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PARTITIONING OF RAINFALL IN A FOREST RECOMPOSITION AREA WITH SPECIES OF SEMIDECIDUOUS SEASONAL FOREST[1]

PARTIÇÃO DA CHUVA EM ÁREA DE RECOMPOSIÇÃO FLORESTAL COM ESPÉCIES DA FLORESTA ESTACIONAL SEMIDECIDUAL[1]

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ABSTRACT - The relationship between ecosystem restoration and hydrological processes has been poorly studied. Areas planted with tree species are important for studying the rainfall partitioning process at the canopy level. For this purpose, a reforested area approximately 70 years old was selected at the Tupi Experimental Station (TES), where a plot of 400 m^2 was demarcated. Eleven tree species were identified among the 40 trees, 39 of which are native and only one exotic. All precipitation events were obtained with rainfall gauges made from 2 L PET plastic bottles; four in open area, 25 within the forest for throughfall and three polyurethane stemflow collectors for stemflow determination were used. Interception was estimated using the canopy water balance equation. During the 1-year experimental period, 60 storm events were collected, resulting in 1,522.0 mm of gross precipitation. On average, 15.3% of the gross precipitation was intercepted by the forest, 80.4% crossed the canopy through throughfall and 4.3% as stemflow, totaling 84.7% of net precipitation. There was a statistically significant difference for interception losses between the rainy and dry periods, with the highest values in the rainy season. Linear regression analyzes indicated a high positive correlation between gross precipitation for both throughfall ($R^2 > 0.9$) and stemflow ($R^2 > 0.8$), moderate between gross precipitation and interception (R^2 close to 0.6). The results show that after about 70 years of its implementation, the partitioning of rainfall has values compatible with those found in semideciduous seasonal forests.

Keywords: Throughfall; Interception; Stemflow; Hydrological cycle, Semideciduous seasonal forest.

RESUMO - As relações entre recomposição florestal e os processos hidrológicos são pouco estudadas. Áreas plantadas com espécies arbóreas são importantes para se avaliar a repartição da chuva ao nível das copas. Com esse propósito foi selecionada uma área reflorestada com cerca de 70 anos de idade na Estação Experimental de Tupi, onde demarcou-se uma parcela de 400 m^2. Foram identificadas 11 espécies arbóreas dentre 40 árvores existentes, sendo 39 nativas e apenas uma exótica. Todos os eventos de precipitação foram registrados com pluviômetros feitos com garrafas plásticas PET de 2 L; quatro em área aberta, 25 no interior da floresta para a transprecipitação e para a determinação do escoamento pelo tronco das árvores foram instalados três coletores de espuma de poliuretano. A interceptação foi estimada pela equação do balanço hídrico do dossel. No período de 1 ano foram realizadas 60 coletas de chuva, totalizando 1.522,0 mm de precipitação. Em média, 15,3% da precipitação total foi interceptada pela floresta, 80,4% atravessaram o dossel pela transprecipitação e 4,3% como escoamento pelo tronco, totalizando 84,7% de precipitação efetiva. Houve diferença estatisticamente significativa para as perdas por interceptação entre os períodos chuvoso e seco, com os maiores valores na época das chuvas. Análises de regressão linear indicaram correlação positiva alta entre a precipitação total, tanto para a transprecipitação ($R^2 > 0,9$) quanto para o escoamento pelo tronco ($R^2 > 0,8$), e média para a precipitação total e a interceptação (R^2 próximo a 0,6). Os resultados mostram que após cerca de 70 anos de sua implantação, o processo de repartição da chuva possui valores compatíveis aos encontrados em floresta estacional semidecidual.

Palavras-chave: Transprecipitação; Interceptação; Escoamento pelo tronco; Ciclo hidrológico; Floresta Estacional Semidecidual.

