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ORIGINAL ARTICLE – Conservation of Nature

Litterfall in the Semideciduous Seasonal Forest in Southern Brazil

Grasiele Dick[1] 0000-0002-0896-546X
Mauro Valdir Schumacher[1] 0000-0003-3277-5671

Abstract

Litterfall and nutrient cycling are essential processes for the forest diversity and productivity maintenance. This study aims to characterize the litterfall and evaluate if it has correlations with climatic variables in the Semideciduous Seasonal Forest on advanced succession stage, in Southern Brazil. During the 2007-2010 period, the litterfall was collected every month, sorted into leaves, twigs, and miscellaneous fractions. The litterfall amount average was 7.75 Mg ha^{-1} $year^{-1}$ and leaves constituted the highest litterfall percentage (75.0%), followed by twigs (14.7%), and miscellaneous (10.3%). Higher leaf amounts were recorded in August and September. The minimum air temperature was negatively correlated with the leaves and twigs production, that is, the litterfall amount increases when the air temperature decreases. The litterfall amount corresponds to values expected to advanced successional stage of the forest typology studied. In Semideciduous Seasonal Forest in Southern Brazil, the thermal stress exerts influence on the litterfall amount.

Keywords: nutrient cycling, forest nutrition, seasonality.

1. INTRODUCTION AND OBJECTIVES

Brazil has many types of native forest, and the Semideciduous Seasonal Forest occurs between the South and the Southeast of the country (Ivanauskas & Assis, 2012). This forest is considered an important ecosystem in the Atlantic Forest phytogeographic domain for the diversity and conservation of flora, shelter for fauna, and other functions exerted by forests (Viani et al., 2011).

For this forest productivity and diversity maintenance, the nutrient cycling process is an essential mechanism (Santos Neto et al., 2015). Promoted by litterfall, litter decomposition and mineralization make nutrients available in the soil for absorption by roots, and subsequent transfer to different parts of plants (Poggiani, 2012). Therefore, the knowledge on litterfall rates in the physiognomies composing the Atlantic Forest phytogeographic domain is essential, given the current degree of anthropization (Pereira et al., 2008).

In addition to being an ecological indicator for restoration evaluation of degraded areas, litterfall has an important role in the recovery of soil fertility in the initial stages of ecological succession (Alonso et al., 2015). Litterfall on the forest floor, such as leaves, branches, twigs, barks, and other plant materials, decomposes, and mineralizes to form organic matter, which serves as a nutrient pool (Kimmins, 1987). The dynamics of production of deciduous plant material and its seasonality may vary according to the forest successional stage (Menezes et al., 2015) and disturbance degree (Poggiani, 2012).

The litterfall amount also varies among different types of forest and ecosystems (Kimmins, 1987). Especially in the Semideciduous Seasonal Forest, litterfall studies in Brazil, carried out in different successional stages, indicated the litterfall amount varied according to the forest conservation, where it is more intense in advanced successional stages, decreasing in initial succession (Pinto et al., 2009; Werneck et al., 2001). In these varied situations, the species diversity and climatic conditions can influence the litterfall amount (Dias et al., 2002; Toledo et al., 2002). The objective of this study was to characterize the litterfall and evaluate if it has correlations with climatic variables on the Semideciduous Seasonal Forest in advanced succession stage, in Southern Brazil.

2. MATERIALS AND METHODS

2.1. Study area

The study was carried in Quedas do Iguaçu, Southwest region of the Paraná state, Brazil (central geographical coordinates 25° 27' 22" S; 52° 54' 39" W). The site has

[1] Universidade Federal de Santa Maria (UFSM), Santa Maria, RS, Brasil

13,000 ha area, covered by two types of native forests (Semideciduous Seasonal and Mixed Ombrophilous Forests) in different conservation stages, surrounded by pulp plantations of *Araucaria angustifolia* (Bertol.) Kuntze, *Pinus* spp. and *Eucalyptus* spp. The study area was delimited just in a remnant of the Semideciduous Seasonal Forest in advanced succession stage.

A floristic survey in the study area (Viani et al., 2011) indicates richness of the following botanical families: Fabaceae (16 species), Lauraceae (8 species), Myrtaceae (7 species) and Solanaceae (7 species). The authors mentioned above found 1,500 tree ha^{-1} average density in this forest typology, where the most abundant species *Actinostemon concolor* (Spreng.) Müll.Arg., *Nectandra megapotamica* (Spreng.) Mez, *Lonchocarpus campestris* Mart. ex Benth., *Syagrus romanzoffiana* (Cham.) Glassman, *Sebastiania brasiliensis* Spreng., *Diatenopteryx sorbifolia* Radlk., and *Balfourodendron riedelianum* (Engl.) Engl. are typical of Semideciduous Seasonal Forests in advanced succession stages.

