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Accumulated litter, nutrient stock and decomposition in an Atlantic Forest fragment

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ABSTRACT

Litter dynamics is one of the fundamental processes for the growth and maintenance of native forest fragments, being considered the main pathway for nutrient cycling in forests. Therefore, studies on accumulated litter and nutrient content provide information for a better understanding of nutrient dynamics. The aim of the study was to evaluate leaf litter and nutrient stock in different seasons and the instantaneous rate of decomposition in an Atlantic Forest Fragment over two years. Litter sampling was carried out in 12 permanent plots with dimensions of 20 m x 50 m. Litter dry mass and nutrient concentration were determined. The average annual accumulation of litter was 5269 kg ha^{-1}. There was no statistically significant difference in the amount of litter between seasons. There was a statistically significant difference in the contents of N, P, K Ca and Mg between the different seasons. Nutrient stocks were 123.3, 92.8, 13.2, 11.8, 9.6, 3.0 kg ha^{-1} year^{-1} for Ca, N, Mg, S, K and P respectively. The total of nutrients in the accumulated litter was 253.7 kg ha^{-1} year^{-1}. The litter renewal time was 281 days. The times required for 50% and 95% litter decomposition were 196 and 850 days. The average litter stocks, nutrients and decomposition are in line with other studies, indicating that the Atlantic Forest fragment seasonal semi-deciduous presents indicators of nutrient cycling. These results show that the ecosystem is sustainable from the point of view of cycling and nutrient release.

Keywords: ecosystem functions, nutrient cycling, secondary succession.

Serapilheira acumulada, estoque de nutrientes e decomposição em um fragmento de Floresta Atlântica

RESUMO

A dinâmica da serapilheira é um dos processos fundamentais para o crescimento e manutenção dos fragmentos florestais nativos, sendo considerada a principal via de ciclagem de nutrientes nas florestas. Portanto, estudos sobre a serapilheira acumulada e conteúdo de nutrientes subsidiam informações para uma melhor compreensão da dinâmica dos nutrientes. O objetivo do estudo foi avaliar o estoque de serapilheira e nutrientes em diferentes estações do ano e a taxa instantânea de decomposição em um fragmento de Floresta Atlântica ao longo de dois anos. A amostragem da serapilheira foi realizada em 12 parcelas permanentes com dimensões de 20 m x 50 m. Determinou-se a massa seca da serapilheira e o teor dos nutrientes. O acúmulo médio anual de serapilheira foi de 5.269 kg ha^{-1}. Não houve diferença estatística na quantidade de serapilheira entre as estações do ano. Houve diferença estatística nos teores de N, P, K Ca e Mg entre as diferentes estações do ano. Os estoques de nutrientes foram de 123.3, 92.8, 13.2, 11.8, 9.6 e 3.0 kg ha^{-1} para Ca, N, Mg, S, K e P, respectivamente. O total de nutrientes na serapilheira acumulada foi de 253,7 kg ha^{-1} ano^{-1}. O tempo de renovação da serapilheira foi de 281 dias. O tempo para a decomposição de 50% e 95% da mesma foi de 196 e 850 dias, respectivamente. A produção média de serapilheira, o estoque de nutrientes e a decomposição estão de acordo com outros estudos realizados, indicando que o fragmento de Floresta Atlântica sazonal semidecidual apresenta indicadores de ciclagem de nutrientes. Esses resultados encontrados mostram que o ecossistema se encontra sustentável sob ponto de vista da ciclagem e liberação dos nutrientes.

Palavras-chave: ciclagem dos nutrientes, indicadores ecológicos, sucessão secundária.

1. INTRODUCTION

The Atlantic Forest biome is a biodiversity hotspot (Myers *et al*., 2000); however, it has been significantly impacted in recent decades by anthropogenic activities, with only 12.4% of the 131 million hectares of native forest remaining (SOS Mata Atlântica, 2020). The continued exploitation of natural resources is responsible for forest fragmentation and consequent loss of biodiversity (Fahrig, 2003). Both the fragmentation of forest remnants and the decrease in biodiversity result in a reduction of carbon stock and nutrient cycling capacity (Bello *et al*., 2015; Wolf *et al*., 2013).

The state of Espírito Santo is located in the Atlantic Forest biome; however, in 2019, only 10.5% of the state area had this natural forest formation (SOS Mata Atlântica, 2020). The forest cover in the south of the state is formed by small fragments of seasonal semideciduous forest, due to a series of anthropogenic disturbances (Godinho *et al*., 2014).

An understanding of the degree of disturbance of forest ecosystems, such as degree of fragmentation and capacity for biomass production, can be obtained through the assessment of nutrient cycling (Haag, 1985; Balieiro *et al*., 2004) and accumulated litter provides qualitative and quantitative support, being one of the main parameters when evaluating nutrient cycling (Scoriza *et al*., 2014). Nutrient cycling returns nutrients absorbed by plants to the soil in the form of plant tissues that decompose to make them available again (Odum, 1988). This process is of great importance for natural systems, especially in tropical areas, where the soils are highly weathered (Laliberte *et al*., 2013). Investigating nutrient cycling is an important strategy in forest regeneration programs (Caldeira *et al*, 2019).

The organic material constituted by leaves, branches, bark and plant reproductive material which is deposited in the soil is called “litter” (Kramer and Kozlowski, 1960; Fassebender, 1993). Assessing the seasonality of litter deposition and nutrient content for periods of less than two years may not provide an understanding of nutrient dynamics throughout the biogeochemical cycle. This information helps to choose the most suitable species for the formation and enrichment of the fragments (Caldeira *et al*., 2008).

