the frame were collected, including those recently fallen or partially decomposed.

The collected litterfall was placed in paper bags, dried in a forced air circulation oven at 65 °C until constant weight, and weighed. All materials were then placed in nylon bags (litter bags) made of a 1 mm mesh. The litter bags were returned to the field in April 2018 (zero days). In addition to the litterfall collected for decomposition, 28 composite samples (three sub-samples) were retrieved from each coffee crop system for macronutrient analysis (time zero).

The litter bags were collected from the field from May 2018 (30 days) to April 2019 (360 days), with one litter bag per replication at 30, 60, 180, 300, and 360 days after the litterfall (DAL) was returned to the soil. The samples were placed in plastic bags and taken to a laboratory, where they were cleaned (removal of soil with a paintbrush), and dried in an oven at 65 °C until constant weight to obtain their dry weights (Silva et al., 2014).

The first litter bag samples (March 2018) and all litter bags collected after each decomposition time were cleaned, dried, weighed, crushed in a steel stainless knife mill, and analyzed for nitrogen (N), phosphorus (P), potassium (K), calcium

(Ca), magnesium (Mg), and sulfur (S) concentrations, using the methodology described by Malavolta et al. (1997). The percentage weight loss was calculated after each decomposition time using Eq. 1:

$$SR(\%) = \frac{Mf}{Mi}100 \qquad (1)$$

where:
- SR - remaining litterfall expressed in %;
- Mf - final litterfall weight at time x; and,
- Mi - initial litterfall weight at time zero.

The constant of decomposition (k) of litterfall at 360 DAL was determined as described by Thomas & Azakawa (1993), and the time for the decomposition of 50% of the litterfall (half-life time, $t^{1/2}$) was determined as described by Rezende et al. (1999). The exponential model was used to obtain the constant of decomposition (expressed in g g^{-1} per day), as described in Eq. 2:

$$Xt = X0e^{-kt} \qquad (2)$$

where:
- Xt - sample weight at time x;
- X0 - weight of the dry material placed in the litter bag at time zero;
- t - decomposition time (days);
- e - exponential; and,
- k - decomposition constant estimated by the equation.

The half-life time (days) was obtained using Eq. 3:

$$t^{\frac{1}{2}} = \frac{\ln(2)}{k} \qquad (3)$$

where:
- $t^{1/2}$ - half-life time;
- ln - natural logarithm; and,
- k - constant obtained in Eq. 2.

The nutrient stock was calculated by Eq. 4:

$$E = (MSR \times CN) \qquad (4)$$

where:
- E - nutrient stock (kg ha^{-1});
- MSR - litter mass remaining at each time (kg ha^{-1}); and,
- CN - concentration of nutrients at each time (kg kg^{-1}).

All variables were subjected to the Shapiro-Wilk test for normality of errors. The subplot scheme in space was used, consisting of two crop systems (SH_{CS} and FS_{CS}) in the plots and six evaluation times of litterfall decomposition (0, 30, 60, 180, 300, and 360 DAL) in the subplots. The F test ($p \leq 0.05$) was used to evaluate the differences in crop systems, and analyses of variance and regression for evaluation times. The statistical program Sisvar (Ferreira, 2019) was used for all analyses.

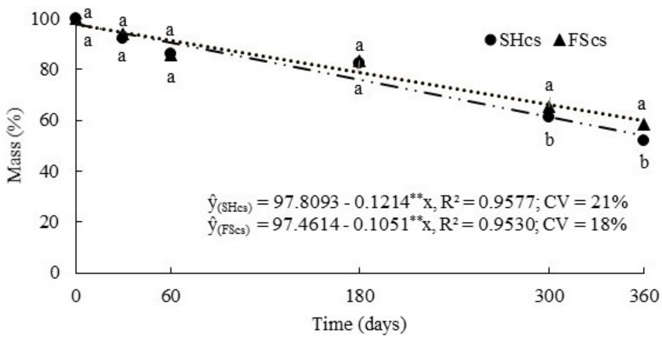
Results and Discussion

The litterfall weight decreased linearly (Figure 1) throughout the year, as observed in both the SH_{CS} and FS_{CS}. These reductions relating to exposure time are expected, since during this period several factors contribute to the litterfall decomposition, including physical and chemical conditions of the environment, composition of the litter material, presence of edaphic fauna, and microorganism stimulation (Urbano et al., 2018).

