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Litter Biomass and Carbon Stock in a Mature Eucalyptus Stand in Southern Brazil

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Abstract: ***This study quantified litter biomass and carbon (C) stock in a ~25-year-old Eucalyptus stand in Santa Maria, RS, Brazil. Samples were collected from 30 random points (25×25 cm frame), separated into branch, leaf, and miscellaneous fractions, dried at 70 °C for 72 h, and weighed. Total accumulated litter reached 14.66 Mg ha⁻¹, with branches (7.28 Mg ha⁻¹) being the most representative, followed by miscellaneous (5.31) and leaves (2.06); total C stock was 7.33 Mg ha⁻¹. The accumulation pattern reflects stand maturity and highlights the litter layer's potential for soil C increment through decomposition, reinforcing the role of forest plantations in climate change mitigation.***

Keywords: Eucalyptus, Litter biomass, Carbon stock, Nutrient cycling, Forest plantation.

1. INTRODUCTION

Climate change is one of the greatest current challenges, characterized by rising global temperatures and extreme weather events. Carbon dioxide (CO_2), resulting from the burning of fossil fuels and deforestation, is one of the main drivers of the greenhouse effect (IPCC, 2021).

An effective strategy to mitigate CO_2 emissions is the capture and storage of carbon in plant biomass and soil, a process by which trees sequester CO_2 through photosynthesis (Jose, 2009; Nair et al., 2010).

Litter, essential in forest ecosystems, acts as a nutrient reservoir and carbon store, releasing it slowly into the soil as it decomposes (Prescott, 2018). This process helps maintain soil fertility and reduce atmospheric CO_2 (Lavallee et al., 2018).

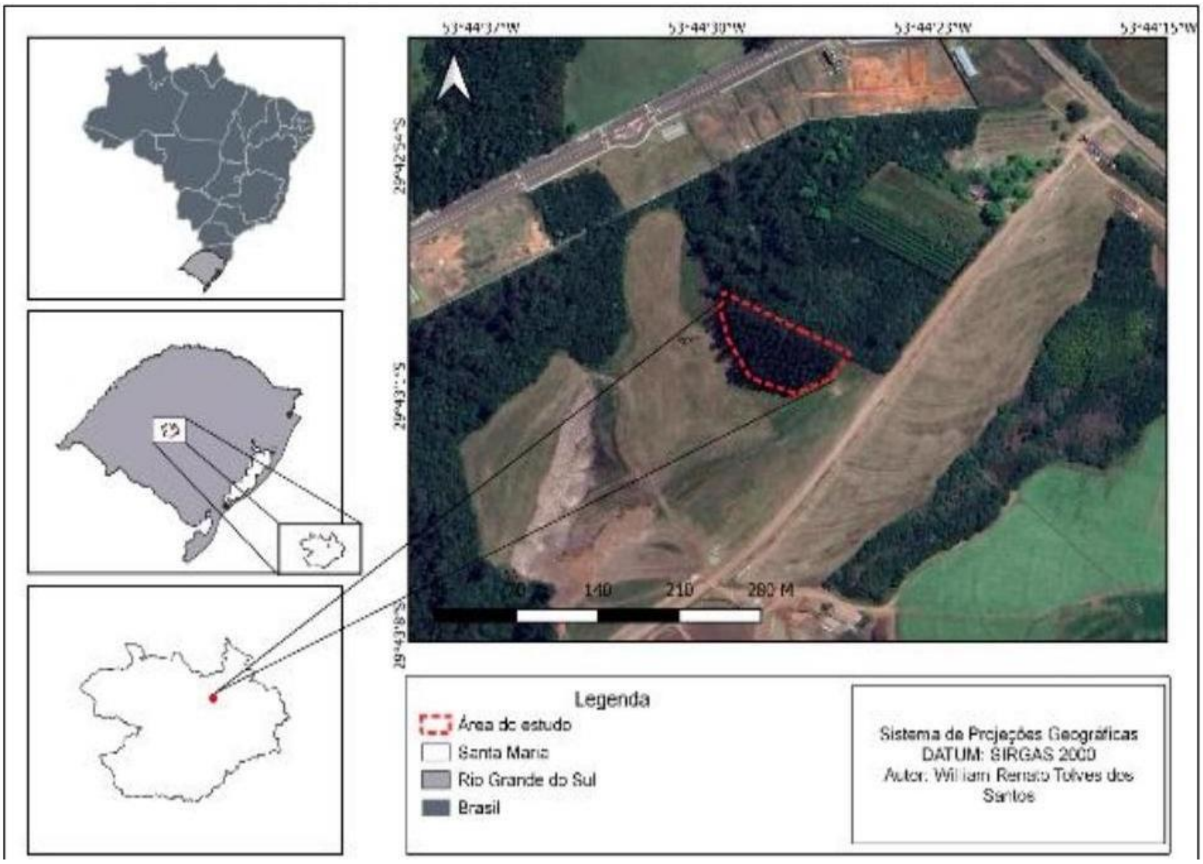
The study of litter is extremely relevant, as it allows evaluating how much the forest produces, the amount of matter it decomposes, the phenological phase of the species, and is also a very important factor for understanding the nutrient cycling process (Caldeira et al., 2007; Lima et al., 2015). Since litter is considered the main pathway for transferring organic carbon to the soil, its quantification is also important (Caldeira et al., 2008).