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1 INTRODUCTION

The Atlantic Forest is a highly diverse vegetation with a large number of endemic species, significantly reduced and fragmented (currently covering only 12.4% of its original extent over three hectares). Its protection and restoration are fundamental to guarantee ecosystem services for 70% of the population living in its domains and 80% of the Brazilian economy (Ribeiro et al., 2009; FOUNDATION SOS MATA ATLÂNTICA; NATIONAL INSTITUTE OF SPACE RESEARCH - INPE, 2021). In the state of São Paulo, it represents 22.9% of its territory (Nalon et al., 2022), with the semideciduous seasonal forest phytophysiognomy accounting for 7% (Fioravanti, 2020). Complex interactions between rainfall and the forest can impact local hydrology and must be explicitly considered in restoration projects (Terra et al., 2018; Andreasen et al., 2023).

When rain (P) reaches the forest, part or all of it is intercepted by the tree canopies and evaporates (I), no longer playing any role in the terrestrial phase of the hydrological cycle. Rain that is not retained reaches the forest floor as throughfall (Tf), which consists of the fraction that drips from the canopies or passes directly through them, and as stemflow (Sf) (Crockford and Richardson, 2000). Together they make up net precipitation (Np) (Arcova et al. 2003; Honda, 2013). Throughfall corresponds to approximately 80% of gross precipitation (Levia and Frost, 2006) and stemflow is generally very small, being between 1% and 5% of gross precipitation (Honda, 2013). The volume of water intercepted is not negligible and can be up to 50% of annual precipitation (Carlyle-Moses and Gash, 2011) and constitutes a considerable reduction in the amount that actually reaches the soil and, as a consequence, there is a decrease in water productivity (Crockford and Richardson, 2000; Honda, 2013).

The spatial variability of throughfall is important, especially during small rainfalls, when most of the canopy is not saturated (Levia et al., 2011). Huitao et al. (2012) studied the spatial variation of throughfall in a secondary forest in the subtropical region of China, to determine the optimal number of collectors, within certain error limits, in plots of 25 m x 25 m. They concluded that 25 collectors were sufficient to estimate throughfall with an acceptable error of 10% at confidence levels of 90 and 95%, even for small rainfall.

For practical reasons, stemflow can only be measured in a limited number of trees for a given period (Holwerda et al., 2006). The simplest way to extrapolate the stemflow volume of a plot is to calculate the average stemflow volume and multiply it by the total number of trees per unit area (e.g., per hectare of a forest) (Levia and Germer, 2015). In general, the spatial variability of stemflow decreases as precipitation increases (Lloyd and Marques, 1988).

Interception, throughfall and stemflow are influenced by the climate (quantity, intensity, duration and temporal distribution of rainfall), meteorological conditions (air temperature and humidity, wind speed and direction, presence of fog) and vegetation (species composition, age, basal area, forest density, canopy morphology and architecture, presence of epiphytes) and the interaction between these three factors (Crockford and Richardson, 2000; Fleischbein et al., 2005; Giglio and Kobiyama, 2013). Thus, it varies in time and space (Levia and Frost, 2006). Aspects related to vegetation cover are of great importance as management, changes in species and land use and occupation can affect the rain distribution process (Rogerson, 1968; Lima, 1976; Lima and Nicolielo, 1983; Gênova et al., 2007; Honda, 2013).

Yue et al. (2021) analyzed and synthesized the rainfall partitioning on a global scale using 236 independent publications. They found that: (1) the median values of interception, stemflow and throughfall represent 21.8%, 3.2% and 73.0% of gross precipitation; (2) rainfall partitioning varies between different biomes, due to differences in plant composition, canopy structure and macroclimate; (3) stemflow is influenced by tree characteristics such as crown height-to-width ratio, basal area, and height, while interception and throughfall are affected by tree characteristics as well as climatic factors.