The humid subtropical climate characterized by hot summers, with an average annual temperature of 20 °C, 1,780 mm average annual rainfall and 60 mm in the driest month (Matzenauer et al., 2011). The region is characterized by two seasons: rainy summer and winter characterized by physiological drought and temperatures below 15 °C (Table 1).

The study area relief is undulating and the altitude is 450 m in relation to the average sea level (FUPEF, 2001). The predominant soil class is the typical Dystroferric Red Oxisol, characterized by low fertility and Fe_2O_3 levels varying between 18% and 36% up to 100 cm depth in the B-horizon (EMBRAPA, 2013).

Table 1. Monthly variation on air temperature and pluviometric precipitation during the study period, in the Semideciduous Seasonal Forest in Southern Brazil.

Variables	Year	Month											
		Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb
Tmin (°C)	2007-2008	19.5	17.6	11.7	12.0	9.8	12.4	15.9	17.6	16.7	19.1	19.5	19.5
	2008-2009	18.9	18.8	16.3	15.0	14.5	16.3	16.9	18.8	19.5	19.6	19.7	19.8
	2009-2010	20.0	19.1	17.0	15.2	15.4	16.4	18.0	18.7	19.9	19.8	20.6	21.0
	2010-2011	20.3	18.4	16.6	14.7	15.0	14.3	17.1	18.5	19.3	20.6	20.3	–
Tmax (°C)	2007-2008	31.9	29.1	22.7	24.0	21.9	25.5	30.3	29.0	28.6	31.5	29.7	30.2
	2008-2009	30.0	28.9	25.7	25.7	25.2	28.4	29.3	30.8	29.8	29.9	30.5	30.0
	2009-2010	30.3	28.8	27.7	25.5	26.3	27.7	29.3	29.5	31.4	30.2	30.2	30.9
	2010-2011	30.9	29.0	27.5	27.0	27.1	28.1	29.8	29.9	29.8	30.3	28.5	–
Ptmin (mm)	2007-2008	85.0	208.8	234.4	22.2	71.8	10.2	16.0	99.0	151.8	301.0	77.4	161.8
	2008-2009	16.1	130.0	102.1	243.2	110.3	247.5	290.2	289.2	162.8	69.3	218.1	161.2
	2009-2010	67.5	19.9	127.7	65.7	272.6	181.6	428.0	412.4	537.6	265.3	214.9	125.3
	2010-2011	183.5	355.3	99.6	2.0	168.6	15.0	170.3	155.7	209.8	334.6	327.0	266.3
Ptmax (mm)	2007-2008	44.0	80.0	55.0	19.0	35.0	6.0	9.0	35.0	67.0	66.8	26.0	46.0
	2008-2009	7.8	54.7	31.9	80.0	46.5	59.5	153.2	62.5	44.3	20.6	55.9	484
	2009-2010	19.6	11.5	91.5	36.4	93.4	69.8	97.6	114.5	112.6	78.2	49.2	43.2
	2010-2011	80.9	149.9	39.6	1.4	41.9	6.0	61.1	49.0	79.7	49.6	53.9	73.9

Tmin: average minimum air temperature; Tmax: average maximum air temperature; Ptmin: minimum total pluviometric precipitation; Ptmax: maximum total pluviometric precipitation.

Source: Weather station of Araupel S.A. company, 2007-2011.

2.2. Litterfall sampling

Three plots with 20 m × 20 m dimensions were installed to collect litterfall in the Semideciduous Seasonal Forest. Installed 20 meters away from the forest border, the plots were maintained 30 meters of minimum distance between each other, randomly distributed. In each plot was installed four litterfall collectors with 1 m² area, made of shading-net (1 mm mesh) and 0.70 m suspended above the soil level. From January 2007 to December 2010, all the litterfall deposited in these plots was collected every month and sent to the laboratory. The litterfall samples were sorted into leaves, twigs (diameter ≤ 0.5 cm), and miscellaneous fractions (i.e., flowers, seeds, fruits, and other residues). The samples fractions were dried in a circulation oven at 70 °C for 72 hours, followed by weighing in a balance (0.01 g accuracy).