Litterfall decomposition commonly increases in periods with higher rainfall in different ecosystems (Bauer et al., 2016), since biochemical processes in the soil depend on the presence of water for the decomposition of organic materials (Silva et al., 2009a), which explains the differing results found throughout the year.

At the last evaluation (360 DAL), the weight of the litter bags in the SH_{CS} decreased by 54.1% in relation to the initial weight; FS_{CS} decreased to a lesser extent with a remaining weight of 59.6% (Figure 1). The constant of decomposition (Table 1) confirms these results; FS_{CS} presented a constant of decomposition (k) of 0.0015 g g^{-1} per day at 360 DAL and, consequently had a higher half-life time (470 DAL) than the SH_{CS}, which showed a higher constant of decomposition (0.0018 g g^{-1} per day), and a half-life time of 397 DAL. Therefore, the FS_{CS} required more time for the nutrients to be available in the soil for absorption by plants.

The half-life time represents the time for the decomposition of 50% of the litterfall, which can be dependent on several factors, such as the soil cover plant, temperature and moisture conditions, soil microbial activity, and plant parts present in



** - Significant at $p \leq 0.01$ by the F test. Data in the vertical alignment followed by the same letter do not differ by the F test ($p \geq 0.05$)

Figure 1. Remaining litterfall weight presented in litter bags in function of days after the litterfall was returned to the soil, between May 2018 and April 2019, in coffee crops under shaded (SH_{CS}) and full sun (FS_{CS}) systems

Table 1. Constant of decomposition (k) of litterfall at 360 days after the litterfall was returned to the soil, along with half-life time ($t^{1/2}$), for coffee crops under shaded (SH_{CS}) and full sun (FS_{CS}) systems

Crop system	k (g g^{-1} per day)	$t^{1/2}$ (days)
SH_{CS}	0.0018 a	397 b
FS_{CS}	0.0015 b	470 a
CV (%)	18.6	18.1
F	18.14**	12.07**

Means followed by the same letter in the columns are not significantly different ($p \leq 0.01$) according to the F test. CV, coefficient of variation; F, calculated F values; **, significant at $p \leq 0.01$ by the F test the litterfall (Urbano et al., 2018), with the latter most affecting the results, since the plots were close to each other.

Rosa et al. (2017) found estimated times for 50% decomposition of litterfall (half-life time) of 467, 419, and 434 days for five-, six-, and seven-year-old teak plantations, respectively. These values were similar to those found for the SH_{CS} (397 days), where there was a predominance of teak plant residues in the litterfall. Cavalcante et al. (2020) observed a shorter half-life time (270 days) for clonal teak leaves.

