NUTRIENT RETURN THROUGH LITTERFALL IN A *Eucalyptus dunnii* Maiden STAND IN SANDY SOIL[1]

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[1] Received on 27.08.2015 accepted for publication on 04.10.2016.

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ABSTRACT – In a forest stand, litterfall is primarily responsible for the retention and return of nutrients to the soil. The objective of this study was to evaluate the return of nutrients through litterfall in a stand of *Eucalyptus dunnii* in a Pampa biome. For quantification of litterfall, four 420-m² installments were marked; within each one, four 0.50-m² collection plots were distributed. For the collection of thick branches, four 7.00-m² sub-plots were staked out. The collected litterfall was separated into leaf, twig, thick branch, and miscellany fractions for subsequent chemical analysis. The total litterfall measured was 6.99 Mg ha^{-1} yr^{-1}, and comprised 61.57% leaves, 17.34% twigs, 13.83% thick branches, and 7.26% miscellany. The total amount of macronutrients in the litterfall was 160.22 kg ha^{-1} yr^{-1}, and the macronutrient transfer order was the same for the leaf, twig, and thick branch fractions (Ca > N > K > Mg > S > P). The total quantity of micronutrients was 7.55 kg ha^{-1} yr^{-1}, and the transfer order was Mn > Fe > B > Zn > Cu. Maintaining litterfall on the site, especially in degraded or low fertility soils like in the Pampa biome, may contribute to possible improvements in soil characteristics.

Keywords: Forest nutrition; Nutrient cycling; Pampa biome.

DEVOLUÇÃO DE NUTRIENTES ATRAVÉS DA SERAPILHEIRA PRODUZIDA EM UM POVOAMENTO DE Eucalyptus dunnii *Maiden EM SOLO ARENOSO*

RESUMO – A produção de serapilheira é a principal responsável pela retenção e devolução de nutrientes para o solo em um povoamento florestal. O objetivo deste trabalho foi avaliar a devolução de nutrientes por meio da serapilheira produzida em um povoamento de Eucalyptus dunnii, no bioma Pampa. Para a quantificação da serapilheira produzida, foram demarcadas quatro parcelas de 420 m², e no interior de cada parcela foram distribuídos quatro coletores de 0,50 m². Para a coleta dos galhos grossos demarcou-se quatro sub-parcelas de 7,00 m². O material coletado foi separado nas frações folhas, galhos grossos, galhos finos e miscelânea, com posterior análise química. A serapilheira produzida foi de 6,99 Mg ha^{-1} ano^{-1}, distribuída em 61,57%, 17,34%, 13,83% e 7,26%, nas folhas, galhos finos, galhos grossos e miscelânea, respectivamente. A quantidade de macronutrientes na serapilheira foi de 160,22 kg ha^{-1} ano^{-1}, sendo que, a ordem de transferência foi a mesma para as frações folhas, galhos finos e galhos grossos (Ca > N > K > Mg > S > P). Para os micronutrientes a quantidade foi 7,55 kg ha^{-1} ano^{-1}, seguindo a ordem decrescente de Mn > Fe > B > Zn > Cu. A manutenção da serapilheira no sítio, principalmente em solos degradados ou de baixa fertilidade natural, como é o caso da região do bioma Pampa, poderá contribuir com possíveis melhorias nas características do solo.

Palavras-chave: Nutrição florestal; Ciclagem de nutrientes; Bioma Pampa.

http://dx.doi.org/10.1590/0100-67622016000600009

1. INTRODUCTION

Litterfall is primarily responsible for the retention and return of nutrients to the soil in an ecosystem, constituting a component of paramount importance in forests and forest plantations (FIGUEIREDO FILHO et al., 2003; VITAL, 2004; SCHUMACHER et al., 2013). According to Zimmermann et al. (2002) and Schumacher et al. (2004), litter production and the return of nutrients in forest stands are the most important means of biogeochemical cycling (nutrient flow in the soil-plant-soil system), especially in highly weathered soils of low fertility, where plant biomass is the main nutrient reservoir.

New eucalyptus plantations are being established in areas that lack prior significant forestry histories, such as the Pampa biome, which naturally has low fertility soils (CORRÊA et al., 2013; VIERA et al., 2014). Moraes (2012) stated that there are many questions about the potential environmental impacts that forestry can have on the region, especially when modifying the local biome.