Based on the data of monthly litterfall collections, the average year amount produced was estimated with the equation PS = (Σ PMS × 10,000) / AC, where: PS = annual litterfall (Mg ha^{-1} year^{-1}), PMS = monthly litterfall (Mg ha^{-1} month^{-1}), and AC = collector area (m²) (Lopes et al., 2002).

2.3. Data analysis

The litterfall data were submitted to analysis of variance (ANOVA) in a completely randomized experimental design. The Scott-Knott test (α = 5%) was applied to evaluate differences in the monthly average litterfall (leaves, twigs and miscellaneous) between treatments (i.e. months). For ANOVA, four values (samples) were considered for each month (treatments) during the 2007-2010 period. The correlations between litterfall and climatic variables were evaluated by Pearson's bilateral test. All analyzes were performed with Assistat version 7.7 (Silva & Azevedo, 2002).

3. RESULTS AND DISCUSSION

The total litterfall amount in the Semideciduous Seasonal Forest in the four years of evaluation was 31.01 Mg ha^{-1}, with an annual average value of 7.75 Mg ha^{-1} year^{-1}. The leaves were the predominated fraction of the litterfall (75.0%), followed by twigs (14.7%), and miscellaneous (10.3%) (Table 2).

Table 2. Litterfall in the Semideciduous Seasonal Forest in Southern Brazil.

	Leaves	Twigs	Miscellaneous	Total
2007				
Total (Mg ha^{-1} year^{-1})	5.93	1.67	0.92	8.57
Monthly average (Mg ha^{-1})	0.49	0.13	0.76	0.71
Percentage (%)	*69.7*	*19.5*	*10.8*	*100*
2008				
Total (Mg ha^{-1} year^{-1})	5.29	1.00	0.80	7.09
Monthly average (Mg ha^{-1})	0.44	0.83	0.66	0.59
Percentage (%)	*74.6*	*14.1*	*11.3*	*100*
2009				
Total (Mg ha^{-1} year^{-1})	5.85	1.08	0.38	7.31
Monthly average (Mg ha^{-1})	0.48	0.90	0.31	0.60
Percentage (%)	*80.0*	*14.8*	*5.2*	*100*
2010				
Total (Mg ha^{-1} year^{-1})	6.11	0.83	1.10	8.04
Monthly average (Mg ha^{-1})	0.50	0.69	0.91	0.67
Percentage (%)	*75.9*	*10.4*	*13.7*	*100*
Period averages				
Annual average (Mg ha^{-1} year^{-1})	5.81	1.14	0.80	7.75
Standard deviation	0.24	0.07	0.05	0.31
CV	4.13	6.14	6.25	4.00
Percentage (%)	*75.0*	*14.7*	*10.3*	*100*

CV: coefficient of variation.

The species diversity of this floristic composition (Viani et al., 2011) and partial deciduality provided continuous patterns of litterfall during the evaluated periods. The large litterfall amounts produced by varied species is a factor directly related to accelerated nutrient cycling, more organic matter formation, soil fertility increase, and soil protection (Kimmins, 1987).

The litterfall amounts, ranging from 7.09 to 8.57 Mg ha^{-1} year^{-1}, correspond to values expected to advanced successional stage of the forest studied. The litterfall amount in this type of Semideciduous Seasonal Forest can vary from 5.09 to over 12.00 Mg ha^{-1} year^{-1} depending on succession stages (Table 3). In this forest typology, litterfall amounts in advanced stage tends to be higher than those of areas in initial succession.

The floristic composition variability, species abundance between succession stages (Viani et al., 2011) and soil fertility influenced the litterfall amount of the Semideciduous Seasonal Forest (Pinto et al., 2009). The litterfall amount variation was also related to forests conservation status and seasonality climatic variables effect (Werneck et al., 2001).

About the litterfall composition and seasonality, twigs and miscellaneous varied according to the month and year, but regarding the amount of leaves, same tendencies are observed over time (Figure 1). The monthly variability of miscellaneous in litterfall composition is related to the amount of flowers, fruits and seeds produced by different species, with varied phenological phases; temporal heterogeneity on twigs amounts is a senescence physiological reflection (Taiz & Zeiger, 2013) and an influence of other events (i.e., trees falls, rainfall, lightning and strong winds) (Pinto et al., 2009).

Table 3. Litterfall in different succession stages of the Semideciduous Seasonal Forest typology, Brazil.

