ENFLO
Ecologia e Nutrição Florestal/*Ecology and Forest Nutrition*
www.enflo.com.br

ISSN: 2316-980X http://dx.doi.org/10.5902/2316980X67763 Scientific Article/Artigo Científico

Leaf litterfall, decomposition and nutrients release in a Seasonal Semideciduous Forest in Southern Brazil[1]

Monique Pimentel Lagemann[2]; Hamilton Luiz Munari Vogel[3]; Frederico Costa Beber Vieira[4]; Leandro Homrich Lorentz[5]; Mauro Valdir Schumacher[6]; Grasiele Dick[7]

Abstract: Biogeochemical cycling study of ecosystems and their functioning are fundamental for planning conservation practices and management of forest remnants in Brazil. The objective of the study was to characterize the leaf litterfall production rate and the nutrients release via decomposition in a fragment of Seasonal Semideciduous Forest, in Southern Brazil, in advanced stage of regeneration. For two years, evaluations of litterfall and leaf litter decomposition (using the mass loss method with litterbags) were performed monthly, as well as their nutrient content analysis. Annual input of leaf litterfall was 4,532.7 kg ha^{-1} of dry matter, which promoted, for the two-year period, a supply of 195.5, 9.2 and 55.3 kg ha^{-1} of N, P and K, respectively. The litter nutrients use efficiency followed the decreasing order P > K > N. The annual decomposition constant for leaf litter was 1.16, reaching a half-life at 215 days, making 84.4% N, 72.7% P and 92.9% K available at the decomposition end of two years. In the two years of collection, the largest deposition rate of litter occurred in the spring, with the highest peak in October, indicating a seasonal deposition behavior. The forest fragment presents high production of leaf litter (66% leaves) and input of N. The rapid decomposition of leaf litter contributes to the release of nutrients over time, N and K initially, and P in the long run. P is limited due to the high efficiency of its use.

Keywords: Nutrient cycling; Litterbags; Forest Nutrition; Native forest

Produção de serapilheira foliar, decomposição e disponibilização de nutrientes em Floresta Estacional Semidecidual no Sul do Brasil

Resumo: O estudo da ciclagem biogeoquímica dos ecossistemas e o seu funcionamento, são fundamentais para o planejamento de práticas de conservação e manejo dos remanescentes florestais no Brasil. O objetivo do estudo foi caracterizar a produção de serapilheira foliar e a disponibilização de nutrientes via decomposição foliar em fragmento de Floresta Estacional Semidecidual, na região Sul do Brasil com clima subtropical. Em um fragmento em estágio avançado de regeneração, durante dois anos, foram avaliadas mensalmente a serapilheira produzida e a decomposição das folhas, pelo método de perda de massa com *litterbags*. Com a determinação dos teores de nutrientes no tecido vegetal foram obtidas as quantidades de nutrientes aportadas pela serapilheira e a disponibilização de nutrientes via decomposição. A produção de serapilheira foliar foi de 4.532,7 kg ha^{-1} ano^{-1}, com um aporte de 195,5 kg ha^{-1} de N, 9,2 kg ha^{-1} de P e 55,3 kg ha^{-1} de K, durante dois anos. A eficiência do uso de nutrientes da serapilheira seguiu a ordem decrescente P > K > N. A constante de decomposição anual para a serapilheira foliar é de 1,16, alcançando o tempo de meia-vida aos 215 dias, disponibilizando pela decomposição 84,4% de N, 72,7% de P e 92,9% de K ao final dos dois anos. O fragmento florestal apresenta alta produção de serapilheira foliar e aporte de N. Há limitação de P devido à alta eficiência do seu uso. A rápida decomposição da serapilheira foliar contribui para a disponibilização de nutrientes ao longo do tempo, N e K inicialmente e P a longo prazo.

Palavras-chave: Ciclagem de nutrientes; *Litterbags*; Nutrição florestal; Floresta nativa

---

[1] Received on 21 September 2021 and accepted for **scientific article** publication on 04 March 2022.
[2] Forest Engineer, M.Sc. Federal University of Santa Maria, RS state, Brazil. E-mail: <moniquelagemann@gmail.com>
[3] Forest Engineer, Dr. Professor at Federal University of Pampa, RS state, Brazil. E-mail: <hamiltonvogel@unipampa.edu.br>
[4] Agronomist, Dr. Professor at Federal University of Pampa, RS state, Brazil. E-mail: <fredericovieira@unipampa.edu.br>
[5] Agronomist, Dr. Professor at Federal University of Pampa, RS state, Brazil. E-mail: <leandrolorentz@unipampa.edu.br>
[6] Forest Engineer, Dr.nat.techn. Full Professor at Federal University of Santa Maria, RS state, Brazil. E-mail: <mauro.schumacher@ufsm.br>
[7] Forest Engineer, Dra. Post-Doctoral student at Postgraduate Program in Forest Engineering, Federal University of Santa Maria, RS state, Brazil. E-mail: <grasidick@hotmail.com>

Introduction

The Atlantic Forest biome comprises an area of 21.77 thousand ha, which is equivalent to 4.5% of Brazil's forest cover (SNIF, 2016). Due to its high degree of endemism of plant and animal species, Atlantic Forest is one of the most diverse and distinct biome in the world. However, the conservation of the biome is fragile and threatened, since 92% of the forest area is mostly composed of small fragments (<100 ha). Fragmentation as a degrading process is due to anthropic pressure (SCHEER et al., 2011), causing deforestation and threatening the fauna, putting at risk the functionality of these ecosystems (BELLO et al., 2015).

Each ecosystem has structural and functioning patterns that are decisive for its productivity, which also regulates the cycling of nutrients. Productivity is determined according to the characteristics of climate, succession stage (DICKOW et al., 2012), altitude (SOUSA-NETO et al., 2017), forest typology (MARTINELLI et al., 2017), soil and fertility (PINTO et al., 2009), and is modified by disturbing conditions (SCHUMACHER et al., 2018).

In biogeochemical cycling, litter is the compartment responsible for the return of organic matter and nutrients from the plant component to the soil (DICKOW et al., 2012), controlling the carbon and mineral cycle through decomposition (GRUGIKI et al., 2017). Litter also promotes soil quality, both physically and biologically, making it a favorable environment for the activity of edaphic fauna and decomposing microorganisms (ASSIS et al., 2017). Decomposition rate is mainly affected by precipitation, temperature, soil fauna activity, chemical characteristics of plant material and allelopathic compounds (ASSIS et al., 2017; ZHANG et al., 2008), undergoing changes in time and in the decomposition patterns according to habitat conservation and disturbance occurrence (SILVA et al., 2018).