The Pampa biome is the only Brazilian biome restricted to one state. This biome occupies 63% of the Rio Grande do Sul state, with an area of approximately 176,500 square kilometers that extends into Uruguay and Argentina (IBGE, 2004). The Pampa has diverse vegetation consisting mainly of grasses, herbs, and a few scattered shrubs; however, it is estimated that approximately 49% of its area has lost its native vegetation due to anthropogenic exploitation for livestock grazing, (the main economic activity of the region), rice growing, or eucalyptus plantations (BRASIL, 2007).

Each ecosystem has its own characteristic storage and nutrient cycling patterns among its components. Thus, studies on nutrient cycling are critical to determining the sustainability of eucalyptus plantations. In addition, a better understanding of nutrient dynamics in culture allows for the optimization of nutritional management factors such as dosage, methodology, and timing of fertilizer application in certain ecosystems (ZAIA; GAMA-RODRIGUES, 2004; GODINHO et al., 2014.). Despite the importance of the forestry sector to the Rio Grande do Sul economy, some aspects, especially those related to the interactions of these crops with the environment, have not been widely studied (MORAES, 2012).

The objective of this study was to evaluate the return of nutrients through litterfall in a stand of *Eucalyptus dunnii* Maiden in soil subject to arenization in the Pampa biome.

2. MATERIALS AND METHODS

2.1. Characterization of the site

The study was conducted at Fazenda Sesmaria Santo Inácio (29° 47'S, 55° 17'W), owned by Stora Enso Florestal RS Ltda. The site is located in the city of Alegrete, by the western border of the Rio Grande do Sul state, Campanha region. According to the climate classification proposed by Matzenauer et al. (2011), the region has a humid subtemperate climate, with an average annual temperature and rainfall of 18.6 °C and 1,574 mm, respectively. The region may have a dry period in summer.

The study area has dystrophic typic Paleudult soil (EMBRAPA, 2006). Chemical properties of the soil were analyzed according to the methodology described by Tedesco et al. (1995) at the time of settlement implementation (Table 1). According to the interpretation suggested by CQFS (2004), the analysis showed that the soil had low organic matter content, very low pH, very low Ca, low Mg, very low base saturation (V%),and high aluminum saturation (m%) , representing a low fertility soil.

Table 1 – Chemical and physical characteristics of the soil in a *Eucalyptus dunnii* stand in Alegrete, RS.
***Tabela 1** – Características químicas e físicas do solo no povoamento de Eucalyptus dunnii em Alegrete, RS.*

Depth.	Ds[a]	pH	OM[b]	P*	K*	Ca	Mg	Al	m[c]	v[d]	S	B	Cu	Zn
cm	g cm^{-3}	H_2O	%	-- mg dm^{-3} --		----- $cmol_c$ dm^{-3}-----			----- % -----		-------- mg dm^{-3} --------			
0-20	1.52	4.74	1.00	1.87	20.3	0.46	0.33	1.99	71.3	9.07	2.71	0.35	2.29	0.57
20-40	1.58	4.84	0.91	1.60	12.0	0.79	0.24	1.95	65.0	10.99	5.09	0.42	2.14	0.53
40-60	1.53	4.96	0.85	1.49	9.6	1.21	0.27	1.91	55.7	15.15	3.36	0.47	2.20	0.24
60-80	1.49	4.98	0.78	1.49	8.3	1.84	0.34	2.03	48.3	20.51	4.16	0.43	2.23	0.23
80-100	1.43	5.00	0.72	1.54	8.3	1.88	0.40	1.75	43.1	21.22	6.12	0.43	2.01	0.29

* Extraction method Melich I; [a]Soil density; [b]Organic matter; [c] Aluminum saturation; [d] Base saturation.

In 2008 *E. dunnii* seeds were planted in a compartment that had been degraded by agriculture and grazing and had rarely exhibited arenization points. Plant spacing was 2.0 m × 3.5 m.

The area was prepared with ant control solution, herbicide application, in line subsoiling (using 300 kg ha^{-1} N-P_2O_5-K_2O 06-30-06 + 0.6% boron), irrigation, and hoeing. After 90 days of cultivation, 140 kg ha^{-1} N-P_2O_5-K_2O 20-05-22 + 0.2% + 0.4% boron zinc was incorporated into the soil near the seedlings. At 270 days, 140 kg ha^{-1} N-P_2O_5-K_2O 22-00-18 + 1.0% sulfur + 0.3% boron was applied mechanically between lines.

At the beginning of the study, when the subjects were 60 months old, the stand had an average DBH (diameter at breast height, 1.30 m from ground level) of 11.9 cm, an average height of 13.8 m with 1,143 individuals per hectare, and a total trunk volume (with bark) of 124.3 m^3 ha^{-1}.