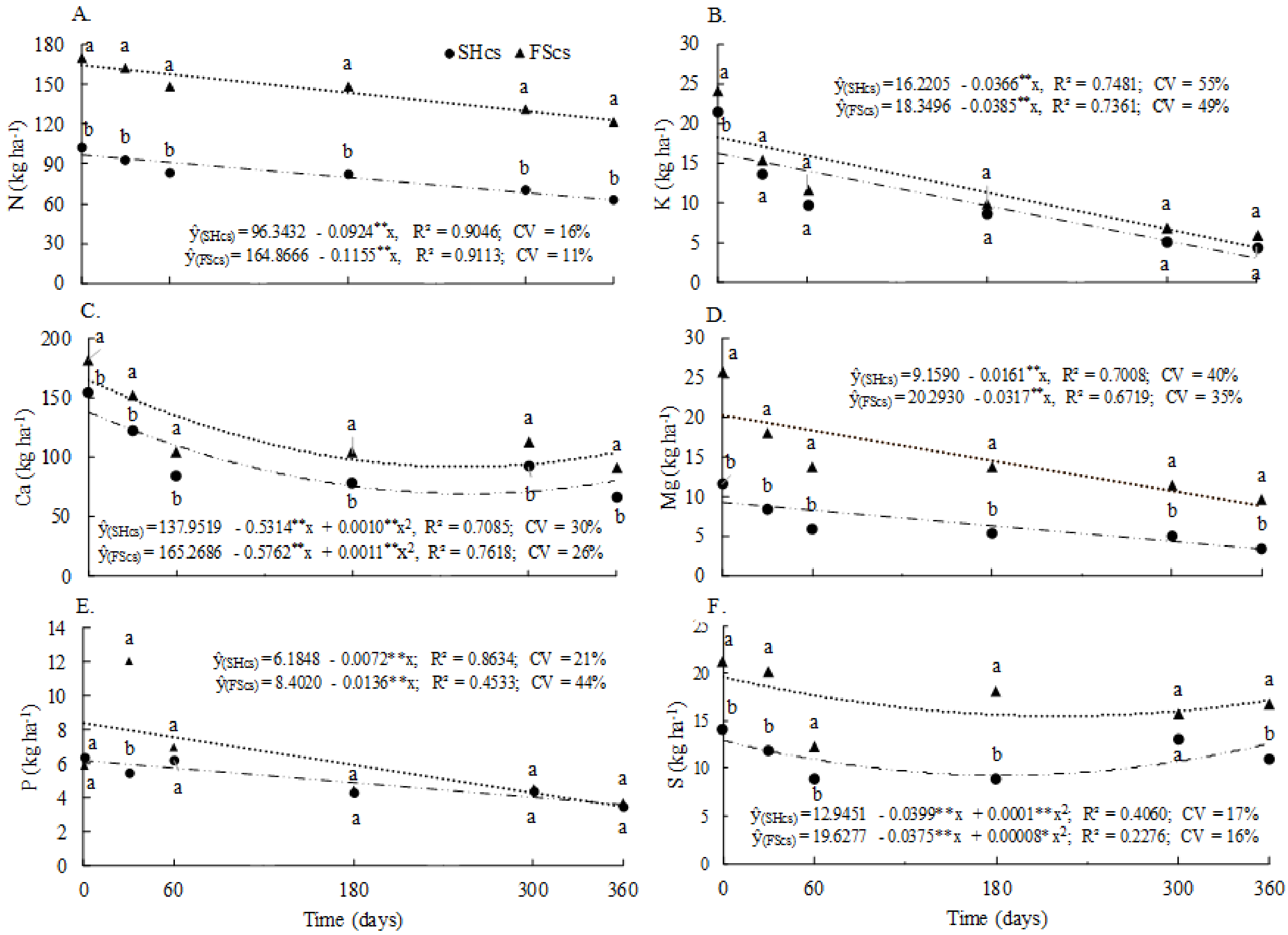
The litterfall in the SH_{CS} presented a faster decomposition, since it was mainly composed of leaves and reproductive structures of teak plants. In contrast, the litterfall in the FS_{CS} had residues of coffee plants from pruning, which resulted in more lignified branches with higher C/N ratios, contributing to increased decomposition time (Pegoraro et al., 2011). This reinforces that the type of plant residues in the litterfall is relevant for the decomposition process (Teixeira et al., 2012; Silva et al., 2014).

Litterfall decomposition was evaluated in the plant residues (leaves, branches, reproductive structures, and peels) on the soil within the sample area (0.0625 m^2); whereas, most studies used plant residues composed only of leaves. Regardless, the constant of decomposition (k) found in the study areas was similar to other results found in different regions, such as the results presented by Rosa et al. (2017), for five-, six-, and seven-year-old teak stands, where the decomposition constant was calculated using the annual litter production values and their accumulation on the soil. Considering a 12-month period, the decomposition constants were 0.0014, 0.0016, and 0.0015 g g^{-1} per day, respectively.

Silva et al. (2014) found k values between 0.0019 and 0.0033 g g^{-1} per day in a native forest fragment, and a forest plantation with native species (*Tabebuia impetiginosa*, *T. serratifolia*, *T. roseo-alba*, *Alchornea triplinervia*, and *Astronium urundeuva*) and another with *Artocarpus heterophyllus* in the state of Bahia, Brazil. Grugiki et al. (2017) found k values of 0.0013 to 0.0024 g g^{-1} per day in the Atlantic Forest biome. Silva et al. (2009b) found k values of 0.0010 to 0.0050 g g^{-1} per day in the dry season and 0.0061 to 0.0119 g g^{-1} per day in the rainy season, in a transition area between the Amazon and Cerrado biomes. Despite the results indicating higher decomposition in the rainy season, the plant parts in the litterfall (pruning residues) had a higher C/N ratio, which affects FS_{CS} (Acosta et al., 2014), increasing the decomposition time.