The dynamics of biogeochemical cycling, through litterfall, decomposition and availability of nutrients, presents a different behavior between regions with tropical and subtropical climate in the Atlantic Forest biome. While the litterfall seasonality in the tropical region is regulated by low rainfall (ZHANG et al., 2014), under subtropical climate it is due to low temperatures (KÖNIG et al., 2002), as well as the decomposition rates that decrease towards the poles (ZHANG et al., 2008). However, knowledge about the ecology of secondary forests of the different types of forest belonging to the Atlantic Forest located in the subtropical climate, becomes a tool for planning practices aimed at their conservation, recovery and sustainable management. Thus, this study aimed to evaluate leaf litterfall and the nutrients release via decomposition in a fragment of Seasonal Semideciduous Forest in the subtropical region, in Southern Brazil.

Material and methods

Characterization of the experimental area

The study was developed in a fragment of the Seasonal Semideciduous Forest in an advanced stage of regeneration in the region of São Sepé county, central region of Rio Grande do Sul State, Brazil. The fragment is located between the coordinates 30°12'45” S and 53°42'57” W at 200 m a.s.l., with an area of approximately 40 ha, classified as a small forest fragment (RIBEIRO et al., 2009), without human interference and isolated from agricultural activities for approximately 50 years. The native forest fragment belongs to a private soybean farm, signed through a research agreement between the Federal University of Pampa (UNIPAMPA-Campus São Gabriel) and Cooperative Tritícola Sepeense Ltda. (COTRISEL) of São Sepé county.

The region's climate is humid subtropical, Cfa according to the Köppen classification, with an average annual rainfall from 1.600 to 1.900 mm, and an average annual air temperature of 18°C to 20°C (ALVARES et al., 2014). Along the study period, rainfall was uniformly distributed, accounting an annual average of 1.800 mm; no water restrictions were observed, but the lowest volumes were recorded in winter, while peaks occurred from October to December (INMET, 2018). In the same period, the average air temperature was 20°C; the highest values were recorded in the months of January and February (average 25°C), and the lowest values in the months June and July (average 13.6°C) according to data from the station at 62 km, in Santa Maria-RS (INMET, 2018).

The soil at the site is classified as Haplic Planosol (Embrapa, 2018), with low levels of P in the soil (Table 1), intermediate levels of K, Ca and Mg, high levels of S, Cu, Zn and B according to the reference values for forest crops (CQFS, 2016).

Table 1 - Chemical characterization of the soil in the Seasonal Semideciduous Forest site in Central Depression region, RS, Brazil.

Tabela 1 - Caracterização química do solo em Floresta Estacional Semidecidual na região da Depressão Central, RS, Brasil.

Depth	**OM**	**Clay**	**pH**	**P-Mehlich**	**Exch. K**	**S**	**m**	**BS**	
(cm)	---- % ----		H_2O	-------------- mg dm^3 --------------			--------- % ----------		
0-20	2.7	18	4.8	6.7	52	14.4	6.1	37.4	
20-40	1.3	19	4.9	7.9	28	4.5	28	24.3	
Depth	**Ca**	**Mg**	**Al**	**H+Al**	**CEC_e**	**CEC_{pH7}**	**Cu**	**Zn**	**B**
(cm)	-------------------------- $cmol_c$ dm^3--------------------------						--------- mg dm^3 ---------		
0-20	3.5	1.0	0.3	7.7	4.9	12.3	0.54	2.88	0.4
20-40	1.2	0.5	0.7	5.5	2.5	7.3	0.59	0.59	0.3

Exch. K: exchangeable K; m: Aluminum saturation index; BS: Base saturation; CEC_e: Cation exchange capacity (effective); CEC_{pH7}: Cation exchange capacity (total).

The floristic diversity of the fragment is considered as intermediate and the species of greater importance are *Trichilia claussenii* C.DC., *Matayba elaeagnoides* Radlk., *Ocotea pulchella* (Nees) Mez, *Sorocea bonplandii* (Baill.) W.C. Burger, Lanjouw & Boer, *Helietta apiculata* Benth. and *Sebastiania commersoniana* (Baill.) L.B. Sm. & Downs.

Litterfall

The litterfall was evaluated through collections in 25 circular traps (Ø = 50 cm, mesh = 2 mm, soil height = 100 cm) systematically deployed in five rectangular plots of 20 m x 15 m, with a distance of 30 m between plots, represented in Figure 1.

Litterfall was collected from the traps monthly, for two years, from October 2014 to September 2016. After each collection, the material was classified into leaves, thin branches (<0.5 cm in diameter) and miscellaneous (fruits, flowers, seeds, bark and unidentified material). Coarse branches were not sampled. Subsequently, the samples were dried in an oven at 65°C until reaching constant weight and weighed on a precision scale (0.01 g) to determine the dry mass (g). Annual production of each fraction was calculated according to Equation 1 (SCHUMACHER & VIERA, 2015):

$$LF = \sum MLF \times 10.000/CA \quad \text{(Eq.1)}$$

Where, LF: Litterfall (kg ha^{-1} $year^{-1}$), ∑MLF: Monthly litterfall (kg ha^{-1}) and CA:

Collector area (0.1963 m²).

Pearson's simple linear correlation analysis was performed at 5% probability of error between the components of the litterfall and the climatic variables monthly precipitation and average monthly temperature. Precipitation was obtained according to data from the Mineral Resources Research Company informed by the National Water Agency (ANA) for the region of São Sepé, Rio Grande do Sul state. The average monthly temperature was obtained by the Meteorological Database for Teaching and Research of the National Institute of Meteorology (BDMEP/INMET) of the climate station in the São Gabriel County, Rio Grande do Sul state (as it is the closest station to the experiment site).

Figure 1 - Sketch of the distribution of litter traps in one of the plots allocated within the forest (A). Aspect of one of the litter traps (B). Central Depression Region, RS, Brazil.
Figura 1 - Esquema da distribuição dos coletores de serapilheira em uma das parcelas alocadas na floresta (A). Aspecto de um dos coletores de serapilheira utilizado (B). Região da Depressão Central, RS, Brasil.

Leaf litter decomposition

The litterbags method was employed to evaluate the decomposition of the leaf litter fraction. The leaf fraction used to fill out the litterbags was collected in August 2014, in the same study area, taking into account only the newly fallen material (only the leaves of layer L of the litterfall). After dried in a circulation oven with air renewal at 65°C until constant weight, 12 g of leaves were packed in each litterbag, made of nylon, with 4 mm mesh size and dimensions of 20 cm x 20 cm. Close to the location of the litter deposition assessment plots, three plots (30 m long x 4 m wide) were demarcated, where the bags with the leaf fraction were allocated. In each plot, 30 lines with an equidistance of one meter were demarcated and four litterbags were installed in each line, thus totaling 360 bags to assess the decomposition in each plot.