Eucalyptus, widely cultivated due to its rapid growth, is effective in carbon sequestration (Campoe et al., 2020). However, sustainable management of these plantations is essential to ensure the conservation of litter and stored carbon (Ferraz et al., 2019). Studies on litter production have been conducted mainly in commercial-age plantations, with few in advanced-age plantations.

Given the above, the objective of this study was to quantify the biomass and carbon accumulation in the litter of an advanced-age Eucalyptus sp. stand on the Campus of the Federal University of Santa Maria, Rio Grande do Sul, aiming to contribute to the understanding of the role of these mature forests in the carbon cycle and in addressing climate change.

2. MATERIALS AND METHODS

2.1 Study Area



The study was conducted in the experimental area of the Main Campus of the Federal University of Santa Maria (UFSM), in Santa Maria, Rio Grande do Sul, Brazil. The study area is a Eucalyptus sp. stand, with non-uniform spacing (3x2 m and 3x3 m) and approximately 25 years old, located at coordinates 29°42’59.36"S and 53°44’27.29"W (Figure 1).

The region’s climate is humid subtropical (Cfa, according to Köppen), without a dry season, with well-distributed rainfall and an average annual precipitation of 1,708 mm. The average annual temperature is 19.0°C (Alvares et al., 2013). The relief is gently undulating, with average altitudes of 150 meters. The moderately deep soil is classified as a Typic Aluminic Brunish-Gray Argisol (Lemos, 1973; Santos et al., 2018).

2.2 Dendrometric Parameters of the Stand

In the study area, dendrometric variables were measured to characterize the stand. Measurements of DBH (Diameter at Breast Height at 1.30 m height) and height were performed in an area of 0.53 ha, excluding 2 border rows to avoid the edge effect. The DBH of all 191 trees was measured with a diameter tape. The height of 36% of the trees was measured with a Vertex IV hypsometer, and the others were estimated using SAS (Statistical Analysis System) software version 8. The number of trees per hectare, average diameter, average height, Asmann dominant height, basal area per hectare (Equation (1)), and total volume per hectare (Equation (2)) were calculated (Table 1).

Table 1: Dendrometric parameters of the Eucalyptus sp. stand in Santa Maria, RS.

N (ha)	DAP (cm)	h (m)	h (dom)	G (m^2/ha)	Vol (m^3/ha)
360	25,54	25,94	34,00	21,41	271,87
Standard Deviation	10,23	7,57			

N = number of trees per hectare; DBH = average diameter at breast height; h = average height; hdom = Asmann’s dominant height; G = basal area per hectare; Vol = total volume per hectare.
Source: Prepared by the author, 2023.