The macronutrient stock in the remaining litterfall (Figure 2) showed a linear response as a function of time for N, K, P, and Mg.

The nitrogen stock in the remaining litterfall was higher in the FS_{CS} at all evaluation times (Figure 2A). This is attributed to



** - significant at p ≤ 0.01 and * - significant at p ≤ 0.05 by the F test. Data in the vertical alignment followed by the same letter do not differ by the F test (p ≥ 0.05)

Figure 2. Nitrogen (A), potassium (B) , calcium (C), magnesium (D), phosphorus (E), and sulfur (F) stocks in the remaining litterfall as a function of days after the litterfall was returned to the soil, from April 2018 to April 2019, in coffee crops under shaded (SH_{CS}) and full sun (FS_{CS}) systems

the higher photosynthetic rate of plants in the FS_{CS} due to the positive correlation between irradiance and N concentrations, when other factors such as water and nutrient availability are not limiting (Fahl et al., 1994), and to the addition of N in the FS_{CS} via fertilization, which contributes to greater absorption of nutrients by plants and, consequently, greater accumulation in the plant tissues, which partially return to the soil through natural senescence and pruning and blooming residues.

Potassium stocks presented a decreasing linear response to the decomposition time (Figure 2B). This is probably because it is not associated with any structures of plant tissues, allowing for a high mobility and leaching potential (Bambi et al., 2011; Cavalcante et al., 2020).

Potassium had a high percentage of cycling through the decomposition of litter, with a stock of 16.2 kg ha^{-1} (time zero) reduced to 3 kg ha^{-1} over 360 days, representing 81.4% of the nutrient increased in the soil under SH_{CS}, which did not receive an external source of fertilization. In the FS_{CS}, the reduction was 75.4%, with an initial stock of 18.3 kg ha^{-1} (time zero) reduced to 4.5 kg ha^{-1} of potassium at the end of the evaluation period (360 days), contributing to the nutrition of coffee plants which received 48 kg ha^{-1} of external source of potassium fertilization annually.

Calcium stocks were higher in the litterfall under the FS_{CS} at all evaluation times (Figure 2C). This nutrient is found in large quantities in stems (Lopes, 2001), which is present in higher quantities in the litterfall in this system due to the removal of less-productive branches of coffee plants, whereas the litterfall in the SH_{CS} was mainly composed of leaves and reproductive structures.

The calcium ranged from 137.9 (zero days) to 80.1 kg ha^{-1} (360 days) in the soil under SH_{CS} and from 165.3 (zero days) to 104.3 kg ha^{-1} (360 days) under FS_{CS} , with litterfall being the only source of this nutrient in both cultivation systems, since the soil has not been corrected by liming.

Magnesium stocks in the litterfall were higher under FS_{CS} (Figure 2D), mainly because of the residues from pruning and bud removal, which deposit large quantities of buds and young leaves to the soil. Moreover, Mg is a mobile element in plants that is present in large quantities in growth tissues (Malavolta et al., 1997). Thus, the magnesium assimilated by the plants in the SH_{CS} is mainly stored in branches and stems, which are not renewed annually.

Magnesium presented a linear response to the evaluation times, with higher stocks at the beginning of the period, with variations from 9.1 (time zero) to 3.6 kg ha^{-1} (360 days) in SH_{CS} and from 20.3 (time zero) to 8.8 kg ha^{-1} (360 days) in FS_{CS} , with nutrient cycling being the only method of maintaining nutrients in both cultivation systems.

Stocks of phosphorus in FScs (FScs: $\hat{y} = 8.4020 - 0.0136^{**}x$ and $R^2 = 0.4533$) and sulfur in both systems (SHcs: $\hat{y} = 12.9451 - 0.0399^{**}x + 0.0001^{**}x^2$ and $R^2 = 0.4060$; FS_{CS}: $\hat{y} = 19.6277 - 0.0375^{**}x + 0.00008^{*}x^2$ and $R^2 = 0.2276$), presented significant responses, however the R^2 values were lower than 0.6, indicating an incipient model adjustment.