The evaluations were carried out monthly, between October 2014 and October 2016, with the collection of a litterbag line in each plot (12 monthly samples). The definition of the line to be collected was based on a previous draw. The litterbags were collected carried out in a thorough manner, to avoid material loss, placing the material in plastic packaging and sending for the laboratory. In the laboratory, the samples went through a cleaning process, with the aid of tweezers and a brush to remove adverse material, such as roots, small plants, insects, soil or other material that did not come from the leaf fraction, due to the permanence of them on the ground.

Then, the samples were dried in an oven at 65°C until constant weight and the dry mass was determined on a precision scale (0.01 g). Based on the results, the percentage of remaining leaves (W%) was calculated (Equation 2).

$$W\% = \frac{Wt\ x\ 100}{Wo} \qquad \text{(Eq. 2)}$$

Where, Wt = average litter mass remaining at $t = i$, and Wo = the initial leaf litter mass, both expressed in g.

The annual decomposition rate (k) of the leaves was calculated by adjusting the negative exponential equation (Equation 3), described by Olson (1963).

$$W(t) = Wo.e^{-kt} \qquad \text{(Eq. 3)}$$

Where, W = the mass of leaf litter remaining in the litterbag as a function of $t = i$, and Wo = the mass of initial leaf litter, both expressed in g.

The leaf litter half-life (50%) was calculated by t0.5 = ln 2/K and the decomposition time of 95% by t0.95 = 3/K, based on the coefficient (K) obtained using LOG in base 10 for the constant k of the equation (OLSON, 1963).

Content, efficiency and release of nutrients in leaf litter

The chemical analyzes of the leaf litterfall (only the leaves were analyzed) and the leaf material of the litterbags, proceeded by means of three samples composed at $t = i$, ground in a Wiley blade mill with a 30 mesh sieve submitted to sulfuric digestion. After obtaining the digestion extract, aliquots were removed to determine the levels of N, P and K (g kg^{-1}), determined, respectively, by Kjeldhal distiller (TEDESCO et al., 1995), spectrophotometry (MURPHY; RILEY, 1962) and by flame photometry (TEDESCO et al., 1995).

The amounts of nutrients (kg ha^{-1}) added by the leaf fraction of the litterfall were obtained by the product between the monthly biomass production (kg ha^{-1}) and the nutrient contents (g kg^{-1}) at $t = i$. The efficiency of nutrient use was estimated for the elements N, P and K of the litter, through the relationship between the input rate of the leaf fraction from the litter and the amount of nutrients transferred by that fraction (VITOUSEK, 1982). The availability of nutrients (R%) was obtained by the equation (Equation 4; GUOANDSIMS, 1999).

$$R\% = \frac{WoCo - WtCt}{WoCo} x100 \qquad \text{(Eq. 4)}$$

Where, WoCo = relationship between the leaf litter mass (g) inside the litterbag and the respective nutrient content (g kg^{-1}) at $t = 0$, and WtCt = relationship between the leaf litter mass (g) in the litterbags and corresponding nutrient content (g kg^{-1}) at $t = i$.

Results

Litterfall: production, contents and quantity of nutrients in the leaves

The Semideciduous Seasonal Forest under study obtained 6.869,9 kg ha^{-1} year^{-1} litterfall, of which 4.532,7 kg ha^{-1} year^{-1} are from the leaf fraction (Table 2), which represented 66.0% of the litter composition. Leaf production was lower in the period from April to June, while the largest leaf production occurred from July to October.

Litterfall production had no significant correlation with precipitation and temperature (Table 3). However, input rates of thin branches and miscellaneous had significant correlation with the temperature.

Among the nutrients monitored in leaf litter in this study, N had the largest concentration, followed by K and P (Table 4), contributing with an average annual contribution of 97.74, 27.64 and 4.58 kg ha^{-1}, respectively.

Table 2 - Litterfall (kg ha^{-1}) from October/2014 to September/2016 in the Seasonal Semideciduous Forest in Central Depression region, RS, Brazil.
Tabela 2 - Produção de serapilheira (kg ha^{-1}) de outubro/2014 a setembro/2016 na Floresta Estacional Semidecidual na região da Depressão Central, RS, Brasil.

Period	Leaves	Thin branches	Miscellaneous	Total Litterfall
1st year	----------------------------------	kg ha^{-1}	------------------------------	
Oct/14	624.5	108.9	221.2	954.6
Nov/14	371.4	75.1	165.7	612.2
Dec/14	302.6	139.6	293.1	735.3
Jan/15	159.0	52.3	92.7	304.0
Feb/15	270.7	50.3	144.9	465.8
Mar/15	262.4	63.4	136.5	462.3
Apr/15	246.1	70.0	67.1	383.2
May/15	349.2	84.5	75.2	508.9
Jun/15	206.2	12.0	9.8	227.9
Jul/15	493.7	14.1	46.6	554.4
Aug/15	454.2	77.1	73.5	604.8
Sep/15	592.2	198.2	147.5	938.0
Total	4,332.1 (64.2%)	945.5 (14.0%)	1,473.7 (21.8%)	6,751.3 (100%)
Std. dev.*	150.4	51.7	79.2	226.0
2nd year	----------------------------------	kg ha^{-1}	------------------------------	
Oct/15	566.0	113.1	223.0	902.1
Nov/15	292.6	67.8	123.1	483.5
Dec/15	277.7	61.7	143.5	482.9
Jan/16	482.7	110.6	212.5	805.9
Feb/16	398.2	420.6	226.7	1045.6
Mar/16	339.1	78.2	104.3	521.6
Apr/16	181.4	5.6	32.3	219.2
May/16	98.8	16.5	14.1	129.3
Jun/16	255.1	17.8	25.5	298.4
Jul/16	411.5	18.3	37.0	466.8
Aug/16	685.8	53.9	36.3	775.9
Sep/16	744.3	56.7	56.2	857.3
Total	4,733.4 (76.7%)	1,020.7 (14.6%)	1,234.5 (17.7%)	6,988.5 (100%)
Std. dev.	196.4	111.5	81.8	291.4
Average two years	4,532.7 (65.9%)	983.1 (14.3%)	1,354.1 (19.7%)	6,869.9

* Standard deviation.

Table 3 - Pearson's correlation coefficients among the litter components of the Semideciduous Seasonal Forest and the climatic variables in Central Depression region, RS, Brazil.
Tabela 3 - Coeficientes de correlação de Pearson entre os componentes da serapilheira da Floresta Estacional Semidecidual e as variáveis climáticas na região da Depressão Central, RS, Brasil.

Climatic variables	Leaves	Thin branches	Miscellaneous	Litterfall
Monthly rainfall	0.252 $^{n.s.}$ (*P*= 0.235)	0.0781 $^{n.s.}$ (*P*= 0.717)	0.374 $^{n.s.}$ (*P*= 0.072)	0.312 $^{n.s.}$ (*P*= 0.138)
Average monthly temperature	-0.169 $^{n.s.}$ (*P*= 0.431)	0.419 * (*P*= 0.0417)	0.695 * (*P*= 0.0001)	0.242 $^{n.s.}$ (*P*= 0.254)

Where: *n.s.* = non-significant (P> 0.050); * significant (P <0.050).