2.2. Litterfall

For quantification of litterfall, four 20.0 m × 21.0 m (420 m^2) plots were marked in the settlement area. Within each plot, for sampling fractions leaves, thin branches (diameter less than 0.5 cm) and miscellany, were distributed four collectors of 0.50 m^2 systematically (on the line between two trees, between the lines between two trees, diagonally between four trees, and close to the tree bole). For the thick branch (diameter 0.5 cm) fraction, four 7.00 m^2 subplots were demarcated in four different positions: two with an average DBH tree at the center, one with a mean DBH tree plus one standard deviation at the center, and one with a medium DBH tree minus one standard deviation at the center.

Material was collected every two weeks from January to December 2013 and was forwarded to the laboratory, where it was separated into leaf, twig, thick branch, miscellany fractions, and was combined into monthly composite samples. The samples were placed in packaging paper, dried in an air-circulating oven at 70°C for 72 hours, and weighed to determine the dry mass. After weighing, samples were ground using a Wiley mill with a 30 size mesh screen for subsequent chemical analysis.

Nutrient concentrations for each fraction were determined by chemical analysis following the methodology described by Tedesco et al. (1995) and Miyazawa et al. (2009). Nitrogen was determined with the Kjeldahl (sulfuric digestion) method; phosphorus and boron were determined by visible spectrophotometry (after nitric-perchloric digestion and dried digestion, respectively), potassium by flame photometry, sulfur by turbidimetry, and calcium, magnesium, copper, iron, manganese and zinc by atomic absorption spectrophotometry (after nitric-perchloric digestion).

Litterfall per hectare was estimated as a function of the area and the average monthly dry mass of the sample units. The total amounts of nutrients contained in each fraction were estimated by multiplying the concentrations of nutrients by dry weight.

2.3. Statistical analysis

Statistical analysis was performed using Assistat 7.7® (SILVA; AZEVEDO, 2002). Analysis of variance was performed on the data, assuming a completely randomized design with four treatments (the litter fractions) and twelve repetitions (months), and a Tukey test was performed to compare means (α= 0.05).

3. RESULTS

Total litterfall was 6.99 Mg ha^{-1} $year^{-1}$. The leaf fraction constituted the largest fraction of litterfall (61.57%), followed by the twig (17.34%), thick branch (13.83%) and miscellany fractions (7.26%). Table 2 presents the monthly mean and total depositions for each fraction of litter during 2013.

Table 2 – Litterfall in a *Eucalyptus dunnii* stand, Alegrete, RS, in 2013.
T*abela 2* – *Produção de serapilheira em um povoamento de* ***Eucalyptus dunnii****, em Alegrete, RS, no ano de 2013.*

Fraction	kg ha^{-1} ± deviation	(%)*	Mean monthly
Leaves	4306.74 ± 233.81	61.57	358.89
Twigs	1213.04 ± 84.38	17.34	101.09
Thick branches	967.74 ± 72.45	13.83	80.65
Miscellany	507.51± 35.52	7.26	42.29
Total	6995.03 ± 338.08	100.00	582.92

* Correspond to the percentage of each fraction in the total litterfall.

The leaf fraction exhibited the highest nutrient concentrations for all macronutrients (Table 3). In almost all of the studied fractions, Ca was the highest concentration nutrient, with the exception being the miscellany fraction, in which N was the highest concentration nutrient. Among the macronutrients, P and S had the lowest concentrations, possibly since P is a highly mobile nutrient in the phloem of plants and therefore can be translocated to young plant tissues during senescence. Among the tested micronutrients, Mn exhibited the highest concentration in all litter fractions (Table 3).

The total nutrient return to the soil was 160.22 kg ha^{-1} yr^{-1}, with 46.23% of the total from Ca (Table 4). Macronutrient transfer orders were the same for the leaf, twig, and branch fractions (Ca > N > K > Mg > S > P). The miscellany fraction exhibited a transfer order of N > Ca > K > Mg > S > P. For soil micronutrients, the nutrient return was 7.55 kg ha^{-1} (Table 5), 87.30% of which was Mn. Micronutrient transfer orders for all fractions were Mn > Fe > B > Zn > Cu.

The amount of nutrients present in the different litter fractions are presented in Table 4 and Table 5. We found that 74,11% of the total nutrients were found in the leaf fraction, resulting in the following nutrient content order: leaves > twigs > thick branches > miscellany.