The litterfall in the SH_{CS} and FS_{CS} areas presented variations in phosphorus (Figure 2E) concentrations, with 6.2 kg ha^{-1} (0 DAL) to 3.6 kg ha^{-1} (360 DAL) for SH_{CS}, and 8.4 kg ha^{-1} (0 DAL) to 3.5 kg ha^{-1} (360 DAL) for FS_{CS}, characterizing losses of 42 and 58% in phosphorus stocks in the litterfall under SH_{CS} and FS_{CS}, and releases of P to soil of 2.6 kg ha^{-1} for SH_{CS}, and 4.9 kg ha^{-1} for FS_{CS}, respectively.

Sulfur stocks (Figure 2F) in the remaining litterfall varied from 12.9 to 9.2 kg ha^{-1} in the SH_{CS}, and from 19.6 to 15.6 kg ha^{-1} in the FS_{CS}. Both crop systems showed initial decreases in sulfur stock, with increases at the last two evaluations (300 and 360 DAL), which can be related to the immobilization of this nutrient by decomposing microorganisms (Aidar & Joly, 2003), since neither cultivation system was fertilized by sulfur sources.

In general, macronutrient stocks in the litterfall were lower in the last evaluation (360 DAL). N, P, K, Ca, and Mg stocks in the remaining litterfall decreased in both crop systems (SH_{CS} and FS_{CS}), since they were mineralized and made available in the soil over time, thus becoming part of the biogeochemical cycle.

At the last evaluation (360 DAL), the return of macronutrients to the soil though the litterfall decomposition represented 33.3 and 41.6 kg ha^{-1} of nitrogen, 2.6 and 4.9 kg ha^{-1} of phosphorus, 13.2 and 13.8 kg ha^{-1} of potassium, 57.8 and 60.9 kg ha^{-1} of calcium, 5.8 and 11.4 kg ha^{-1} of magnesium, and 0.3 and 2.5 kg ha^{-1} of sulfur for SH_{CS} and FS_{CS}, respectively. Although the SH_{CS} area did not have an external source of soil fertilizer, the data indicate that most macronutrients had similar returns to the soil in both crop systems, showing that they are efficient systems for nutrient cycling.

The amounts of macronutrients (kg ha^{-1}) added to the soil through the litterfall decomposition at 360 DAL showed the decreasing order Ca > N > K > Mg > P > S, for both SH_{CS} and FS_{CS}. Cavalcante et al. (2020) studied the decomposition and release of leaf nutrients in clonal teak stands in Mato Grosso, Brazil, and found the addition of nutrients in the soil by decomposing litter in decreasing order of Ca > Mg > N > K > P. Rosa et al. (2015), and when the fractions were analyzed separately (leaves, branches and miscellaneous – bark, flowers, and fruits), the order of transfer of nutrients from the litter to the soil was represented as leaves Ca > N > Mg > K > P > S; branches N > Ca > K > Mg > S > P; and miscellaneous N > Ca > K > Mg > P > S.

Conclusions

1. Litterfall presented weight loss throughout the decomposition time, which was greater in shaded coffee (SHcs).

2. The stocks of N, K, and Mg decreased linearly throughout the decomposition time, whereas Ca and S stocks increased in both SHcs and full sun coffee (FScs).

3. In litterfall, potassium stock was similar in both SHcs and FScs systems; however, the stock of nitrogen, calcium, and magnesium concentrations were higher in the FScs system throughout the evaluation period.

Acknowledgements

The authors thank the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) for the financial support for the development of this project (Processo no. 23038.021530/2016-35/Projeto AUPEX no. 1954/2016).