A synthesis of research results on rainfall partitioning in semideciduous seasonal forests under different environmental conditions and forest characteristics points to average values of interception, stemflow and throughfall in relation to gross precipitation of 21.3%, 1.4% and 77.5%, respectively (Table 1). The range of values is large, with the minimum and maximum recorded for the three processes being 12.1% and 31.6%, 0.1% and 10.0% and 67.0% and 87.3%, respectively.

In the context of ecosystem restoration, the relationships between vegetation and hydrological processes have been little studied (Honda and Durigan, 2017). In this sense, areas planted with native essences are important for studying the partitioning of rainfall across tree canopies (Arcova et al., 2020).

The objectives of this paper were to study the distribution of rainwater in an area reforested with 70-year-old semideciduous seasonal forest species into throughfall, stemflow and interception.

Table 1. Synthesis of rainfall partitioning studies in semideciduous seasonal forest.

Tabela 1. Síntese dos estudos de partição da chuva em floresta estacional semidecidual.

Locality	Mean annual rainfall (mm)	Forest type	Tf	Sf	I	Source
			(% of P)			
Belo Horizonte MG	1,500	Secondary + Cerrado	67.0	10.0	23.0	Vieira e Palmier, 2006
Viçosa MG	1,341	Secondary Mid-advanced	76.7	2.6	20.7	Oliveira Junior, 2006
Viçosa MG	1,220	Secondary Initial regeneration	79.05	0.38	20.57	Alves et al., 2007
		Secondary Advanced regeneration	80.86	0.77	18.37	
Viçosa MG	1,268	Secondary Initial regeneration	85.09	0.69	14.92	Lorenzon et al., 2013
		Secondary Advanced regeneration	74.95	1.90	25.07	
Viçosa MG	1,268	Secondary Initial reg.+advanced	81.0	0.9	18.1	Freitas et al., 2013
Campinas SP	1,424	Urban forest	71.1			Guirao e Teixeira Filho, 2013
Viçosa MG	1,268	Secondary Initial regeneration	79.36	0.44	20.2	Freitas et al., 2016
		Secondary Advanced regeneration	72.68	1.52	25.8	
Pinheiral RJ	1,300	Submontane Initial secondary	77.63	0.26	22.11	Diniz et al., 2013
		Submontane Medium secondary	79.04	0.22	20.73	
		Submontane Advanced secondary	76.87	0.11	23.01	
Iperó SP	1,400	Secondary	76.2	1.0	22.8	Tonello et al.,2014
Jundiaí SP			68.3	0.12	31.6	Gonzalez, 2017
Lavras MG	1,511	Montane Emergent canopy trees	87.3	0.6	12.1	Junqueira Junior et al., 2019
		Mean	**77.5**	**1.4**	**21.3**	

The averages of Tf, Sf and I were calculated from research in which throughfall and stemflow were monitored (n=15).

As médias de Tf, Sf and I foram calculadas em pesquisas que a transprecipitação e o escoamento pelo tronco das árvores foram monitorados (n=15).

2 MATERIAL AND METHODS

2.1 Site Description

The study was conducted in the Tupi Experimental Station (TES), which is an area of 198.4 ha, protected and managed by the Forestry Foundation, linked to Secretariat for the Environment, Infrastructure and Logistics of São Paulo (Pinheiro et al., 1999) (Figure 1). It is located at geographic coordinates 47°31'42.24"W (longitude); 22°44'8.10"S (latitude), average altitude of 515 m, district of Tupi in the municipality of Piracicaba, São Paulo.

Figure 1. Google® satellite image with the location of Tupi Experimental Station (borders in white), in the district of Tupi, municipality of Piracicaba, São Paulo State.

Figura 1. Imagem de satélite do Google® com a localização da Estação Experimental de Tupi (contorno em linha branca), no distrito de Tupi, município de Piracicaba, SP.

The predominant original vegetation in the region is semideciduous seasonal forest; the term seasonal refers to changes in appearance or behavior depending on the seasons. It is characterized by having a canopy that is not perfectly continuous (irregular), between 15 and 20 m high, with the presence of emerging trees up to 25-30 m high, occupying the most varied soil conditions (Rodrigues, 1999).