Semideciduous Seasonal Forest		Litterfall (Mg ha^{-1} year^{-1})	Source
Advanced succession stage		8.21	Pimenta et al. (2011)
		9.50	Pezzato & Wisniewski (2006)
		11.70	Pezzato & Wisniewski (2006)
		8.82	Pinto et al. (2009)
		12.97	Toledo et al. (2002)
		6.78	Werneck et al. (2001)
		8.81	Pinto et al. (2009)
Intermediary succession stage		6.58	Werneck et al. (2001)
Initial succession stage		6.31	Pinto et al. (2009)
		5.09	Werneck et al. (2001)
		6.31	Pinto et al. (2009)
Others	Riparian forest	10.00	Vital et al. (2004)
	Gaps in forest	5.97	Martins & Rodrigues (1999)

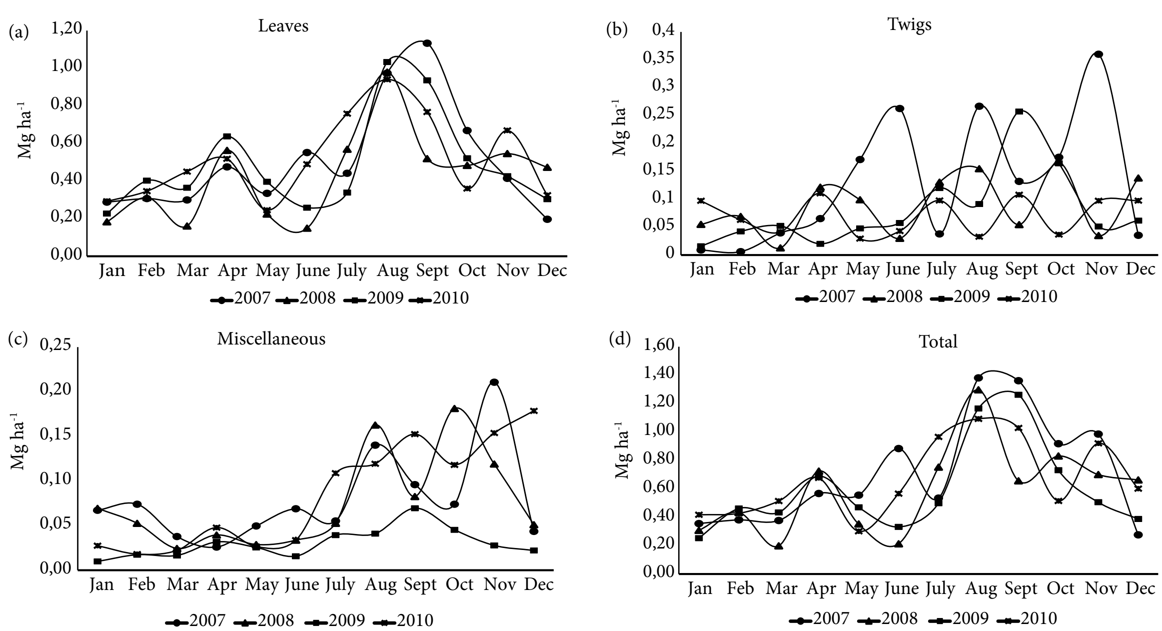

Figure 1. Seasonality of litterfall in the Semideciduous Seasonal Forest in Southern Brazil.

Leaves in the litterfall composition are results found in all studies, regardless of forest typology or succession stage (Poggiani, 2012). Leaves are rich in nutrients, and the cycling fastest route can be used as a total litterfall indicator, as it follows the same tendencies of production (Pinto et al., 2009). Out of all the litterfall, leaves decomposition is more accelerated, and large amounts of this component in the litterfall contribute to the continuous organic matter formation and productive capacity of this forest (Ferreira et al., 2014).

Considering the litterfall monthly averages, the twigs amount and miscellaneous did not vary, but leaf production was higher in August and September, corresponding to 30% of the total litterfall of leaves (Table 4).

In August and September, the highest amount of leaves in the litterfall reflects the plant physiological responses to thermal stress (Taiz & Zeiger, 2013), caused by the lower temperatures recorded in July; in the study area, the minimum temperature in this period was lower than 15 °C (Table 1). These results are corroborated by the correlation analyses that indicate the minimum air temperature negatively correlated with the leaves and twigs production (Table 5), that is, the litterfall amount (75% leaves in composition) increases when the air temperature decreases.