Literature Cited

Acosta, J. A. de A.; Amado, T. J. C.; Silva, L. S. da; Santi, A.; Weber, M. A. Decomposição da fitomassa de plantas de cobertura e liberação de nitrogênio em função da quantidade de resíduos aportada ao solo sob sistema plantio direto. Ciência Rural, v.44, p.801-809, 2014. https://doi.org/10.1590/S0103-84782014005000002

Aidar, M. P. M.; Joly, C. A. Dinâmica da produção e decomposição da serapilheira do araribá (*Centrolobium tomentosum* Guill. ex Benth. - Fabaceae) em uma mata ciliar, Rio Jacaré-Pepira, São Paulo. Revista Brasileira de Botânica, v.26, p.193-202, 2003. https://doi.org/10.1590/S0100-84042003000200007

Alvares, C. A.; Stape, J. L.; Sentelhas, P. C.; Gonçalves, J. L. de M.; Sparovek, G. Köppen's climate classification map for Brazil. Meteorologische Zeitschrift, v.22, p.711-728, 2013. https://doi.org/10.1127/0941-2948/2013/0507

Bambi, P.; Lobo, F. de A.; Dalmolin, A. C.; Dias, C. A. A. Decomposição e redistribuição de nutrientes das folhas de espécies da floresta de transição Amazônia - Cerrado, MT. Ciência e Natura, v.33, p.17-31, 2011.

Bauer, D.; Santos, E. L. dos; Schmitt, J. L. Avaliação da decomposição de serapilheira em dois fragmentos de Caatinga no Sertão Paraibano. Pesquisas, Botânica, v.69, p.307-318, 2016.

Cavalcante, V. S.; Santos, M. L. dos; Cotta, L. C.; Neves, J. C. L.; Soares, E. M. B. Clonal teak litter in tropical soil: decomposition, nutrient cycling, and biochemical composition. Revista Brasileira de Ciência do Solo, v.45, p.1-18, 2020. https://doi.org/10.36783/18069657rbcs20200071

DaMatta, F. M.; Ronchi, C. P.; Eduardo Ferreira Sales, E. F.; Araújo, J. B. S. O café conilon em sistemas agroflorestais. In: Ferrão, R. G.; Fonseca, A. F. A. da; Ferrão, M. A. G.; De Muner, L. H. Café conilon: Incaper, 2017. Cap.19, p.481-494.

Fahl, J. L.; Carelli M. L. C.; Vega, J.; Magalhães, A. C. Nitrogen and irradiance levels affecting net photosynthesis and growth of young coffee plants (*Coffea arabica* L.). Journal of Horticultural Science, v.69, p.161-169, 1994. https://doi.org/10.1080/14620316.1994.11515262

Ferreira, D. F. Sisvar: a computer analysis system to fixed effects split plot type designs. Revista Brasileira de Biometria, v.37, p.529-535, 2019. https://doi.org/10.28951/rbb.v37i4.450

Garlet, C.; Schumacher, M. V.; Dick, G.; Viera, M. Ciclagem de nutrientes em povoamento de *Eucalyptus dunnii* Maiden: produção de serapilheira e devolução de macronutrientes no bioma Pampa. Revista Ecologia e Nutrição Florestal, v.7, p.1-9, 2019. https://doi.org/10.5902/2316980X37057

Gomes, S. S.; Gomes, M. da S.; Gallo, A. de S.; Mercante, F. M.; Batistote, M.; Silva, R. F. da. Bioindicadores de qualidade do solo cultivado com milho em sucessão a adubos verdes sob bases agroecológicas. Revista de La Facultad de Agronomia, v.114, p.30-37, 2015.

Grugiki, M. A.; Andrade, F. V.; Passos, R. R.; Ferreira, A. C. F. Decomposição e atividade microbiana da serapilheira em coberturas florestais no sul do Espírito Santo. Floresta e Ambiente, v.24, p.1-12, 2017. https://doi.org/10.1590/2179-8087.018915

Guimarães, N. de F.; Gallo, A. de S.; Souza, M. D. B. de; Agostinho, P. R.; Gomes, M. da S.; Silva, R. F. da. Influência de sistemas de produção de café orgânico arborizado sobre a diversidade da fauna invertebrada epigéica. Coffee Science, v.10, p.280-288, 2015.

Inkotte, J.; Martins, R. C. C.; Scardua, F. P.; Pereira, R. S. Métodos de avaliação da ciclagem de nutrientes no bioma Cerrado: uma revisão sistemática. Ciência Florestal, v.29, p.988-1003, 2019. https://doi.org/10.5902/1980509827982

INMET - Instituto Nacional de Meteorologia. Dados meteorológicos. Available on: <http://www.inmet.gov.br/portal/index.php?r=estacoes/estacoesAutomaticas>. Accessed on: Mai. 2019.