4. DISCUSSION

The overall litterfall quantity obtained in this study was similar to that found by other authors; Vieira et al. (2009) observed an average annual litter production

Table 3 – Average concentration of nutrients in fractions of litterfall in *Eucalyptus dunnii* stand in Alegrete, RS, in 2013.
Tabela 3 – *Concentração média de nutrientes nas frações da serapilheira produzida em povoamento de* ***Eucalyptus dunnii*** *em Alegrete, RS, no ano de 2013.*

Fraction	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn
	g kg^{-1}						mg kg^{-1}				
Leaves	7.76 a	0.52 a	3.77 a	12.52 a	2.43 a	0.78 a	40.99 a	5.46 a	106.92 a	1252.73 a	12.44 a
Twigs	2.97 c	0.17 b	2.20 b	7.59 bc	2.12 a	0.29 b	10.07 bc	7.14 a	49.83 b	504.89 b	13.20 a
Thick branches	1.81 c	0.17 b	1.77 b	9.21 ab	1.80 a	0.28 b	6.66 c	5.89 a	51.18 b	471.68 b	24.60 a
Miscellany	5.56 b	0.32 b	2.09 b	4.61 c	2.00 a	0.37 b	13.87 b	4.80 a	108.37 a	480.92 b	10.64 a

*The values in the vertical followed by the same letter do not differ significantly by Tukey test at 5% error.

Table 4 – Amount of macronutrients in litterfall fractions from a *Eucalyptus dunnii* stand in Alegrete, RS, in 2013.
Tabela 4 – *Quantidade de macronutrientes nas frações da serapilheira produzida em povoamento de* ***Eucalyptus dunnii*** *em Alegrete, RS, no ano de 2013.*

Fraction	N	P	K	Ca	Mg	S
	kg ha^{-1}					
Leaves	33.76 (79.98)*	2.29 (82.97)	17.13 (73.24)	51.55 (71.74)	10.36 (65.20)	3.32 (80.78)
Twigs	3.66 (8.67)	0.18 (6.52)	2.93 (12.53)	8.48 (11.80)	2.64 (16.61)	0.38 (9.25)
Thick branches	1.86 (4.41)	0.11 (3.99)	2.16 (9.23)	9.41 (13.09)	1.71 (10.76)	0.21 (5.11)
Miscellany	2.93 (6.94)	0.18 (6.52)	1.17 (5.00)	2.42 (3.37)	1.18 (7.43)	0.20 (4.87)
Total	42.21 (100.00)	2.76 (100.00)	23.39 (100.00)	71.86 (100.00)	15.89 (100.00)	4.11 (100.00)

* Values in parentheses refer to the percentage (%) of each fraction in the total of certain macronutrients contained in the litter in the year of study.

Table 5 – Amount of micronutrients in litterfall fractions from a *Eucalyptus dunnii* stand in Alegrete, RS, in 2013.
Tabela 5 – *Quantidade de micronutrientes nas frações da serapilheira produzida em povoamento de* ***Eucalyptus dunnii*** *em Alegrete, RS, no ano de 2013.*

Fraction	B	Cu	Fe	Mn	Zn
	g ha^{-1}				
Leaves	174.66 (86.71)*	23.48 (57.44)	451.80 (72.57)	5222.66 (79.18)	55.22 (58.84)
Twigs	12.14 (6.03)	8.17 (19.99)	56.25 (9.04)	593.86 (9.00)	17.62 (18.77)
Thick branches	6.64 (3.30)	6.13 (15.00)	53.95 (8.67)	535.56 (8.12)	16.04 (17.09)
Miscellany	7.98(3.96)	3.10 (7.58)	60.54 (9.72)	243.57 (3.69)	4.97 (5.30)
Total	201.42 (100.00)	40.88 (100.00)	622.54 (100.00)	6.595.65 (100.00)	93.85 (100.00)

* Values in parentheses refer to the percentage (%) of each fraction in the total of certain micronutrients contained in the litter in the year of study.

of 5.8 Mg ha^{-1} in an *E. urophylla* × *E. grandis* settlement; Inkotte et al. (2015) observed an average annual litter production of 8.5 Mg ha^{-1} in an *E. dunnii* settlement. Corrêa et al. (2013) observed a deposition of approximately 4.1 Mg ha^{-1} yr^{-1} in an *E. dunnii* settlement; however, the plants used in the study were younger than those in our study, which could explain the difference in litter quantity.

Several studies observed that the predominant litter fraction was the leaf fraction. Like in the present study, Figueiredo Filho et al. (2003), Toledo and Pereira (2004), Corrêa et al. (2013), Tang et al. (2013) and Cizungu et al. (2014) stated that 60 to 93% of the collected litter was leaf litter. One explanation for this predominance is that the trees are young and consequently have not deposited many branches.