The accumulation of litter on the soil and the regulation of decomposition is mainly determined by the successional stage of the ecosystem, the degree of disturbance and meteorological variables such as rainfall and air temperature (Scoriza *et al*., 2014; Machado *et al*., 2015). Other studies also indicate that the topographic gradient, the seasons of the year and the litter nutritional composition are important for the regulation of the decomposition rates (Santos *et al*., 2019; Machado *et al*., 2015). Moreover, nutritional composition strongly influences the biological activity and thus decomposition and release of nutrients to the soil (Simpson *et al.*, 2007; Krishna and Mohan, 2017).

Based on these reasons, quantifying litter stock and its nutrients is essential for forest restoration strategies. Considering that meteorological variables and nutritional quality influence litter decomposition, this study evaluated litter and nutrient stock in different seasons and the decomposition rate in an Atlantic Forest Fragment over two years.

2. MATERIAL AND METHODS

2.1. Location and characterization of the study area

The study area is located in a Private Natural Heritage Reserve (RPPN), Fazenda Boa Esperança (Brasil, 1998). The RPPN is located in the municipality of Cachoeiro de Itapemirim, southern Espírito Santo, at coordinates UTM/SIRGAS2000 268275.48 E and 7707754.70 S. The RPPN has a total area of 517 ha, comprising four forest fragments. The present study, located in the Itapemirim River Watershed, was carried out in a forest fragment with an area of 358.86 ha, belonging to the Burarama – Pacotuba – Cafundó ecological corridor. The average altitude of the 12 plots was 110 m, ranging from 91 m to 160 m. The average slope was 6.7%, ranging from 1% to 25%.

The vegetation in the present study area is classified as Submontane Seasonal Semideciduous Forest (IBGE, 2012). In a study on the structure of the arboreal component of the area, Archanjo *et al*. (2012) observed high richness of late secondary species and low density of early succession groups (Table 1), indicating that it is a well-preserved forest fragment with an advanced stage of succession. The characterization of the vegetation in the studied plots (Archanjo *et al*., 2012) and the topography (Delarmelina, 2015) are described in Table 1.

The climate of the region, according to the classification of Köppen, is of the Aw type (tropical with a dry season in winter) (Alvares *et al*., 2014), with an average temperature of the minimum of the coldest month of 11.8ºC, and the average of the highs of the hottest month of 34ºC (Pezzopane *et al*., 2012). According to rainfall characterization maps of Espírito Santo, the annual rainfall in the study area is between 1200 and 1300 mm (Incaper, 2017).

Precipitation data, for the study period and for the historical series (1987 - 2016), were obtained from the National Water Agency (ANA) station (02041002), located in the municipality of Castelo - ES, approximately 12 km away from the study area. The temperature data are from the automatic surface meteorological station of the National Institute of Meteorology (INMET) (Alegre-A617), located in the municipality of Alegre – ES, approximately 26 km from the studied area. The history of monthly averages for this variable was obtained with data from the same station, in the period 2006 to 2016, Figure 1.

Table 1. Characterization of the RPPN vegetation in Cachoeiro de Itapemirim, ES. Brazil.

Parameters	Values	Parameters	Values
Density (ha^{-1})*	1823	Pioneers (%) **	0.2
Number of species	258	Early Secondary Stage (%)	26.5
Number of families	54	Late Secondary Stage (%)	58.1
Diversity index (H')	4.13	Uncharacterized (%)	15.2
Equability (J)	0.74		
Dominant Families		**Most common species**	
Fabaceae (44 sp)		*Astronium concinnum*	
Myrtaceae (27 sp)		*Pseudopiptadenia contorta*	
Euphorbiaceae (14 sp)		*Neoraputia alba*	
Sapotaceae (13 sp)		*Astronium graveolens*	
Rubiaceae (12 sp)		*Gallesia integrifólia*	

*DBH ≥ 5 cm; ** Proportion of individuals by succession category.
Source: Delarmelina (2015), adapted by the author.

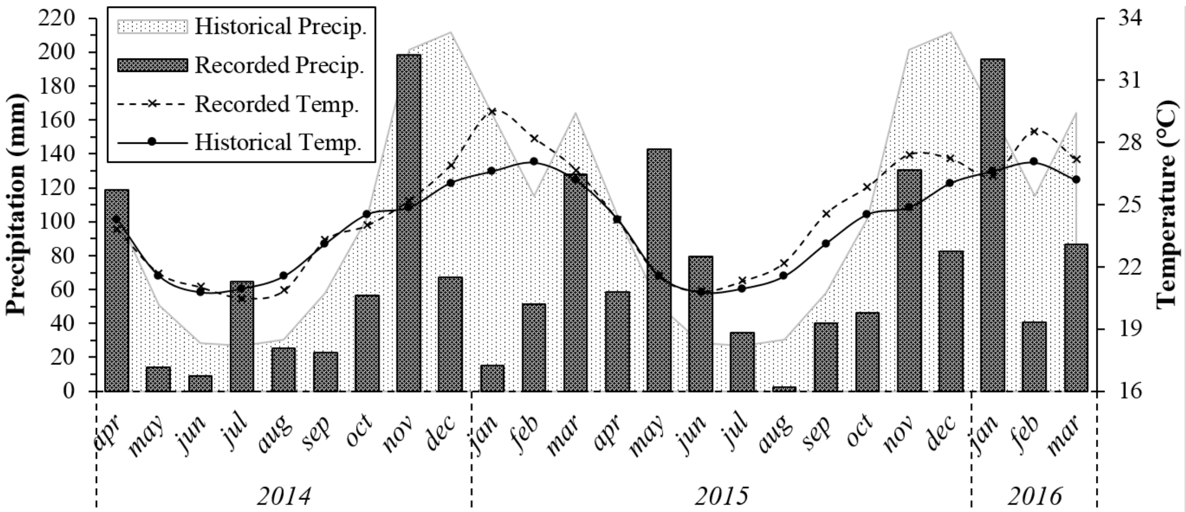

Figure 1. Climatic diagram referring to the study period and historical series of the RPPN in Cachoeiro de Itapemirim, ES, Brazil.