The climate of the Piracicaba region, according to the Köppen climate classification, can be classified as Cfa (humid subtropical with oceanic climate, with absence of dry season with hot summer) (Alvares et al., 2013), although more recent studies show a trend of change to Aw (tropical with dry season) (Alvares et al., 2022). Meteorological observations obtained from the meteorological station of the “Luiz de Queiroz” College of Agriculture – USP, 10 km from the experimental area, between 1917 and 2022 (Escola Superior de Agricultura “Luiz de Queiroz”, 2022) indicate an average annual air temperature of 24.8°C, average humidity annual of 73.1% and average annual precipitation of 1,274.2 mm, with almost 78% occurring between October and March.

The geology of the area is made up of sedimentary rocks from the Tubarão group, predominantly the Itararé formation and secondarily the Tatuí formation (Vidal Torrado, 1994). The TES is located in the Peripheral Depression, Middle Tietê region, characterized by a slightly rugged topography, with differences in level that rarely exceed 200 meters, predominantly low hills, with smooth shapes separated by young valleys, without important alluvial plains, determined by the intersection of convex profiles of the slopes (Pinheiro et al., 1999). The soil of the study area was classified as Typic Hapludult (Bovi et al., 2020).

The experiment was installed in a 2.76 ha plot (Figure 2) reforested with native essences (Figure 3), in 1952 (plot 36a). There is no record of the number of individuals planted, the spacing adopted and other information about planting (Giannotti et al., 2003). According to reports from TES employees, between 15 and 20 years ago, the area was colonized by the weed Trapoeraba (*Commelia benghalensis* L.). This invasive species influences natural regeneration due to the accumulation of biomass and water, as well as limiting light incidence. It can also affect morphological parameters and compromise the formation of understory vegetation (Cruz, 2014). The tree species within this area have autocory and barocory dispersal. As they are lightweight, they cannot penetrate the formation created by the Trapoeraba, which reaches approximately 15 to 20 cm in height, preventing them from reaching the ground for the germination process.

Figure 2. Google® satellite image with the location where the experiment was implemented in the Tupi Experimental Station (white arrow).

Figura 2. Imagem de satélite do Google® do local onde foi implementado o experimento na Estação Experimental de Tupi (seta branca).

Figure 3. Photo showing vegetation, where the experimental plot was located to study the rainfall partitioning.

Figura 3. Vista geral da vegetação, onde foi implantada a parcela experimental para estudo da repartição da chuva.

In order to characterize the tree species in the experimental plot, a dendrometric survey was carried out. Figure 4 shows the location of the trees, including those with water collectors stemflow, as well as the throughfall rain gauges. In Table 2, the trees are identified, as well as their diameter at breast height (DBH) and their basal area (BA) noted. The inclusion criterion used was trees from 5 cm DBH (Machado et al., 2008; Batista et al., 2014).