The seasonal leaves fall occurs due to endogenous hormonal regulation, by thermal stress, triggering a cascade of physiological events in the plant, finishing with leaves abscission (Dias et al., 2002). However, climatic extreme absence (intense and dry cold prolonged periods), coupled with floristic diversity in this Semideciduous Seasonal Forest, allows the forest to litterfall throughout the year (Viani et al., 2011).

In others litterfall studies of the seasonal forest in Southern Brazil, the peak of leaves production were also reported in September when the temperature begins to rise, indicated as a tendency of this forest in the South region (König et al., 2002; Pimenta et al., 2011). The growth stagnation caused by winter leads to senescent foliage elimination, optimal utilization aiming to new growth period, which begins in Spring, with the new foliage appearance (Toledo et al., 2002).

In this forest in Southern Brazil, the thermal stress influence on the litterfall amount is corroborated. However, in the same type of forest in the Southeast country region. where air temperature extremes are not pronounced, the pluviometric precipitation is a more effective factor that influences litterfall amount, with peaks after water deficit (Dias et al., 2002; Pinto et al., 2009; Toledo et al., 2002).

Table 4. Monthly values (average ± standard deviation) of litterfall in the Semideciduous Seasonal Forest in Southern Brazil.

Months	Leaves	Twigs	Miscellaneous	Total
	Mg ha^{-1}			
January	0.25 ± 0.05 c*	0.06 ± 0.03 a	0.04 ± 0.03 a	**0.35 (4.5)**
February	0.34 ± 0.04 c	0.06 ± 0.01 a	0.04 ± 0.02 a	**0.44 (5.7)**
March	0.31 ± 0.12 c	0.04 ± 0.01 a	0.03 ± 0.01 a	**0.38 (4.9)**
April	0.55 ± 0.06 b	0.08 ± 0.05 a	0.04 ± 0.01 a	**0.67 (8.6)**
May	0.30 ± 0.07 c	0.07 ± 0.06 a	0.03 ± 0.01 a	**0.40 (5.2)**
June	0.36 ± 0.18 c	0.10 ± 0.01 a	0.04 ± 0.02 a	**0.50 (6.4)**
July	0.53 ± 0.11 b	0.10 ± 0.04 a	0.06 ± 0.03 a	**0.69 (8.9)**
August	0.98 ± 0.03 a	0.14 ± 0.10 a	0.12 ± 0.05 a	**1.24 (16.0)**
September	0.84 ± 0.35 a	0.14 ± 0.08 a	0.10 ± 0.03 a	**1.08 (13.9)**
October	0.51 ± 0.12 b	0.14 ± 0.06 a	0.10 ± 0.06 a	**0.75 (9.7)**
November	0.51 ± 0.12 b	0.14 ± 0.04 a	0.13 ± 0.07 a	**0.78 (10.1)**
December	0.32 ± 0.11 c	0.08 ± 0.04 a	0.07 ± 0.07 a	**0.47 (6.1)**

* Averages followed by the same letter in the column do not differ significantly by the Scott-Knott test at 5% probability of error. Values in parentheses: percentages about total produced relation.

Table 5. Pearson's correlation between litterfall and climate variables in the Semideciduous Seasonal Forest in Southern Brazil.

Fractions	Tmax (°C)	Tmin (°C)	Pt (mm)
Leaves	−0.066	−0.307*	−0.109
Twigs	−0.248	−0.316*	0.075
Miscellaneous	0.049	−0.124	0.062

* Significant correlation at 5% probability of error. Tmin: average minimum air temperature; Tmax: average maximum air temperature; Pt: average pluviometric precipitation.

4. CONCLUSIONS

The litterfall amounts in the forest studied, which range from 7.09 to 8.57 Mg ha^{-1} year^{-1}, correspond to values expected in the advanced successional stage. Leaves predominated in the litterfall composition (75%), and thermal stress influences the litterfall amount, when minimum air temperature was negatively correlated with leaves and twigs production.

The litterfall is a relevant mean of forest nutrition in natural ecosystems; however, to better understand the nutrient cycling in Semideciduous Seasonal Forest, further studies are necessary to evaluate the nutritional and organic composition (cellulose, hemicellulose and lignin) of the litter and its decomposition dynamics (release of nutrients rate, decomposing fauna action, etc.).

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CORRESPONDENCE TO

Grasiele Dick
Universidade Federal de Santa Maria (UFSM), Av. Roraima, 1.000, CEP 97105-900, Santa Maria, RS, Brasil
e-mail: grasidick@hotmail.com

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