Lopes, A. S. Guia de fertilidade do solo. Lavras: Ed. da UFV, 2001. 250p.

Malavolta, E.; Vitti, G. C.; Oliveira, S. A. Avaliação do estudo nutricional das plantas: princípios e aplicações. 2.ed. Piracicaba: Patafós, 1997. 319p.

Pegoraro, R. F.; Silva, I. R. da; Novais, R. F. de; Barros, N. F. de; Fonseca, S. Fenóis derivados da lignina, carboidratos e aminoaçúcares em serapilheira e solos cultivados com eucalipto e pastagem. Revista Árvore, v.35, p.359-370, 2011. https://doi.org/10.1590/S0100-67622011000200020

Rezende, C. de P.; Cantarutti, R. B.; Braga, J. M.; Gomide, J. A.; Pereira, J. M.; Ferreira, E.; Tarré, R.; Macedo, R.; Alves, B. J. R.; Urquiaga, S.; Cadisch, G.; Giller, K. E.; Boddey, R. M. Litter deposition and disapperance in Brachiaria pastures in Atlantic forest region of South Bahia, Brazil. Nutrient Cycling in Agroecosystems, v.54, p.99-112, 1999. https://doi.org/10.1023/A:1009797419216

Rodrigues, V. G. S.; Costa, R. S. C.; Leônidas, F. C.; Mendes, A. M. Sistemas agroflorestais com cafeeiro. In: Marcolan, A. L.; Espindula, M. C. (eds.). Café na Amazônia. Brasília: Embrapa Informação Tecnológica, 2015. Cap.20, p.435-446.

Rosa, T. de F. de D.; Scaramuzza, W. M. L. P.; Feitosa, I. P.; Abreu, F. F. M. de. Produção e decomposição de serapilheira em povoamentos de teca no estado de Mato Grosso, Brasil. Ciência Florestal, v.27, p.1117-1127, 2017. https://doi.org/10.5902/1980509830288

Rosa, T. de F. de D.; Scaramuzza, W. L. M. P.; Silva, R. G. Concentração e acúmulo de nutrientes em povoamentos de teca no estado de Mato Grosso, Brasil. Cerne, v.21, p.51-57, 2015. https://doi.org/10.1590/01047760201521011274

Silva, C. J. da; Lobo, F. de A.; Bleich, M. E.; Sanches, L. Contribuição de folhas na formação da serrapilheira e no retorno de nutrientes em fl M. E. de transição no norte de Mato Grosso. Acta Amazônica, v.39, p.591-600, 2009b. https://doi.org/10.1590/S0044-59672009000300014

Silva, H. F.; Barreto, P. A. B.; Sousa, G. T. de O.; Azevedo, G. B.; Gama-Rodrigues, E. F.; Oliveira, F. G. R. B. Decomposição de serapilheira foliar em três sistemas fl Gama-Ro no Sudoeste da Bahia. Revista Brasileira de Biociências, v.12, p.164-172, 2014.

Silva, W. M. da; Cremon, C.; Mapeli, N. C.; Ferri, M.; Magalhães, W. de A. Atividade microbiana e decomposição de diferentes resíduos orgânicos em um solo sob condições de campo e estresse hídrico simulado. Agrarian, v.2, p.33-46, 2009a.

Teixeira, M. B.; Loss, A.; Pereira, M. G.; Pimentel, C. Decomposição e ciclagem de nutrientes dos resíduos de quatro plantas de cobertura do solo. Idesia, v.30, p.55-64, 2012. https://doi.org/10.4067/S0718-34292012000100007

Thomas R. J.; Asakawa N. M. Decomposition of leaf litter from tropical forage grasses and legumes. Soil Biology and Biochemistry, v.25, p.1351-1361, 1993. https://doi.org/10.1016/0038-0717(93)90050-L

Urbano, C. N.; Simonete, M. A.; Ernani, P. R.; Chaves, D. M.; Moro, L. Aporte de serapilheira e nutrientes ao solo em povoamentos jovens de *Eucalyptus* no planalto catarinense. Revista Ecologia e Nutrição Florestal, v.6, p.33-44, 2018. https://doi.org/10.5902/2316980X27068