To determine the attributes of the soil the samples were chipped, dried in the shade and sieved (2 mm of mesh), obtaining the fine air-dried soil (TFSA). Later, they were used to determine physical and chemical attributes, according to Embrapa (2011). By means of TFSA, the granulometric composition, sand, silt and clay was obtained. The pH was determined in water (ratio 1:2.5); P, extracted with Mehlich-1 Extractor and read in a molecular absorption spectrophotometer; K and Na, extracted with Mehlich-1 Extractor and read in flame spectrophotometry; Ca^{2+} and Mg^{2+}, extracted with KCl 1 mol L^{-1} and determined by an atomic absorption spectrophotometer; Al^{3+} , extracted with KCl 1 mol L^{-1} and determined by titration; the H + Al (potential acidity), extracted with a 0.5 mol L^{-1} Ca acetate solution buffered at pH 7.0 and determined by titration.

Based on the values obtained from the chemical analysis, the sum of bases (SB) was determined, as well as the effective cation exchange capacity (t), the potential cation exchange capacity (T), the base saturation (V) and the saturation by aluminum (m), according to Embrapa (2011). As shown in Table 2, the highest clay contents were found in the deepest horizons and in the Ferrassol profile. The sand fraction predominated over clay in Planosol and Cambisol profiles. Soil pH ranged from 3.3 to 6.07 and higher acidity was found in Ferrasol type.

Table 2. Chemical and physical attributes of soil.

Horiz.	Depth	Sand	Silt	Clay	pH	P	K	Ca^{2+}	Mg^{2+}	Al^{3+}	SB	t	T	V	m
	cm	%			H_2O	mg dm^{-3}		$cmol_c$ dm^{-3}						%	
Planosol															
A1	0-12	83.3	6.3	10.4	6.0	13.8	70.0	5.5	1.6	0.0	7.2	7.2	9.5	75.8	0.0
A2	12-41	88.0	5.1	6.9	5.8	8.5	27.0	1.2	0.7	0.0	2.0	2.0	3.3	60.4	0.0
E	41-58	87.9	6.1	6.0	6.1	14.5	14.0	0.8	0.4	0.0	1.2	1.2	2.0	60.6	0.0
Btg	58-85	70.7	6.5	22.8	5.1	0.5	3.0	3.4	3.6	1.1	7.0	8.1	10.3	68.1	13.5
Cg	85+	45.6	4.8	49.6	5.2	1.9	5.0	3.8	5.6	4.4	9.6	14.0	24.8	38.7	31.5
Cambisol															
A1	0-7	53.8	17.1	29.1	5.9	7.3	162.0	6.6	2.8	0.0	9.8	9.8	11.8	83.1	0.0
A2	7-17	53.4	19.2	27.4	6.0	1.9	50.0	4.4	1.8	0.0	6.4	6.4	8.9	71.9	0.0
Bi	17-32	50.3	18.1	31.6	5.7	0.7	37.0	3.8	1.8	0.0	5.7	5.7	8.0	71.2	0.0
C	32-47	42.6	19.1	38.3	5.6	0.4	37.0	3.1	2.0	0.0	5.1	5.1	6.6	77.4	0.0
Cr	47+				-	-	-	-	-	-	-	-	-	-	-
Ferrasol															
A1	0-6	32.7	7.4	59.9	4.4	3.1	53.0	2.0	0.6	0.8	2.7	3.5	9.3	29.0	22.9
AB	6-21	30.9	5.3	63.8	4.0	1.5	27.0	0.4	0.3	1.8	0.7	2.5	6.6	11.1	70.9
Bw1	21-47	24.4	5.1	70.5	3.3	0.5	11.0	0.2	0.1	1.7	0.3	2.0	4.8	6.6	84.2
Bw2	47-98	20.3	3.0	76.7	4.3	0.1	2.0	0.1	0.4	1.4	0.5	1.9	5.6	9.1	73.3
BC	98+	47.7	4.4	47.9	5.3	0.1	0.0	0.0	0.6	0.8	0.7	1.5	3.3	20.5	54.4

Horiz: Horizon; P: Phosphorus; K: Potassium; Ca^{2+}: Calcium; Mg^{2+}: Magnesium; Al^{3+}: Aluminum; SB: Sum of exchangeable bases; t: Effective cation exchange capability; T: Cation exchange capacity at pH 7.0; V: base saturation; m: Aluminum saturation.

The contents of K, Ca^{2+} and Mg^{2+}, as well as SB and t were higher in the superficial horizons of the Cambisol and Ferrasol profiles. In general, the soils in the region of the Planosol and Cambisol profiles were more fertile than the soil in the region of the Ferrasol profile, as verified by the higher values of P, SB and V.