Assmann’s principle (1970) defines dominant height as the average height of the 100 trees with the largest diameter per hectare. It can be obtained by averaging the 100 tallest trees or, alternatively, averaging the height of 20% of the trees with the largest diameter or height in the stand.

$$G = \frac{\sum(\pi \cdot DAP^2)}{A} \quad (1)$$

where:

G = is the basal area per hectare (in m^2/ha);
Π = is the constant pi (approximately 3.1416);
DBH = diameter at breast height, measured at a distance of 1.30 m from the ground (cm);
A = area of the plot (in hectares).

$$V = \frac{\sum\left(f \cdot (\pi \cdot DAP^2 \cdot H)\right)}{A} \quad (2)$$

where:

V = is the volume per hectare (m^3/ha);
F = the form factor (0.45 was used);
Π = the constant pi (approximately 3.1416);
DBH = diameter at breast height, measured at a distance of 1.30 m from the ground (cm);
H = is the tree height (in meters);
A = area of the plot (in hectares).

2.3 Collection and Preparation of Litter Samples

Thirty random collections were made within the study area using a square iron frame of $25\ \text{cm} \times 25\ \text{cm}$, based on the methodology of Kleinpaul et al. (2003). In Figure 2, the frame and the litter collection method are shown, with the exposure of the mineral soil after collection visible.

Figure 2: Demonstration of the frame inserted into the soil before and after collection: A - frame before collection; B - frame collection

After collecting the litter, the samples were stored in paper bags and sent to the Forest Ecology Laboratory (LABEFLO) of the Department of Forest Sciences at the Federal University of Santa Maria. Initially, living components (roots, seedlings, and insects) were removed by sieving. Immediately afterward, all material was separated into the following fractions: leaf, branch, and miscellaneous (bark, reproductive material, material in an advanced stage of decomposition that was not identified, and material that did not fit into the other fractions) (Figure 3). The fractions were placed in paper bags and moved to a forced air circulation and renewal oven at $70°C$ for approximately 72 hours. Finally, the fractions were weighed on a precision balance (0.01g). The data were compiled and analyzed in Excel software, and subsequently, a Tukey post-hoc test with a 5% significance level was performed using R Studio software version 4.4.1.

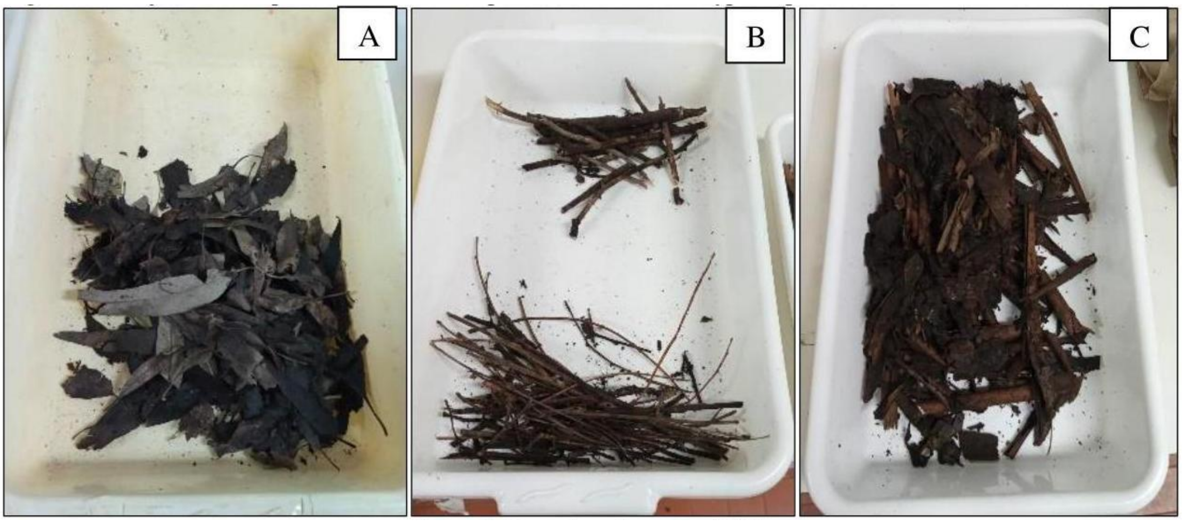


Figure 3: Fragments of the serapilheira collected in the population of Eucalyptus sp.: A-Leaf; B- Branch; C - Miscellaneous

2.4 Biomass and Estimation of Litter Carbon Stock

From the data obtained from litter collection, the total amount of dry matter deposited on the forest soil was calculated. The percentage of each litter fraction was also calculated. The estimate per unit area (hectare) was made by extrapolating the dry mass based on the frame area (0.0625 m2) (Vieira, 2010).