Viera et al. (2010) found a higher concentration of nutrients in the leaves and attributed this to the increased metabolic activity of leaf tissues. They mention that mobile nutrients are concentrated in the newer structures of the plant, even after senescence. Viera et al. (2014) studied *E. urophylla* × *E. globulus* litter and observed that Ca + N represented more than 70% of the total macronutrients returned to the soil.

The miscellany fraction exhibited a higher N concentration than Ca concentration. This has also been recorded by Viera and Schumacher (2010) and Viera et al. (2014); the authors attribute this to the presence of reproductive wastes (which have higher concentrations of N) in the miscellany fraction.

Hernández et al. (2009) studied *E. dunnii* and found a macronutrient transfer order of Ca > N > Mg > K > P. Viera et al. (2014), who studied *E. urophylla* × *E. globulus,* and Ashagrie and Zech (2013), who studied *E. globulus*, found a transfer order of Ca > N > K > Mg > S > P. Corrêa et al. (2013), who studied *E. dunnii*, and Silva et al. (2015), who studied *E. camaldulensis*, observed a transfer order of Ca > N > K > Mg > P > S, results similar to those obtained in this study. It is possible that Ca was dominant because of its low mobility in phloem, which hinders its translocation during senescence.

However, Vieira et al. (2009), (studying *E. urophylla* × *E. grandis*), Cunha et al. (2005) (studying *E. grandis*), and Freitas et al. (2013) (studying *E. grandis* × *E. urophylla*) observed that the most abundant macronutrient in the litter was N, and the nutrient transfer order was N > Ca > K > Mg > P, demonstrating that nutrient input varied for each element. These differences were probably related to the soil conditions and physiological characteristics of the species.

The transfer order of micronutrients found in the present study (Mn > Fe > B > Zn > Cu) was identical to that found by Corrêa et al. (2016) with *E. dunnii* in sandy soils and similar to that obtained by Viera et al. (2014) with *E. urophylla* × *E. globulus* (Mn > Fe > Zn > B > Cu).

The results obtained in this study were similar to those reported by Gill et al. (1987), who analyzed the nutrients in *E. tereticornis* litter in highly alkaline soils in India, observing the transfer order Ca > N > Mg > K > S > P for macronutrients and Mn > Fe > Zn > Cu for micronutrients.

In a study of *E. grandis*, Cunha et al. (2005) observed that the order of nutrient amounts in litter fractions was leaves > branches > bark > reproductive structures. Demonstrating that the leaf fraction has relevance in litter deposition. This order occurs because plants try to minimize evaporation and, consequently, the energy expenditure, for biomass production.

In a study of *E. dunnii* on a degraded site, Corrêa et al. (2013) said the area had potential for development of eucalyptus plantations, provided that nutrients be supplied to the site; the low fertility of these soils was counteracted by basic fertilization and coverage practices, evidenced by the concentration of litter nutrients and the amount of litter produced.

The formation and decomposition of litter on degraded soils reactivate nutrient cycling between plants and soil, allowing the formation of a new pedological horizon with more suitable conditions for vegetation restoration (ANDRADE et al., 2003). These authors also claim that in production systems, litter plays an important role in protecting the soil from erosion agents and provides organic matter and nutrients to soil organisms and plants, helping maintain and/or improve both soil and production plant quality.

In a Pampa biome study with different land uses (eucalyptus, pasture and native pasture), Moraes (2012) stated that the eucalyptus culture had high potential residue deposits on the soil surface compared to native pasture or field uses. Our results demonstrate that when the aim is to increase organic matter and nutrient cycling, the large quantity and high nutrient content of eucalyptus litter can improve soil characteristics when it is maintained on a site. This is especially important for degraded or low fertility soils like those in the Pampa biome region.

5. CONCLUSION

The litterfall production of a stand of *Eucalyptus dunnii* Maiden in soil subject to arenization in the Pampa biome was similar to that obtained in other studies.

The annual transfer of nutrients to the soil appeared to follow the descending order of Ca > N > K > Mg > S > P for macronutrients and Mn > Fe > B > Zn > Cu for micronutrients, representing an annual return of 160.22 kg ha^{-1} for macronutrients and 7.55 kg ha^{-1} for micronutrients.

The maintenance of litter on a site may contribute to possible improvements in soil characteristics, especially for degraded or low fertility soils like those in the Pampa biome.

6. ACKNOWLEDGMENTS

We thank StoraEnso for grant support and FAPERGS and CNPq for granting scholarships to the authors.

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