Table 4 - Two-year monthly average (Oct/2014 - Sep/2016) of nutrient contents (g kg^{-1}) and nutrient quantities (kg ha^{-1}, t = 24) in the leaf litterfall in Central Depression region, RS, Brazil.
Tabela 4 - Média mensal de dois anos (out/2014 - set/2016) dos teores de nutrientes (g kg^{-1}) e quantidades de nutrientes (kg ha^{-1}, t = 24) na serapilheira na região da Depressão Central, RS, Brasil.

Month	**N**	**P**	**K**	**N**	**P**	**K**
	--------------- g kg^{-1} ---------------			---------- kg ha^{-1} -----------		
Jan	21.74 (± 2.91)[1]	0.98 (± 0.05)	5.32 (± 1.19)	12.94	0.58	3.17
Feb	24.21 (± 3.85)	1.04 (± 0.21)	4.41 (± 0.83)	8.04	0.34	2.02
Mar	23.69 (± 3.02)	0.99 (± 0.14)	6.26 (± 0.09)	6.87	0.29	1.82
Apr	22.91 (± 0.60)	0.97 (± 0.02)	4.22 (± 1.37)	7.35	0.31	1.35
Mai	22.27 (± 1.42)	0.99 (± 0.22)	8.66 (± 0.32)	7.45	0.33	2.90
Jun	22.57 (± 4.41)	1.13 (± 0.08)	5.89 (± 0.88)	6.79	0.34	1.77
Jul	20.22 (± 1.74)	0.97 (± 0.10)	5.62 (± 1.60)	4.32	0.21	1.20
Aug	18.65 (± 1.18)	0.82 (± 0.13)	8.07 (± 2.20)	4.18	0.18	1.81
Sep	17.62 (± 3.93)	0.95 (± 0.12)	6.76 (± 2.37)	4.06	0.22	1.56
Out	20.62 (± 3.30)	1.06 (± 0.14)	5.80 (± 1.13)	9.33	0.48	2.62
Nov	19.57 (± 1.64)	0.93 (± 0.04)	6.62 (± 2.04)	11.15	0.53	3.77
Dec	22.82 (± 1.38)	1.13 (± 0.22)	5.45 (± 0.85)	15.25	0.76	3.64
Yearly	-	-	-	**97.74**	**4.58**	**27.64**
Average	**21.41**	**1.00**	**6.09**	**8.15**	**0.38**	**2.30**

[1]Values in parentheses referring to standard deviation.

Leaf litter decomposition and release of nutrients

The annual decomposition rate (K value) was 1.16 and the leaf litter half-life was calculated in 215 days, whereas 930 days are estimated for reaching decomposition of 95% of the material (Figure 2). The highest percentage of mass loss was obtained in the first months, reaching 60% of decomposition when *t = 12 months*. At the end of the evaluation (*t = 24 months*), the remaining mass reached 18%, with a decomposition of 82% of the material.

At the beginning of the evaluation, the nutrient release of N via decomposition of leaf litter remained below 10% (Figure 3), reaching about 30% at *t=6*, while P and K showed constant availability. At the end of *t=6* of evaluation, 28.3% of N, 42.2% of P and 58.3% of K had been made available by the decomposition of the litter.

At *t=12*, the release of N reached 62.8%, P 46.9% and K 78.7%, while at *t=24* it was 84.4% N, 72.7% P and 92.9% K through decomposition of leaf litter, following the order of K> N> P. Despite the release of N intensifying only after *t=6*, P and K are release considerably from the beginning, K in a marked way and P remaining between 40-70%.

Considering the amounts of nutrients deposited annually in the leaf litter (Table 4) with the relative release of each nutrient from the leaf biomass in the litterbags (Figure 3), it is possible to infer the quantities of nutrients made release. Thus, in a hypothetical scenario of cessation of litter deposition, the amount of N, P and K contributed by the leaf litter in 12 months would be 61.4, 2.1 and 21.8 kg ha^{-1} in the first year, respectively, and 21.1, 1.2 and 3.9 kg ha^{-1} in the second year, respectively.

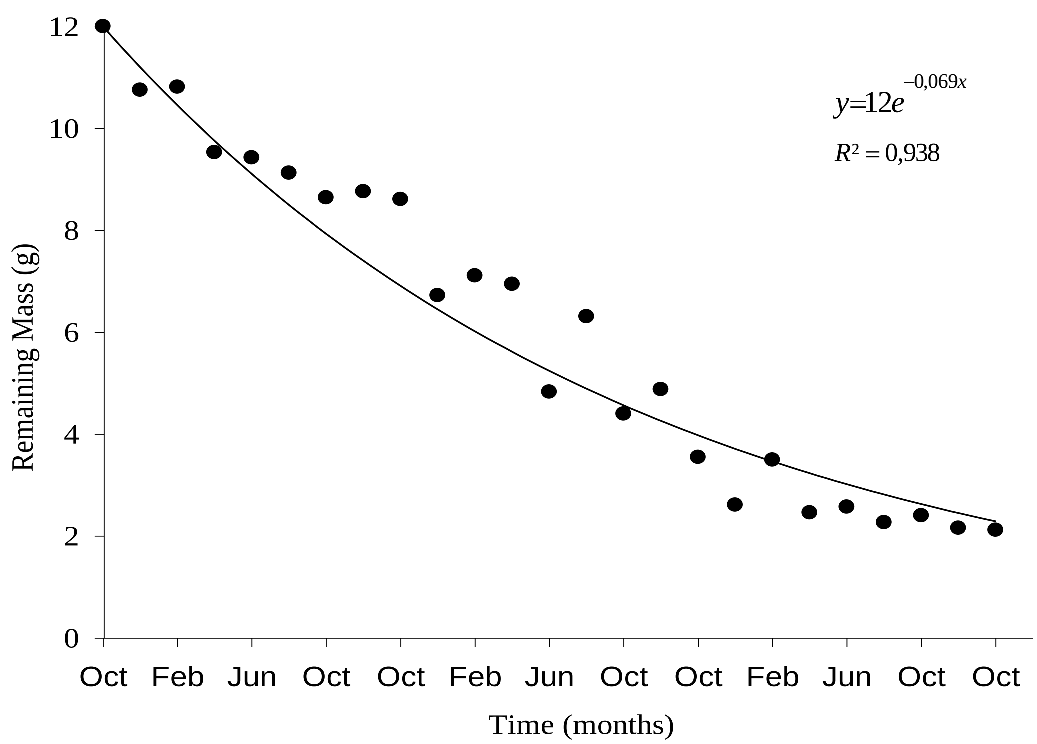

Figure 2 - Remaining mass of leaf litter (t=24, Oct/14 - Oct/16) in Central Depression region, RS, Brazil.
Figura 2 - Massa remanescente da serapilheira (t = 24, out/14 - out/16) na região da Depressão Central, RS, Brasil.