The carbon stored in dry biomass was estimated by multiplying the biomass estimates by the factor 0.5, considering that dry biomass contains 50% carbon (Fang et al, 2001; Fukuda et al, 2003). Subsequently, the carbon stock was extrapolated to megagrams per hectare.

3. RESULTS AND DISCUSSIONS

The total amount of litter accumulated in the soil was 14.66 Mg ha^{-1} (Table 1). The branch fraction represented the highest biomass (49.7%), followed by miscellaneous (36.2%) and leaf (14.1%).

The estimated carbon stock totaled approximately $7{,}33 Mgha^{-1}$ in the studied litter fractions. The branch fraction, with the highest carbon concentration, accounted for $3{,}64 Mgha^{?1}$.

Table 1: Biomass and carbon stock in different fractions of litter collected in an Eucalyptus sp. stand in Santa Maria, RS.

Compartments	Eucalyptus Stand (Mg/ha)	%	Carbon (Mg/ha)
Leaf	2,06	14,1	1,03
Branch	7,28	49,7	3,64
Miscellaneous	5,31	36,2	2,65
Total	14,66	100,0	7,33

Source: Prepared by the authors, 2023.

The results of the analysis of variance (ANOVA) indicated significant differences between the three litter fractions (leaves, branches, and miscellaneous) regarding accumulated biomass ($F = 21.56$, $p < 0.001$). This suggests that the contribution of each fraction to the total litter is statistically different.

The graph in Figure 4 illustrates the weight distribution of the different litter categories. The branch fraction showed the greatest variation and the highest mean weight, with a value significantly higher than the other fractions, while the leaves contributed the lowest biomass value.

Furthermore, the Tukey post-hoc test confirmed that the branch fraction had a significantly greater mean difference compared to the leaves (mean difference = 32.65 g, $p < 0.001$) and the miscellaneous fraction (mean difference = 12.34 g, $p = 0.042$). The miscellaneous fraction also showed a significantly greater contribution than the leaves (mean difference = 20.31 g, $p < 0.001$).

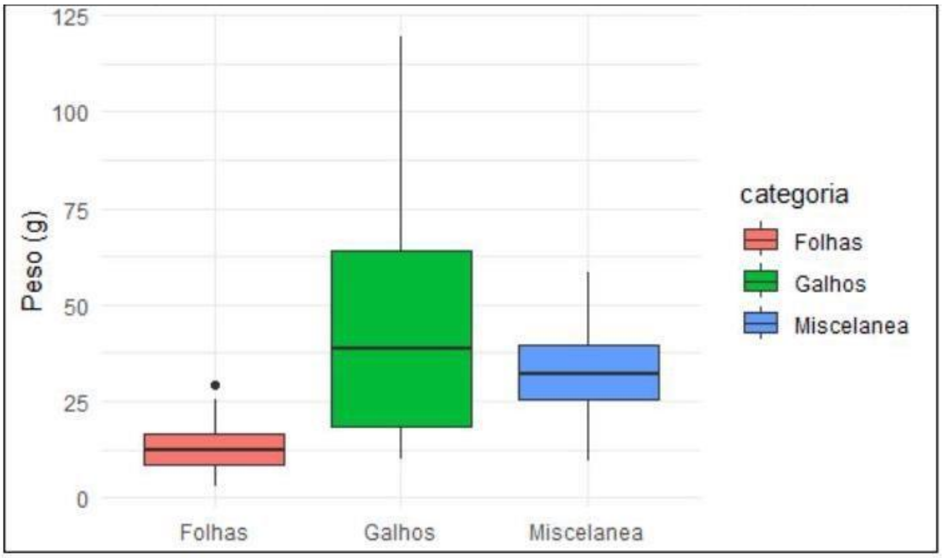


Figure 4: Weight distribution of eucalyptus litter by fraction (leaves, branches, and miscellaneous).

The results of this study demonstrate the significant contribution of litter in eucalyptus plantations to the accumulation of dry matter and carbon in forest soil, highlighting its essential role in nutrient cycling and climate change mitigation.