2.2. Collection and processing of litter

The sampling of litter was carried out monthly from April 2014 to March 2016. For this, 12 permanent plots with dimensions of 20 m x 50 m were demarcated (Figure 1), totaling 12000 m². The plots were systematically distributed in the area, 350 meters away from each other. Monthly, 8 litter samples were collected per plot, totaling 96 monthly samples. The collection area of each sample was determined by a square with 0.25 m on the side and an area of 0.0625 m².

The litter traps were systematically installed in the plots, with a collector close to each vertex and one in the center of the plot, totaling five collectors per plot, 60 collectors in the entire studied area. The collectors were made in a square format, with PVC material and 2 mm nylon mesh, having 0.75 m on each side (area of 0.5625 m²) and 1 m above the ground.

After collection, the samples were stored in paper bags and dried in an air circulation oven at 65°C. When they reached constant weight, the material was weighed on an analytical balance (0.001 g) to obtain the dry mass. With the dry mass data, the total litter per unit area (kg ha^{-1}) was calculated. The samples were shredded in a Willey-type mill with 1 mm mesh (20 mesh) sieves. Subsequently, they were sent for chemical analysis of the plant material.

2.3. Chemical analysis

The chemical analyses of the macronutrients (N, P, K, Ca, Mg and S) contents of the litter were carried out at Laboratory for Agronomic, Environmental Analysis and Preparation of

Chemical Solutions. Nitrogen was extracted by sulfuric digestion and determined in a Kjeldahl distiller, while the other nutrients were extracted by nitro perchloric digestion, with phosphorus and sulfur being determined by optical spectrophotometry, and potassium, calcium and magnesium determined by atomic absorption spectrophotometry (Tedesco *et al*., 1995).

The amount of macronutrients (kg ha^{-1} $month^{-1}$) of the litter was obtained by multiplying the dry mass (kg ha^{-1} $month^{-1}$) by the nutrient content (g kg^{-1}), according to Equation 1 (Cuevas and Medina, 1986).

$$AN = [Nutrient] \text{ x } DM \tag{1}$$

Where:

AN = Amount of nutrients (kg ha^{-1} $monthly^{-1}$);

[Nutrient] = Nutrient content (g kg^{-1});

DM = Dry mass (kg ha^{-1} $monthly^{-1}$).

2.4. Litter decomposition

The indirect estimate of the decomposition constant (k) was obtained from the relationship between the annual litter input (L) and the annual mean of the accumulated litter (Xss), according to Equation 2, proposed by Olson (1963).

$$k = L/Xss \tag{2}$$

Where:

k = decomposition constant;

L = annual litter production (kg ha^{-1}); and

Xss = annual average of litter on the ground (kg ha^{-1}).

The average renewal time was estimated using the 1 / k ratio. The time required for decomposition of 50 and 95% of litter was through Equations 3 and 4, respectively (Shanks and Olson, 1961).

$$T50\% = 0{,}693/k \tag{3}$$

$$T95\% = 3/k \tag{4}$$

2.5. Statistics and data analysis

Data analysis was performed using the R software (R CORE TEAM, 2016). For the amount and concentration of nutrient in litter, the 12 plots represented the repetitions while the seasons were the treatments: summer (January, February and March), autumn (April, May and June), winter (July, August, and September) and spring (October, November, and December). After statistically significant difference was verified by applying the ANOVA Test (p-value $\leq$ 0.05).

The analysis of the influence of meteorological variables on litter was verified through Spearman's correlation between the amounts of litterfall dry mass and the meteorological elements (air temperature, precipitation and evapotranspiration) for the period of this study.

3. RESULTS AND DISCUSSION

3.1. Leaflitter storage

The average accumulated litter in the seasons over the two years was 5269 kg ha^{-1}, not statistically different by the t test ($p \leq 0.05$). Considering the averages of the first and second year, litter stocks were 5457 and 5079 kg ha^{-1} respectively. Regarding litterfal, the highest values were found in the winter seasons and the lowest values in the autumn season (Figure 2).

In the accumulated monthly litter, the variation occurs irregularly. In the first year, the months of August, October, November, December, January and February had greater accumulation, while in the second year the greatest accumulation occurred between May and October and in the month of February.