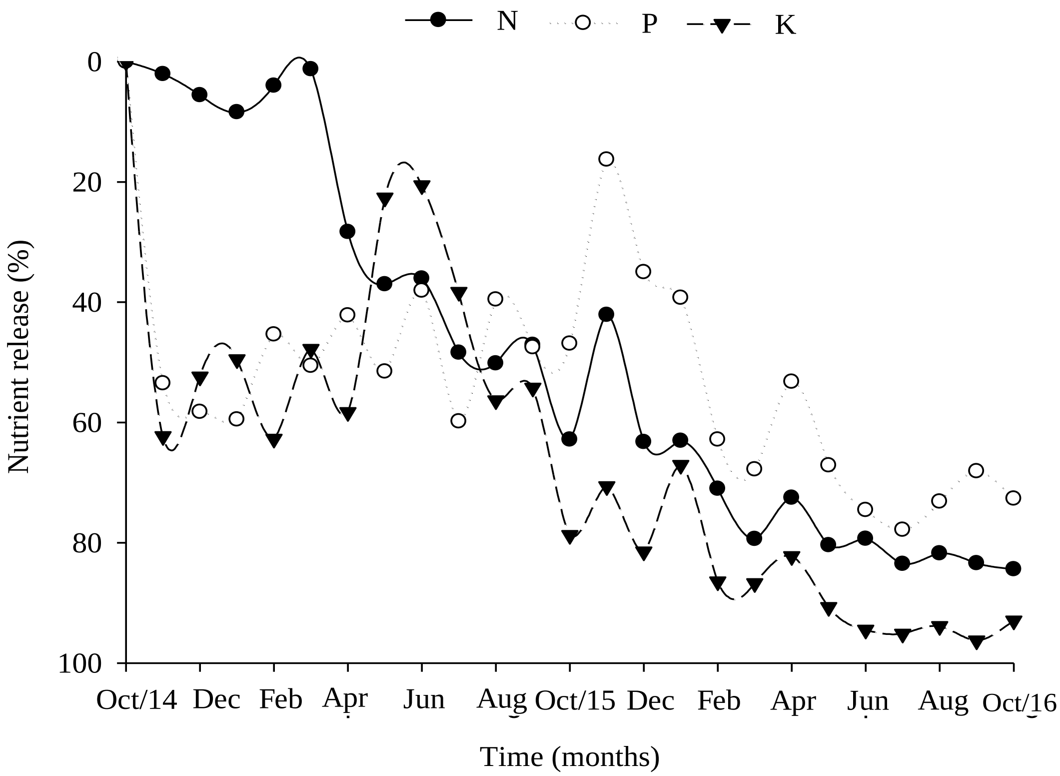

Figure 3 - Nutrient Release of leaf litter via decomposition (t=24, Oct/14 - Oct/16) in Central Depression Region, RS, Brazil.
Figura 3 - Liberação de nutrientes da serapilheira via decomposição (t = 24, out/14 - out / 16) na região da Depressão Central, RS, Brasil.

Discussion

Litterfall: production, contents and quantity of nutrients in the leaves

The remainder of Seasonal Semideciduous Forest in the subtropical region, in an advanced stage of regeneration, shows high production of leaf litter, and nutrient input, mainly N. The litterfall input rate of the present study (6.87 Mg ha^{-1}) falls in the range reported for this typology, and is close to the production of 6.6 Mg ha^{-1} year^{-1} (SCHUMACHER et al., 2018) and 5.1 Mg ha^{-1} year^{-1} (DICK et al., 2015) observed in Seasonal Deciduous Forest in southern Brazil. In a tropical climate in the region of Viçosa-MG, annual input of litter in a Seasonal Semideciduous Forest was reported as 6.31 and 8.82 Mg ha^{-1} in initial and mature successional stages, respectively (PINTO et al., 2009).

The leaf fraction is the main contributor for the litter in our study, accounting about 65-70% of the total biomass, which is in agreement with other studies (DICKOW et al., 2012; PINTO et al., 2009; SANTOS NETO et al., 2015). The work also corroborated with the tendency of variability in the production of leaf litter in the Subtropical Seasonal Forests. In this case, the greatest peaks of leaf litter production correspond to the spring months, by the resumption of vegetative growth (KÖNIG et al., 2002), while smaller contribution is observed in the winter months (DICK et al., 2015; Schumacher et al., 2018). It becomes evident that the forest typology and climatic region are more relevant in the production of litter in the Atlantic Forest than the succession stage (MARTINELLI et al., 2017), which in turns differentiates the quality of litter in advanced stages due to the changes in floristic composition (DICKOW et al., 2012).

It can be seen in Figure 4 that leaves deposition has a tendency to decrease with increasing temperature, with the lowest depositions in the summer months (December to March), although there is no significant correlation (Table 4). For precipitation, there is no clear effect on litter deposition, but there may be a slight tendency for less deposition in months of lower precipitation. Significant correlation was observed only for the thin branches and the miscellaneous *vs* temperature (Table 4). In the present study, the miscellaneous fraction contemplates reproductive materials. The increase in temperature promoted greater production of flowers, fruits and seeds.