Comparing with Kleinpaul et al. (2003), who evaluated litter in 12-year-old eucalyptus plantations on the UFSM Campus, the accumulation was lower (11.63 Mg ha^{-1}) than that found in this study. Both studies showed a predominance of the branch fraction, explained by natural pruning in species of the Eucalyptus genus, resulting in a significant contribution of this fraction (Lamont et al., 2009).

In addition, the structure of the litter can influence soil biodiversity, providing habitats for essential decomposer organisms, which play a critical role in nutrient cycling and humus formation (Prescott, 2018).

In this study, the leaf fraction represented only 14% of the litter, demonstrating a stand in an advanced successional stage and greater decomposition due to the lower C/N ratio in the leaves (Torres et al., 2005). The miscellaneous fraction, also composed of bark, was notable (36%), indicating the smooth plate senescence characteristic of some Eucalyptus species, which contribute calcium to the soil (Lamont et al., 2009).

Litter diversity can also affect the resilience of forest ecosystems, allowing better adaptation to climate change, as observed in studies that associate functional diversity with forest resistance and recovery (Nair et al., 2010).

The carbon stock $(7{,}33 Mgha^{-1})$ was higher than that found by Witschoreck and Schumacher (2003) in eucalyptus forests of different ages, reinforcing that older stands accumulate more carbon, contributing to the improvement of soil conditions through the decomposition of organic matter (Ewel, 1976). Previous studies suggest that proper litter management can increase carbon sequestration capacity, making these ecosystems even more relevant in the context of climate change mitigation (IPCC, 2019).

In addition to the benefits for soil fertility, litter in eucalyptus stands plays a crucial role in mitigating climate change by accumulating organic carbon and reducing the impacts of global warming (IPCC, 2019). Furthermore, litter can act as a barrier that reduces soil erosion and improves water infiltration, benefiting the hydrological health of forests (Fukuda et al., 2003).

Therefore, the preservation and proper management of litter are fundamental for the sustainability of forest ecosystems and for addressing the challenges of climate change.

The implementation of management practices that prioritize the maintenance of litter can be an effective strategy to optimize carbon sequestration and promote the resilience of forests to adverse climatic conditions.

Recognizing and valuing the role of litter is essential to promote sustainable management practices and help protect the global climate for future generations.

4. CONCLUSION

Among the litter fractions, branches had the highest biomass and carbon stock. The total litter carbon stock was 7.33 Mg ha ?$^{?1}$. This estimate indicates the role of planted forests in carbon sequestration and fixation, reinforcing the relevance of eucalyptus forests as an atmospheric sink.

This study focused on the litter layer, its accumulation, and carbon stock. Considering the previously mentioned benefits of litter, this organic material is indispensable for the maintenance and balance of forests, contributing nutrients and consequently increasing the productivity of planted forests.

For future studies on litter, it would be important to increase the number of analyzed fractions, evaluate nutrient content, organic compounds, and the rate at which this material decomposes. Given the importance of eucalyptus in the Brazilian forest context, it is essential to continue studies on litter in eucalyptus stands at different growth stages, in various regions and edaphoclimatic conditions.