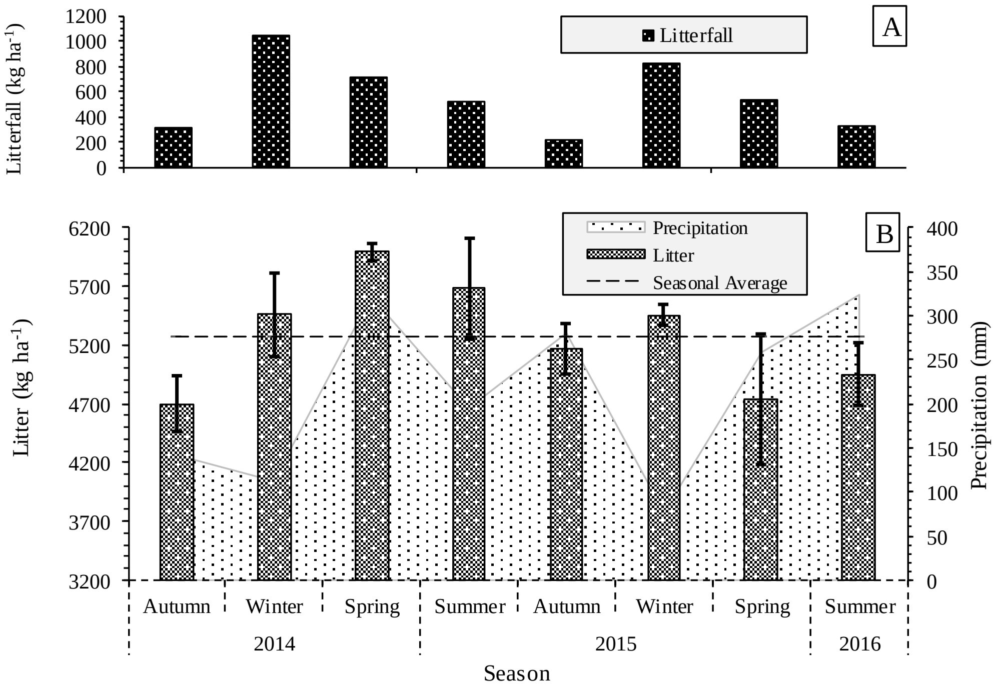

Figure 2. Seasonal Litterfall (A) and Litter (B) variation over two years.

The variation of litter accumulated on the forest floor, observed in the present study, occurs as a function of the difference between litter deposition and its decomposition, not showing a seasonal pattern. According to Delarmelina (2015), it is expected that there is no distinction of a seasonal pattern of litter accumulation due to greater temporal variability of litter deposited, indicating different dynamics of variation for both processes.

Assessing the litter stock on the forest floor in a Submontane Seasonal Semi-deciduous Forest, Godinho *et al*. (2014) found an accumulated 5500 kg ha^{-1}. This value is similar to the mean values in our study, 5269 kg ha^{-1} over two years. In an area undergoing restoration in a region of the Dense Ombrophilous Lowland Forest, Caldeira *et al*, (2019) evaluated litter accumulation under different spacing and number of species. The authors found values ranging from 3910 kg ha^{-1} for the treatment with greater spacing with fewer species to 5110 kg ha^{-1} for the treatment with smaller spacing and with greater species diversity. The average litter accumulation was 4440 kg ha^{-1}.

The amount of litter found in this study was slightly lower than that found in other studies considering the same forest formation. In a Seasonal Semideciduous Forest in the Cerrado biome, Martins *et al*. (2021) found 8300 kg ha^{-1} of accumulated litter, or 57% more. Vital *et al*. (2004), considering the same forest formation located in the state of São Paulo, found an average annual accumulation of 6227 kg ha^{-1}, that is, 18% more than in our study. Santos *et al*. (2019) evaluating the same type of forest formation in the state of Rio de Janeiro found an average stock of 7295 kg ha^{-1}, ranging from 5760 kg ha^{-1} in the rainy season to 8830 kg ha^{-1} in the dry season. One of the possible answers for the lower litter accumulation is justified by the fact that it is a secondary forest succession, being 26% Early Secondary Stage.

Comparing the litter stock in an area under restoration with a primary Atlantic forest, Correia *et al.* (2016) concluded that even after 23 years, the restored area did not reach the levels of accumulated litter in the primary forest. The study by Câmara (2020) shows that litter accumulation was greater in the fragment under advanced stage of regeneration 3529 kg ha^{-1} against only 2146 kg ha^{-1} in the fragment in the early stage. Another work that contributes to this justification is the research by Pinto *et al*. (2009), who, evaluating litter accumulated in Seasonal Semideciduous Forest, found 7008 kg ha^{-1} and 4648 kg ha^{-1} in formations in the maturity and initial stages, respectively.

Litter accumulation is influenced by biological activity, abiotic conditions and litter production rate. The greater the litter production, the greater the tendency of litter accumulation on the ground. The successional stage is another determining factor, thus, more preserved ecosystems present greater production (Pezzato and Wisniewski, 2006; Pinto *et al.* 2009).

There was no seasonality in litter accumulation for the first year, indicating that there was no effect of climatic elements on this variable in this period (Table 3). However, in the second year, the accumulation was significantly and negatively correlated with precipitation, not having a significant correlation with the other climatic elements.

Table 3. Spearman correlation between litterfall and meteorological variables over two years in the RPPN Fazenda Boa Esperança, Cachoeiro de Itapemirim, ES.

Year	Temp.[1]	Precipitation[2]								Et0[3]
		0	1	2	3	4	5	6	7	
2014-2015	0.25	-0.07	-0.17	-0.26	-0.22	-0.46	-0.33	-0.44	-0.57	0.47
2015-2016	-0.37	-0.67*	-0.19	-0.18	0.51	0.39	-0.38	-0.14	-0.09	-0.05

[1]Average air temperature; [2]Precipitation (0: referring to the month of collection; 1: referring to the first month prior to the collection; 2: referring to the second month prior to the collection; 3 referring to the third month prior to the collection; 4: referring to the fourth month previous to the collection to the collection; 5: referring to the accumulated precipitation of three months before the collection; 6: referring to the accumulated precipitation of four months before the collection; and 7: referring to the accumulated precipitation of five months before the collection); [3]Evapotranspiration.
* Significant by t test ($p \leq 0.05$).

3.2. Chemical composition of litter deposited on the soil

There was a statistically significant difference between the seasons for all nutrients, except for sulfur, Figure 3. The mean concentration of nutrients in litter accumulated throughout the seasons followed the order: Ca > N > Mg > S > K > P, representing 23.3, 17.7, 2.5, 2.2, 1.8 and 0.6 g kg^{-1} respectively.