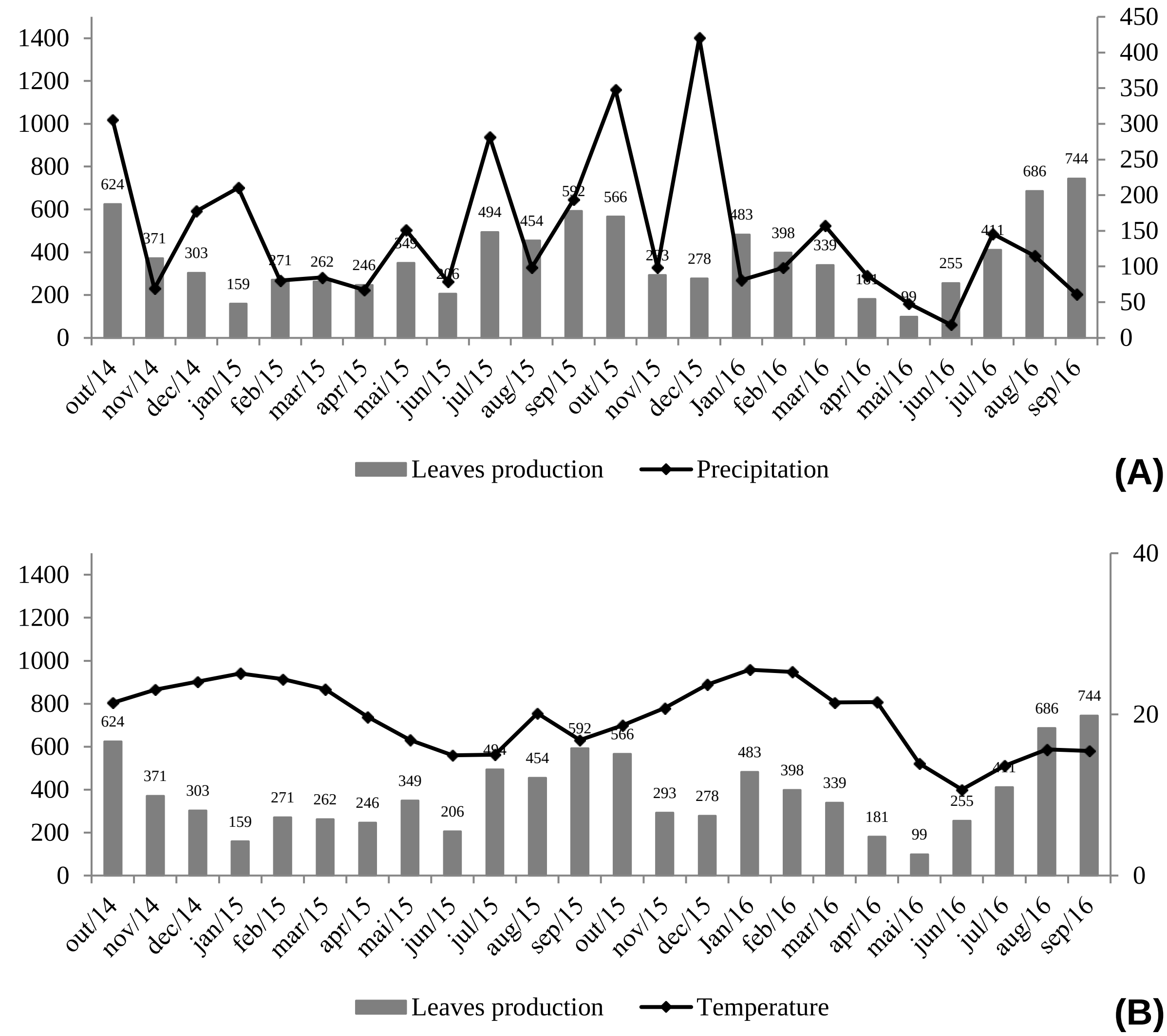

Figure 4. Seasonality of leaves production (kg ha^{-1}) with the average monthly temperature (A) and monthly precipitation (B), from October/2014 to September/2016, in the Seasonal Semideciduous Forest in Central Depression region, RS, Brazil.
Figure 4. Sazonalidade da produção de folhas (kg ha^{-1}) com a temperatura média mensal (A) e precipitação mensal (B), de outubro/2014 a setembro/2016, na Floresta Estacional Semidecidual na região da Depressão Central, RS, Brasil.

The concentration and amount of nutrients provided by the leaf litter follows the order of

N> K> P, as reported in other studies (PINTO et al., 2009; SCHUMACHER et al., 2018). Average nutrient stocks in leaf litter were close to those described for Seasonal Deciduous Forest in the subtropical region, in a Leptosol, of 117.4 kg ha^{-1} year^{-1} of N, 5.6 kg ha^{-1} year^{-1} of P and 27.2 kg ha^{-1} year^{-1} of K (SCHUMACHER et al., 2018).

The leaves fraction is the component with the greatest relative contribution for biomass and nutrients in the litter, representing about 75% of macronutrients and 67% of micronutrients (SCHEER et al., 2011). Because of that, leaves abduction constitutes a strategy of trees for cycling and distributing nutrients for their growth (PIRES et al., 2006). The amounts of nutrients provided by the litter vary according to the degree of fertility of the site (PINTO et al., 2009) and the composition of the species, especially those with high levels of nutrients, due to their characteristics of greater absorption and/or demand by certain nutrients (SCHEER et al., 2011).

Leaf litter decomposition and release of nutrients

The regression analysis of the leaf litter decomposition evidenced a significant adjustment to the exponential decay function (Figure 2). The rapid decomposition of leaf litter contributes to the availability of nutrients throughout the process, even with slow availability of N at the beginning (Figure 3).

The decomposition coefficient is close to that obtained in Subtropical Seasonal Forest in an advanced stage of regeneration, requiring 195 days to reach the half-life (K = 1.28; BRUN et al., 2011). Regarding the typology Seasonal Semideciduous Forest in the tropical region, the time required for the decomposition of the present study was within the range obtained, from 200 to 266 days for 50% of the material to be decomposed (PINTO et al., 2009; CUNHA NETO et al., 2013).

The greatest loss of mass in the first months is characteristic of the leaf decomposition process, regardless of forest type (PINTO et al., 2016) and succession stage (VENDRAMI et al., 2012). In this period, decomposition is associated with the fragmentation of physical agents and biota, releasing the soluble compounds quickly used by decomposers (SCHEER, 2008).

Primary and secondary forests at an advanced stage of succession show more accelerated decomposition than secondary forests at an early stage (SILVA et al., 2018), demonstrating the increase in the decomposition rate with advancing succession (PIRES et al., 2006) and pointing out the resilience of the ecosystem when the process is restored (GIEßELMANN et al., 2011; VENDRAMI et al., 2012). Thus, the decomposition rate is an indicator of the degree of recovery and/or disturbance of the ecosystem (SILVA et al., 2018), as well as the effect of fragmentation (PEREIRA et al., 2013).

Generally, Semideciduous Seasonal Forests are reference ecosystems, as they present faster decomposition than monocultures, even those with native species, where there is greater radiation entry and reduced relative humidity (PIMENTA et al., 2011), highlighting the role of the microenvironment (PINTO et al., 2009; PINTO et al., 2016) and its degree of preservation that favors greater diversity of edaphic fauna (GRUGIKI et al., 2017), and activity of decomposers (PEREIRA et al., 2013). However, in some cases, decomposition rates of litter in commercial plantations of leguminous trees (Fabaceae family) can exceed reference ecosystems. The more labile litter from legume trees is mainly due to the larger N content, in addition to smaller ratios of lignin:N and polyphenols:N, highlighting the influence of the physical-chemical characteristics of the plant material (PINTO et al., 2016).

There is greater release of nutrients evaluated during the first year; in the second year of evaluation the P release (25.1%) was larger than for N and K, highlighting the role of its release in the long term, compared to the release N and K in the first year (Figure 3). The behavior of accentuated release for K and P, and reduced to N in the first months, was obtained in Alluvial Dense Ombrophilous Forest in an initial stage, but with reduced release (SCHEER et al., 2008).