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REFERENCES

[1] ALVARES, C. A.; STAPE, J. L.; SENTELHAS, P. C.; GONÇALVES, J. L. M.; SPAROVEK, G. Köppen's climate classification map for Brazil. Meteorologische Zeitschrift, v. 22, n. 6, p. 711-728, 2013.
[2] ASSMANN, E. The principles of forest yield study. Oxford: Pergamon Press, 1970. 506 p.
[3] CALDEIRA, M. V. W.; MARQUES, R.; SOARES, R. V.; BALBINOT, R. Quantification of litter and nutrients - Montane Mixed Ombrophilous Forest - Paraná. Revista Acadêmica, v. 5, n. 2, p. 101-116, 2007.
[4] CALDEIRA, M. V. W.; VITORINO, M. D.; SCHAADT, S. S.; MORAES, E.; BALBINOT, R. Quantification of litter and nutrients in a Dense Ombrophilous Forest. Ciências Agrárias, v. 29, n. 1, p. 53-68, 2008.
[5] CAMPOE, O. C.; STAPE, J. L.; ALBAUGH, T. J.; ALLEN, H. L.; FOX, T. R.; RUBILAR, R.; RAYMOND, J. E. Eucalyptus production and the supply, use and efficiency of water, light and nutrients. Forest Ecology and Management, v. 473, 118274, 2020.
[6] CAMPOS, J. C. C.; LEITE, H. G. Forest Mensuration: All Ages. 5th ed. Viçosa: Editora UFV, 2017.
[7] EWEL, J. J. Litter fall and leaf decomposition in a tropical forest succession in eastern Guatemala. The Journal of Ecology, p. 293-308, 1976.
[8] FANG, J.; CHEN, A.; PENG, C.; ZHAO, S.; CI, L. Changes in forest biomass carbon storage in China between 1949 and 1998. Science, v. 292, n. 5525, p. 2320-2322, 2001.
[9] FERRAZ, S. F.; VETTORAZZI, C. A.; THEOBALD, D. M.; BALLESTER, M. V. Can land use policies regulate ecosystem services in subtropical forests? A case study of the Atlantic Forest in Brazil. Ecosystem Services, v. 36, 100908, 2019.
[10] FUKUDA, M.; IEHARA, T.; MATSUMOTO, M. Carbon stock estimates for sugi and hinoki forests in Japan. Forest Ecology and Management, v. 184, n. 1-3, p. 1-16, 2003.
[11] IPCC (INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE). Climate Change the Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University, In Press, 2021.
[12] IPCC. Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. In press, 2019.
[13] JOSE, S. Agroforestry for ecosystem services and environmental benefits: An overview. Agroforestry Systems, v. 76, n. 1, p. 1-10, 2009.

[14] KLEINPAUL, I. S.; SCHUMACHER, M. V.; KÖNIG, F. G.; KLEINPAUL, J. J. Litter accumulation in pine and eucalyptus stands on the UFSM campus. In: 9th Rio Grande do Sul State Forestry Congress, Nova Prata, 2003.
[15] LAMONT, B. B.; HE, T.; DOWNES, K. S.; FOX, J. E. D.; CROSS, A. T.; WONG, B. L. Nutrient Cycling in Eucalyptus Forests. Australian Journal of Botany, v. 57, n. 4, p. 279-283, 2009.
[16] LAVALLEE, J. M.; SOONG, J. L.; COTRUFO, M. F. Conceptualizing soil organic matter into particulate and mineral-associated forms to address global change in the 21st century. Global Change Biology, v. 26, n. 1, p. 261-273, 2018.
[17] LEMOS, R. C. Reconnaissance survey of the soils of the State of Rio Grande do Sul, Brazil. Soil Research Division: Technical Bulletin, v. 30, p. 431, 1973.
[18] LIMA, N. L. et al. Litter accumulation in four vegetation types in the state of Goiás. Enciclopédia Biosfera, v. 11, n. 22, p. 41, 2015.
[19] NAIR, P. K.; KUMAR, B. M.; NAIR, V. D. Agroforestry as a strategy for carbon sequestration. Journal of Plant Nutrition and Soil Science, v. 173, n. 1, p. 10-23, 2010.
[20] PRESCOTT, C. E. Litter decomposition: what controls it and how can we alter it to sequester more carbon in forest soils? Biogeochemistry, v. 137, n. 3, p. 337-355, 2018.
[21] SANTOS, H. G. dos; JACOMINE, P. K. T.; ANJOS, L. H. C. dos; OLIVEIRA, V. A. de; LUMBRERAS, J. F.; COELHO, M. R.; ALMEIDA, J. A. de; ARAUJO FILHO, J. C. de; OLIVEIRA, J. B. de; CUNHA, T. J. F. Brazilian Soil Classification System. 5th ed., 2018.
[22] TORRES, J. L. R. et al. Decomposition and nitrogen release from cover crop residues in a Cerrado soil. Brazilian Journal of Soil Science, p. 609-618, 2005.
[23] VIEIRA, M.; SCHUMACHER, M. V. Monthly variation of litter deposition in a Pinus taeda L. stand in a native grassland area in Cambará do Sul-RS. Revista Árvore, v. 34, n. 3, p. 487-494, 2010.
[24] WITSCHORECK, R.; SCHUMACHER, M. V. Estimation of litter carbon in eucalyptus forests of different ages. In: 9th Forestry Congress of the State of Rio Grande do Sul, Nova Prata, 2003.