The concentrate of the nutrients phosphorus, potassium, calcium and magnesium decreased in the seasons of the second year evaluated, showing a statistically significant difference ($p \leq 0.05$). Graphically, the seasonal means of sulfur decreased; however, they did not differ statistically ($p \leq 0.05$).

There was a variation in the order of the amount of nutrients observed in the two years of the present study. When compared to other studies, the first year had the same decreasing order observed by Delamerlina (2015): Ca > N > Mg > K > S > P, differing from the work by Godinho *et al*. (2014), where the descending order was Ca > N > K > Mg > S > P. Studying the nutrient concentration in litter accumulated from leaves and branches, in a Dense Ombrophylous Lowland Forest, Caldeira *et al,* (2019) found a similar order: Ca > N > Mg > K > S > P.

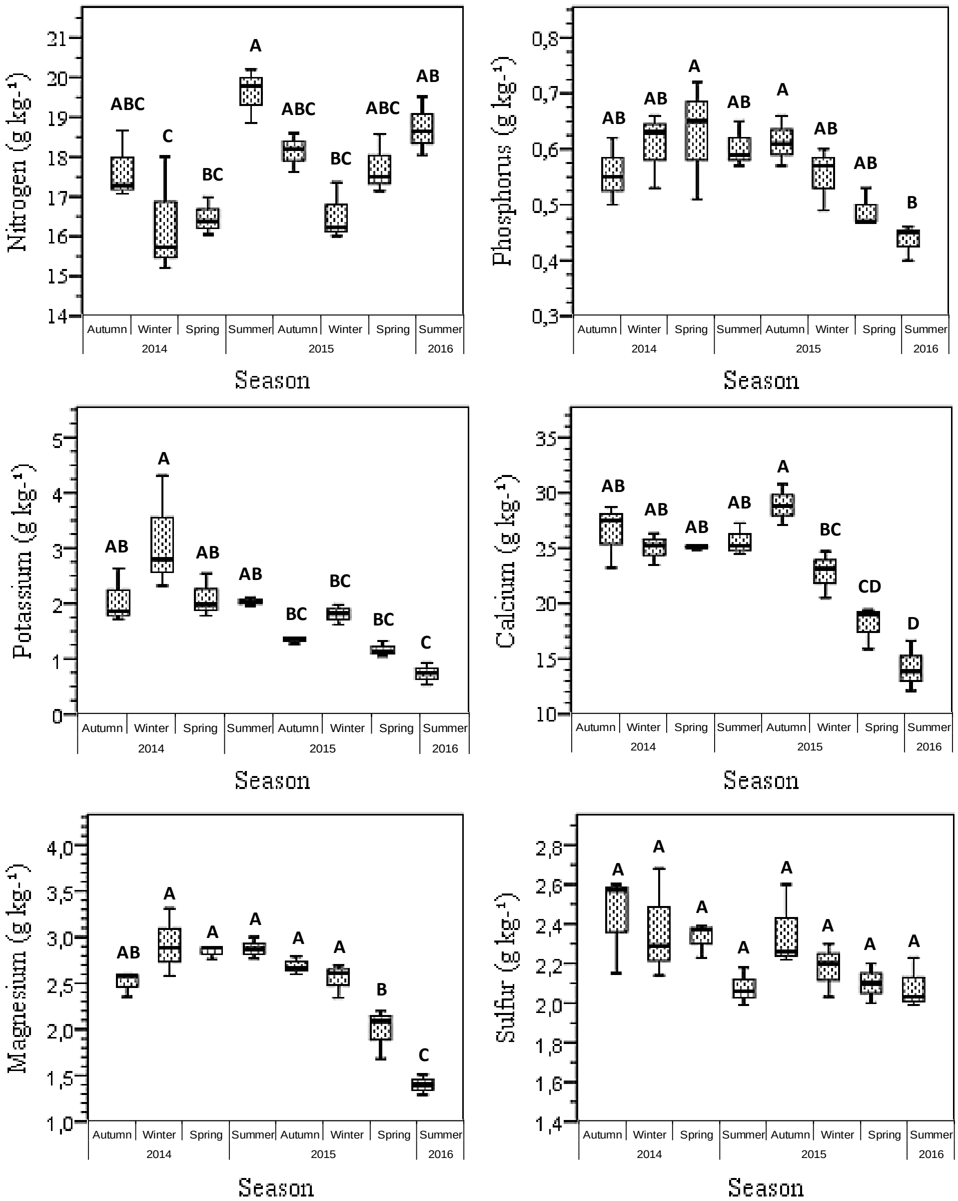

Figure 3. Seasonality of nutrient concentration in accumulated litter over the seasons in a fragment of Atlantic Forest.
Different letters between seasons in a given nutrient represent a statistically significant difference ($p < 0.05$). Bars: Confidence Interval (95%).

Evaluating nutrient cycling in a Seasonal Semideciduous Forest in the state of Rio de Janeiro, Santos *et al*. (2019) found the following order of concentration in both the dry and rainy seasons: Ca > N > Mg > P > K. Also considering the study by Santos *et al*. (2019), the average concentration of nutrients was close to the present research.

Assessing nutrient cycling along a secondary succession of semi-evergreen tropical forest in South-Eastern Mexico, Sánchez-Silva *et al.* (2018) found that leaf litter contents were lower in the dry season, the same behavior in the present study.