In some cases, nutrient release may not occur in the first years, such as immobilization of N and P, as occurs in homogeneous plantations of the genus *Eucalyptus* (VIERA et al., 2014). However, it is possible to observe a pattern of oscillation in the release of nutrients over time, resulting from the set of individual patterns of decomposition of the species that make up the forest typology and affecting the release of nutrients (ASSIS et al., 2017), depending on the litter quality due to species diversity (GIEßELMANN et al., 2011).

The K has high and fast release. In a mature forest in a tropical climate, K mineralization was 90% after 120 days (PINTO et al., 2009), and 80% after one year in Alluvial Dense Rainforest (SCHEER et al., 2008), high release due to its independence of the decomposition process, a non-structural element of the plant tissue (COSTA et al., 2005). Unlike the present study, where P is release, in *Eucalyptu*s plantations there is no net release of P due to its limitation in the system, making decomposition difficult (COSTA et al., 2005).

Conclusions

In the two years of collection, the largest deposition rate of litter occurred in the spring, with the highest peak in October, indicating a seasonal deposition behavior.

The forest fragment presents high production of leaf litter (66% leaves) and input of N.

It was found an annual K factor of 1.16, reaching the litter half-life after 215 days.

The rapid decomposition of leaf litter contributes to the release of nutrients over time, N and K initially, and P in the long run.

P is limited due to the high efficiency of its use.

Acknowledgements

To the Academic Development Program - PDA of the UNIPAMPA University for the granting of a scientific initiation scholarship in the period studied.

References

ALVARES, C.A. et al. Köppen’s climate classification map for Brazil. Meteorologische Zeitschrift. v. 22, n. 6, p. 711-728, 2014. http://www.ingentaconnect.com/content/schweiz/mz/2013/00000022/00000006/art00008?token=004f1a11bab2a729bc7e41225f40382d2c2b4652767446624550576b34272c5f7b3d6d3f4e4b34a

ASSIS, I.R. et al. Leaf residue decomposition of selected Atlantic forest tree species. Revista Árvore. v. 41, n.3, p. 1-9, 2017. https://www.scielo.br/j/rarv/a/tXgzW3N4kGBmpQCKqHcT4pm/?format=pdf&lang=en

BELLO, C. et al. Defaunation affects carbon storage in tropical forests. Science Advances. v.1, n.11 1-11, 2015. https://www.science.org/doi/pdf/10.1126/sciadv.1501105

BRUN, E.J.; SCHUMACHER, M.V.; VACCARO, S. Aspectos da ciclagem de material orgânico e nutrientes na serapilheira de florestas secundárias em Santa Tereza. In: SCHUMACHER, M.V. et al. A Floresta Estacional Subtropical: caracterização e ecologia no rebordo do Planalto Meridional”. Santa Maria: Pallotti, 2011. pp. 195-213.

CQFS - COMISSÃO DE QUÍMICA E FERTILIDADE DO SOLO. Manual de adubação e de calagem para os Estados do Rio Grande do Sul e de Santa Catarina. Sociedade Brasileira de Ciência do Solo: Editora Pallotti (11ed,), 2016. 376p.

COSTA, G.S.; GAMA-RODRIGUES, A.C.; CUNHA, G.M. Decomposição e liberação de nutrientes da serapilheira foliar em povoamentos de *Eucalyptus grandis* no norte fluminense. Revista Árvore. v. 29, n. 4, p. 563-70, 2005. https://www.scielo.br/j/rarv/a/MrDDd9wwKLj99HfLwMyTj8w/?lang=pt&format=pdf

CUNHA NETO, F.V. et al. Acúmulo e decomposição da serapilheira em quatro formações florestais. Ciência Florestal. v. 23, n.3, p. 379-87, 2013. https://www.scielo.br/j/cflo/a/QBkLBDNYCgpF88GhxMTwJWx/abstract/?lang=pt

DICK, G.; D'ÁVILA, M.; SCHUMACHER, M.V. Produção de serapilheira em fragmento de Floresta Estacional Subtropical na região norte do Rio Grande do Sul. Ecologia e Nutrição Florestal. v. 3, n. 1, p 1-8, 2015. https://periodicos.ufsm.br/enflo/article/view/16354/pdf

DICKOW, K.M.C. et al. Produção de Serapilheira em diferentes fases sucessionais de uma Floresta Subtropical secundária, em Antonina, PR. Cerne. v. 18, n. 1, p. 75-86, 2012. https://www.scielo.br/j/cerne/a/mtMs7smVfdQ9wHmD9XPVsBH/?lang=pt

EMBRAPA - Empresa Brasileira de Pesquisa Agropecuária. Sistema brasileiro de classificação de solos. Brasília: Embrapa Solos, 2018. 355p.

GIEßELMANN, U.C. et al. Lack of home-field advantage in the decomposition of leaf litter in the Atlantic Rainforest of Brazil. Applied Soil Ecology, v. 49, n. 1, p 5-10, 2011. https://www.ufz.de/export/data/2/92797_Giesselmann_et_al_2011_Appl_Soil_Ecol.pdf

GRUGIKI, M.A. et al. Decomposição e atividade microbiana da serapilheira em coberturas florestais no Sul do Espírito Santo. Floresta e Ambiente, v. 24, p. 1-12, 2017. https://www.scielo.br/j/floram/a/jzHjCf8BjvVYhdtSJTnbXrd/?lang=pt&format=pdf

GUO, L.B.; SIMS, R.E.H. Litter decomposition and nutrient release via litter decomposition in New Zealand eucalypt short rotation forests. Agriculture, Ecosystems and Environment. v. 75, p. 133-40, 1999. https://agris.fao.org/agris-search/search.do?recordID=NL2000000145

INMET - Instituto Nacional de Meteorologia - Dados meteorológicos, 2018. http://www.inmet.gov.br. Acesso em: 15/12/2018.