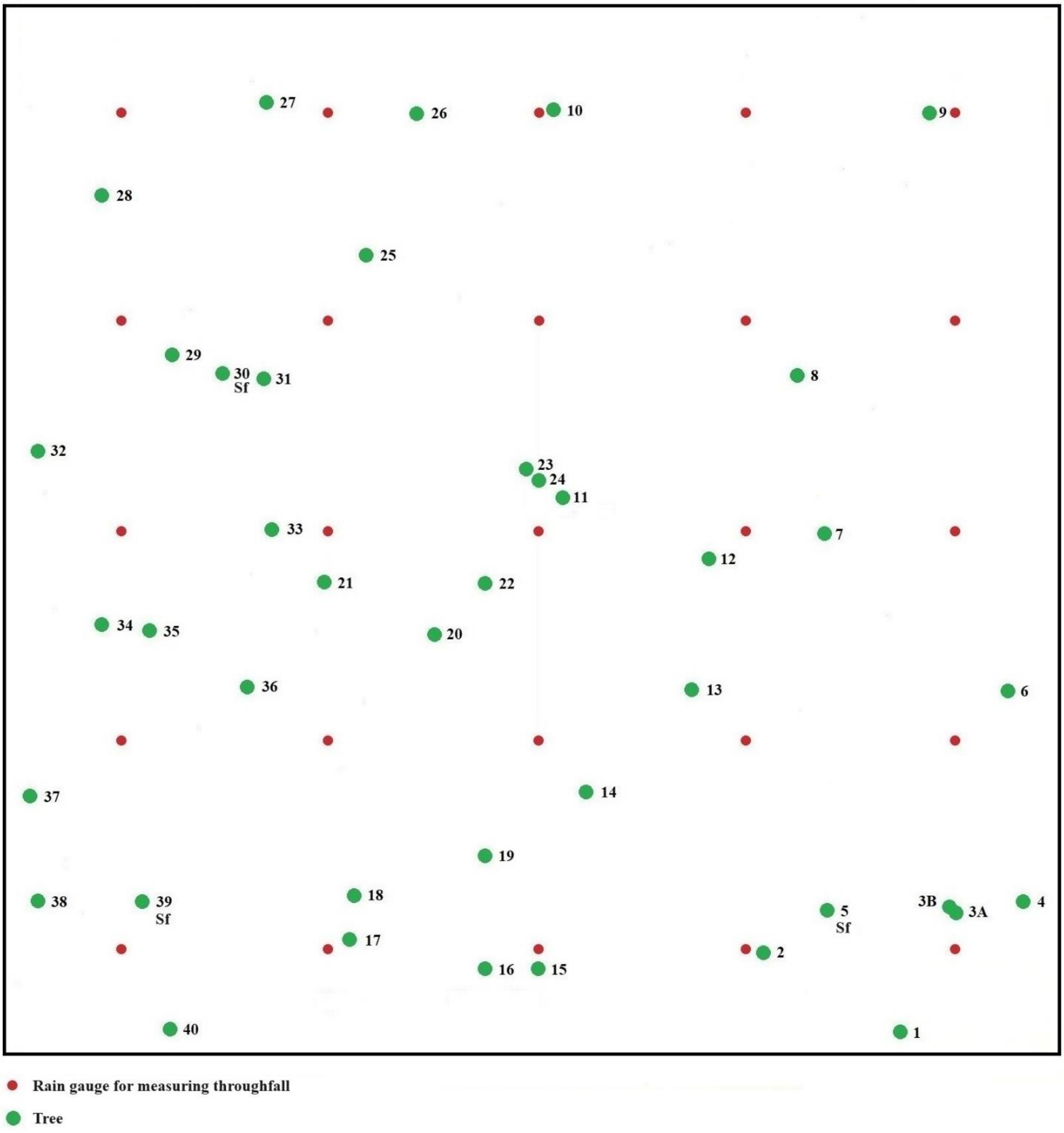

Figure 4. Sketch of the 20 x 20 m plot, with the 25 rain gauges to measure the throughfall, and the arrangement of the 40 trees, including the three with stemflow measurements.

Figura 4. Croqui da parcela de 20 x 20 m, com os 25 pluviômetros para medir a transprecipitação, e a disposição das 40 árvores existentes, incluindo as três com coletores de escoamento pelo tronco.

Table 2. Dendrometric survey of the experimental plot.

Tabela 2. Levantamento dendrométrico da parcela experimental.