The average annual stock, considering the sum of all nutrients in the accumulated litter, was 253.7 kg ha^{-1} $year^{-1}$. Considering the means of each year separately, the nutrient stock was 278.3 and 229.2 kg ha^{-1} for the first and second year, respectively. The 2015 summer season was the one with the highest nutrient stock, 299.6 kg ha^{-1}, followed by the spring of 2014 with 296.5 kg ha^{-1} and the autumn season of 2015 with 279.5 kg ha^{-1}. The smallest amount of nutrients was found in the last season evaluated, summer 2016 with 186.2 kg ha^{-1}.

The nutrient calcium was the most representative, contributing 123 kg ha^{-1} year^{-1}, or 48.6% of the total accumulated, Figure 4. Following the order of importance, we have N, Mg, S, K and P, contributing with the amounts of 92.8, 13.2, 11.8, 9.6, 3.0 kg ha^{-1} year^{-1}, representing 36.6, 5.2, 4.7, 3.8 and 1.2% of the total.

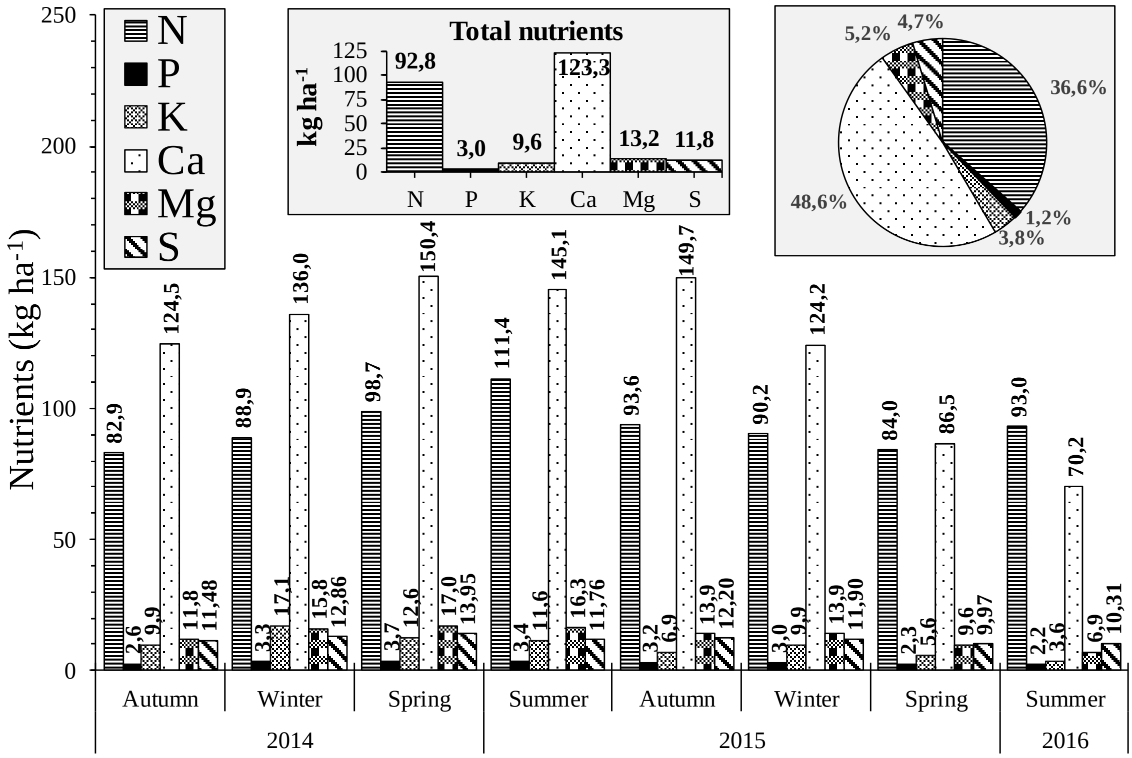

Figure 4. Annual average and seasonal amounts of nutrients in accumulated litter in a fragment of Forest Atlantic.

The largest amounts of Ca and N observed are associated with a large amount of these nutrients in the plant tissue, and Ca still has a slower release by the decomposition process as it is a structural component of plant tissue, with low mobility in this tissue (Godinho *et al*., 2014). Among all the elements analyzed, Ca has the lowest mobility within the plant, its concentration is low in the cytosol of cells, with a tendency to accumulate in the apoplast, vacuole and endoplasmic reticulum (Taiz and Zeiger, 2017).

Considering the sum of Ca + N, the participation of these macronutrients was 85.2%. These values are similar to the study by Godinho *et al.* (2014), in which they found a participation of 87.3%. Assessing the litter accumulated in a Montana Dense Ombrophilous Forest, Freitas *et al*. (2015) found a higher nutrient stock, being 293 kg ha$^{-1;}$ however, the participation of N + Ca was similar to the present study, 83, 7%.

Contrary to Ca, the low P content is due to the high mobility of the element from physiologically mature tissues to younger tissues (Malavolta *et al*., 1997). Regarding K^+, the highest concentrations were verified in the season with the lowest rainfall recorded, winter 2014. This behavior was also observed by Vital *et al*. (2004), in which the decrease in precipitation provided considerable increases in K+. The explanation for these results is anchored in the fact that the nutrient is absorbed and transported in the ionic form K+, which makes it easily leached from the tissue surface during periods of rainfall. From a functional point of view, the element does not have a structural character but it is essential for osmotic regulation such as stomatal opening and closing (Taiz and Zeiger, 2017).