KÖNIG, F.G. et al. Avaliação da sazonalidade da produção de serapilheira numa Floresta Estacional Decidual no município de Santa Maria-RS. Revista Árvore. v. 26, n. 4, p. 29-35, 2002 https://www.scielo.br/j/rarv/a/gL9gMkTWxWWrqCddFY6vL4D/?lang=pt

MARTINELLI, L.A.; LINS, S.R.M.; SANTOS-SILVA, J.C. Fine litterfall in the Brazilian Atlantic Forest. Biotropica, v. 49, n. 4, p. 443-51, 2017. https://onlinelibrary.wiley.com/doi/abs/10.1111/btp.12448

MURPHY, J.; RILEY, J.P. A modified single solution method for the determination of phosfate in natural waters. Analytica Chimica Acta. v. 27, p. 31-36, 1962. https://www.sciencedirect.com/science/article/abs/pii/S0003267000884445

OLSON, J.S. Energy storage and the balance of producers and decomposers in ecological systems. Ecology. v. 44, n. 2, p. 322-31, 1963. https://www.scienceopen.com/document?vid=18cb461e-94b6-4d59-99d3-00aeca7f579f

PEREIRA, G.H.A. et al. Litter decomposition, diversity and functionality of soil invertebrates in an Atlantic rain forest fragment. Bioscience Journal. v. 29, n. 5, p. 1317-27, 2013. http://www.seer.ufu.br/index.php/biosciencejournal/article/view/18017

PIMENTA, J.A. et al. Produção de serapilheira e ciclagem de nutrientes de um reflorestamento e de uma Floresta Estacional Semidecidual no sul do Brasil. Acta Botânica Brasilica. v. 25, n. 1, p. 53-7, 2011. https://www.scielo.br/j/abb/a/xJbqJH3XMQpxtz8QqM4mJTf/?lang=pt

PINTO, H.C.A. et al. Decomposição da serapilheira foliar de floresta nativa e plantios de *Pterogyne nitens* e *Eucalyptus urophylla* no sudoeste da Bahia. Ciência Florestal. v. 26, n. 4, p. 1141-53, 2016. https://periodicos.ufsm.br/cienciaflorestal/article/view/25105/pdf

PINTO, S.I.C. et al. Ciclagem de nutrientes em dois trechos de Floresta Estacional Semidecidual na reserva florestal Mata do Paraíso em Viçosa, MG, Brasil. Revista Árvore. v. 33, n. 4, p. 653-63, 2009. https://www.scielo.br/j/rarv/a/WF8dPjmWVcTdZs8bC4PW7hq/?lang=pt

PIRES, L.A. et al. Produção, acúmulo e decomposição da serapilheira em uma restinga da Ilha do Mel, Paranaguá, PR, Brasil. Acta Botânica Brasilica. v. 20, n. 1, p. 173-84, 2006.https://www.scielo.br/j/abb/a/XdyDFS7MW56ybRppnTgzXvr/?lang=pt

RIBEIRO, M.C. et al. The Brazilian Atlantic Forest: How much is left, and how is the remaining forest distributed? Implications for conservation. Biological Conservation. v. 142, p. 1141-1153, 2009. https://www.sciencedirect.com/science/article/abs/pii/S0006320709000974

SANTOS NETO, A.P. et al. Produção de serapilheira em Floresta Estacional Semidecidual e em plantios de *Pterogyne nitens* Tul. e *Eucalyptus urophylla* S. T. Blake no sudoeste da Bahia. Ciência Florestal, v. 25, n. 3, p. 633-43, 2015. https://periodicos.ufsm.br/cienciaflorestal/article/view/19614/11609

SCHEER, M.B. Decomposição e Liberação de nutrientes da serapilheira foliar em um trecho de Floresta Ombrófila Densa aluvial em regeneração, Guaraqueçaba (PR). Floresta. v. 38, n. 2, p. 253-66, 2008. https://revistas.ufpr.br/floresta/article/view/11620/8155

SCHEER, M.B.; GATTI, G.; WISNIEWSKI, C. Nutrient fluxes in litterfall of a secondary successional alluvial rain forest in Southern Brazil. Revista biologia tropical. v. 59, n. 4, p. 1869-1882, 2011. https://www.scielo.sa.cr/scielo.php

SCHUMACHER, M.V. et al. Aporte de serapilheira e nutrientes em uma Floresta Estacional Decidual na região central do Rio Grande do Sul. Ciência Florestal. v. 28, n. 2, p. 532-41, 2018. https://periodicos.ufsm.br/cienciaflorestal/article/view/32036/pdf

SCHUMACHER, M.V.; VIERA, M. Ciclagem de nutrientes em plantações de eucalipto. In: SCHUMACHER, M.V.; VIERA, M. (eds.). Silvicultura do Eucalipto no Brasil. Santa Maria: Editora UFSM, p. 273-307, 2015. ISBN9788573912234.

SILVA, W.B. et al. Are litterfall and litter decomposition processes indicators of forest regeneration in the neotropics? Insights from a case study in the Brazilian Amazon. Forest Ecology Management. v. 429, p. 189-97, 2018. https://www.cabdirect.org/cabdirect/abstract/20193041107

Sistema Nacional de Informações Florestais - SNIF. Recursos Florestais, 2016. https//www.florestal.gov.br/documentos/publicacoes/2231-boletim-snif-recursos-florestais-2016/file. Acesso em: 20/01/2020.

SOUSA-NETO, E.R. et al. Litterfall mass and nutrient fluxes over an altitudinal gradient in the coastal Atlantic Forest, Brazil. Journal of Tropical Ecology. v. 33, p. 261-9, 2017.

https://www.cambridge.org/core/journals/journal-of-tropical-ecology/article/abs/litterfall-mass-and-nutrient-fluxes-over-an-altitudinal-gradient-in-the-coastal-atlantic-forest-brazil/24E77132E7573D638C44D996AFA915E9

TEDESCO, M.J. et al. Análise de solo, plantas e outros materiais. Porto Alegre: UFRGS, 1995. 118p.

VENDRAMI, J.L. et al. Litterfall and leaf decomposition in forest fragments under different successional phases on the Atlantic Plateau of the state of Sao Paulo, Brazil. Biota Neotrópica. v. 12, n. 3, p. 133-41, 2012. https://www.redalyc.org/pdf/1991/199124391016.pdf

VIERA, M. et al. Deposição de serapilheira e nutrientes em plantio de *Eucalyptus urophylla* × *E. globulus*. Floresta e Ambiente. v. 21, n. 3, p. 1-12, 2014. https://www.scielo.br/j/floram/a/gNkJMgb6MB4QhL3WX7t7Cmr/?format=pdf&lang=pt

VITOUSEK, P. Nutrient cycling and nutrient use efficiency. The American Naturalist. v. 119, n. 4, p. 553-72, 1982. https://www.journals.uchicago.edu/doi/abs/10.1086/283931

ZHANG, D. et al. Rates of litter decomposition in terrestrial ecosystems: global patterns and controlling factors. Journal Plant Ecology. v. 1, n. 2, p. 85-93, 2008. https://academic.oup.com/jpe/article/1/2/85/989869

ZHANG, H. et al. Seasonal patterns of litterfall in forest ecosystem worldwide. Ecology Complexity. v. 20, p. 240-7, 2014. https://www.semanticscholar.org/paper/Seasonal-patterns-of-litterfall-in-forest-ecosystem-Zhang-Yuan/099b20144bae83dc51ff938e03a03443f570482d>.

VITTI, G. C.; LIMA, E.; CICARONE F. Cálcio, Magnésio e Enxofre. Dentro: Fernandes, Manlio Silvestre. (editor). Nutrição mineral de plantas. Sociedade Brasileira de Ciência do Solo. 12, p:299-235, 2006.