Tree nº	Popular name	Scientific name	Diameter (DBH) (cm)	Basal Área (BA) (m^2)
1	Araribá	*Centrolobium tomentosum* Guill.·ex Benth.	5	0.00196
2	Guarantã	*Esenbeckia leiocarpa* Engl.	11.5	0.01039
3A	Jatobá	*Hymenaea courbaril* L.	21.5	0.03631
3B	Jatobá	*Hymenaea courbaril* L.	10.5	0.00866
4	Pau-jacaré	*Piptadenia gonoacantha* (Mart.) Macbr.	5	0.00196
5	Guatambú	*Aspidosperma ramiflorum* Muell.Arg.	16.8	0.02204
6	Angico vermelho	*Anadenanthera macrocarpa* (Berth.) Brenan	18.8	0.02761
7	Monjoleiro	*Acacia polyphylla* DC.	9	0.00636
8	Guarantã	*Esenbeckia leiocarpa* Engl.	6.5	0.00332
9	Guarantã	*Esenbeckia leiocarpa* Engl.	13.3	0.01379
10	Guarantã	*Esenbeckia leiocarpa* Engl.	5	0.00196
11	Açoita cavalo	*Luehea divaricata* Mart.	51.8	0.21033
12	Pau-jacaré	*Piptadenia gonoacantha* (Mart.) Macbr.	13.8	0.01485
13	Guarantã	*Esenbeckia leiocarpa* Engl.	7.3	0.00413
14	Guarantã	*Esenbeckia leiocarpa* Engl.	10.5	0.00866
15	Guapuruvú	*Schizolobium parahyba* (Vell.) Blake	58.5	0.26878
16	Alecrim do mato	*Holocalyx balansae* Mich.	7	0.00385
17	Guarantã	*Esenbeckia leiocarpa* Engl.	12	0.01131
18	Alecrim do mato	*Holocalyx balansae* Mich.	7.3	0.00413
19	Guarantã	*Esenbeckia leiocarpa* Engl.	6.3	0.00307
20	Açoita cavalo	*Luehea divaricata* Mart.	20.8	0.03382
21	Açoita cavalo	*Luehea divaricata* Mart.	37.5	0.11045
22	Guarantã	*Esenbeckia leiocarpa* Engl.	23.3	0.04246
23	Guarantã	*Esenbeckia leiocarpa* Engl.	24	0.04524
24	Guarantã	*Esenbeckia leiocarpa* Engl.	22.8	0.04065
25	Guarantã	*Esenbeckia leiocarpa* Engl.	6	0.00283
26	Grevília	*Grevillea robusta* A.Cunn. ex R.Br.	58.3	0.26649
27	Alecrim do mato	*Holocalyx balansae* Mich.	7.3	0.00413
28	Pau-jacaré	*Piptadenia gonoacantha* (Mart.) Macbr.	7	0.00385
29	Pau-jacaré	*Piptadenia gonoacantha* (Mart.) Macbr.	8.8	0.00601
30	Guarantã	*Esenbeckia leiocarpa* Engl.	9.3	0.00672
31	Guarantã	*Esenbeckia leiocarpa* Engl.	6.5	0.00332
32	Guarantã	*Esenbeckia leiocarpa* Engl.	9.5	0.00709
33	Guarantã	*Esenbeckia leiocarpa* Engl.	6.3	0.00307
34	Açoita cavalo	*Luehea divaricataI* Mart.	33.5	0.08814
35	Açoita cavalo	*Luehea divaricataI* Mart.	32.8	0.08424
36	Açoita cavalo	*Luehea divaricataI* Mart.	41.3	0.13364
37	Guarantã	*Esenbeckia leiocarpa* Engl.	5	0.00196
38	Guarantã	*Esenbeckia leiocarpa* Engl.	5.8	0.00260
39	Angico vermelho	*Anadenanthera macrocarpa* (Berth.) Brenan	16	0.02011
40	Monjoleiro	*Acacia polyphylla* DC.	13	0.01327

Eleven tree species were identified among the 40 existing trees, with 39 being native and only one being exotic (Grevília). From the diameter at breast height (DBH) data, the basal area (BA) of the plot (1.58 m^2) was obtained, corresponding to 39.59 m2 ha^{-1}. Native species are part of the list of species recommended for ecological restoration for the state of São Paulo and are typical of the semideciduous seasonal forest in the center of the state (Barbosa et al., 2017).