In an area under restoration process, Caldeira *et al.* (2017) evaluated the nutrient redistribution rate in two native tree species. For the authors, nutrients N, P and K were the most redistributed with means of 50.4, 70.9, 68.0% respectively. Considering the average redistribution only for the *Bixa arborea* species, the researchers found higher redistributions, 59.7, 84.9 and 72.6% for N, P and K, respectively.

In a Seasonal Semideciduous Forest, the average nutrient stock for the dry and wet season, Santos *et al.* (2019) found 102.5, 96.7, 37.3, 4.9 and 3.0 kg ha^{-1} for Ca, N, Mg, P and K, representing a total of 244.4 kg ha^{-1}. Considering the same nutrients as the work presented, the present study recorded a total of 241.9 kg ha^{-1}.

According to Caldeira *et al*. (2019), the return of nutrients to the soil through accumulated litter, is extremely important in improving and maintaining soil fertility. Also according to Delarmina (2015), because they are part of organic compounds, the nutrients from accumulated litter are less susceptible to leaching than those stored in the soil.

3.3. Litter decomposition

The mean decomposition constant for the two years was k = 1.29 (Table 4). The first year had k = 1.43, indicating a faster decomposition rate when compared to the average of the two years. The second year of monitoring resulted in a decomposition coefficient k = 1.13, indicating a decrease in decomposition when compared to the first year of evaluation and the average of the entire period studied.

The average renewal time 1/k was 281 days, decreasing to 255 days in the first period. The renewal time in the second period was longer, requiring 321 days. Estimates for the average decomposition of 50% and 95% of litter were 196 and 850 days, respectively. It is noted, however, that this time decreases substantially in the first year, requiring only 176 and 764 days, respectively. Approximately 969 days were required for 95% of the litter to decompose.

Table 4. Decomposition constant k, renewal time T50% and T95% of litter accumulated in the RPPN Fazenda Boa Esperança, Cachoeiro de Itapemirim, ES.

Year	k	1/k	T 50%	T 95%	1/k	T 50%	T 95%
		Year			Days		
1st year	1.43	0.70	0.48	2.09	255	176	764
2nd year	1.13	0.88	0.61	2.65	321	224	969
Average	1.29	0.77	0.54	2.33	281	196	850

As shown, the decomposition coefficients in the different periods are within the range considered acceptable. The values of K considered high, according to Olson (1963), are characteristic of tropical forests and these range from 1 to 4. For the present study, the average was 1.29. Evaluating the decomposition coefficients in 3 fragments under increasing stages of regeneration in Seasonal Semideciduous Forest, Câmara (2020) found much lower coefficients: 0.93, 0.99 and 1.05. According to the author, the ecosystem is not yet re-established, with deficiencies still persisting in the processes of transformation of plant material and nutrient cycling.

Evaluating the same type of forest formation, Vital *et al*. (2004); Cunha *et al.* (1997); Patricia and Morellato (1992) reported k = 1.71, 1.2, 1.6 respectively. Pinto *et al.* (2009) compared the decomposition rate in two seasonal semideciduous forest fragments and the value of k was 1.36 and 1.26 in the fragment in the initial stage and in the maturity stage, respectively. These results are similar to the present study. According to the authors, the estimated litter half-life was 186 and 200 days for the early and mature forest, respectively. For 95% of the litter to be decomposed, the estimated time was 807 and 869 days. respectively.

Although there has been variation in the decomposition constant over the years evaluated, it is known that litter in a natural environment is the result of interactions between the characteristics of the environment, the decomposing fauna, and the composition of the plant residue (Swift *et al.*, 1979; Correia and Andrade, 1999). The variation in the accumulated litter decomposition constant is closely linked to the alternation of weather conditions provided over the two years analyzed, especially the rainfall regime (Sanches *et al*., 2009).

According to Sánchez-Silva *et al*. (2018), the average time needed to decompose 50% of the litter in a secondary succession of semi-evergreen tropical forest was 6 months, or 180 days. These results are similar to our findings. The authors observed that the remaining leaf mass was greater in mature forest than in forests in less developed stages.

In tropical forest fragments whose structure presents greater development and with the presence of different strata, the smallest variation in light, temperature and humidity favors the diversification of decomposing organisms, favoring the activity of these organisms in the decomposition process (Pereira *et al*., 2013). In these environments, according to Sanches *et al*. (2009), the seasonality of precipitation directly regulates the activities of decomposing organisms, as the return of precipitation after a dry period increases the biodiversity of these organisms, contributing to the increase in the rate of litter decomposition.

According to Pires *et al*. (2006), accumulated litter regulates several processes in the dynamics of ecosystems, being responsible for the stability of the nutrient cycling system, releasing them to the soil through decomposition. In weathered tropical forest soils with low natural fertility, the maintenance of litter accumulated on the forest floor becomes very important in the nutrient cycling process (Godinho *et al*., 2014).

4. CONCLUSION

The average litter stocks and nutrients on the forest floor are in line with other studies, indicating that the Seasonal Semi-Deciduous Atlantic Forest Fragment presents indicators of sustainability in nutrient cycling.

The statistical analysis did not show a seasonal pattern for the amount of litter accumulated or the influence of meteorological variables, but there was a statistical difference between the concentrations of nutrients in the different seasons of the year.

The time required for the decomposition of 50% and 95% of litter was 196 and 850 days. These results show that the ecosystem is sustainable from the point of view of cycling and nutrient release.

5. ACKNOWLEDGEMENTS

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6. DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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