2.2 Study design

The distribution of rainfall was determined according to the canopy water balance equation (Helvey and Patric, 1965) (Equation 1).

$$P = Tf + Sf + I \qquad \text{Eq. 1}$$

To determine gross precipitation (P) and throughfall (Tf), rain gauges made from 2 L PET plastic bottles were used (Figure 5a and Figure 5c), inspired by a prototype developed by Giglio (2013). To quantify P, 4 rain gauges were used installed in an open area, and for Tf, 25 rain gauges were used placed inside the 20 x 20 m plot, spaced 4 m apart. These devices were kept fixed during the experiment.

In the same plot of 400 m^2, 3 trees were selected in which stemflow water collectors (Sf) similar to those used by Arcova (2003), Arcova et al. (2018) and Honda (2013). These were made of expanded polyurethane surrounding the tree trunks. Each collector was equipped with a water outlet with a hose and a plastic container of 20.8-liter capacity (Figure 5b).

Measurements of the three processes were made with a graduated cylinder (mm^3). The conversion of volume to height of gross precipitation and throughfall (mm) was done using Equation 2:

$$P, Tf_{(mm)} = \text{Volume } P, Sf_{(mm^3)} / \text{Funnel area}_{(mm^2)} \qquad \text{Eq. 2}$$

To determine the volume of stemflow, the arithmetic mean of the three collectors was calculated and multiplied by the number of trees in the plot (Levia and Germer, 2015). The area occupied by the tree canopy was determined for each season of the year using the CanopyCapture version 1.0.2 application, available for download on the website https://nikp29.github.io/CanopyCapture/, developed by Nikhil Patel with contributions from Billy Pierce. The smartphone used was a Motorola G60 with a 32-megapixel front camera, leveled at 1.50 m above ground level. Thus, the stemflow was converted to water height (mm) in the plot using Equation 3:

$$Sf_{(mm)} = \text{Volume } Sf_{(L)} \text{ in the plot} / \text{Plot area}_{(m^2)} \times \text{\% canopy closure} \qquad \text{Eq. 3}$$

Measurements were taken at 08:00 hours after the rain, with the exception of holidays and weekends, taken on the first subsequent working day. The experiment lasted one year, from July 1, 2022 to June 30, 2023.

Gross precipitation was given by the arithmetic mean of the water height of the 4 rain gauges installed in the open and throughfall by the arithmetic mean of the water height values of the 25 rain gauges placed inside the forest. The height of water stemflow was estimated by the arithmetic mean of the 3 collectors and extrapolated to all trees in the plot.

The data were subjected to descriptive and variance analyses, and to mean comparison and simple linear regression tests. Graphs representing the relationships between variables were obtained using simple linear regression equations. Statistical tests were carried out using the SAS® statistical program, considering $p<0.05$ as a significance criterion (SAS Institute Inc., 1999).

Figure 5. (a) Rain gauge in open area to determine gross precipitation; (b) Water collector for stemflow measurement; (c) Rain gauge inside the plot to measure throughfall.

Figura 5. (a) Pluviômetro em área aberta para a determinação da precipitação total; (b) Coletor de água de escoamento pelo tronco; (c) Pluviômetro no interior da parcela para medição da transprecipitação.

3 RESULTS AND DISCUSSION

During the experimental period, 60 gross precipitation events were measured, ranging from 2.5 to 77.6 mm, for a total of 1,522.0 mm. This value was 248 mm greater than the average annual precipitation of the 106-year historical series (1917 to 2022) at the meteorological station of the “Luiz de Queiroz” College of Agriculture – USP, 10 km from TES (Esalq, 2022).

The monthly precipitation gross during the period studied is shown in Figure 6, together with the historical monthly averages (circles) corresponding to the last 106 years and their respective standard deviation (vertical bars). The rainy period - October to March - presented values above (1,257.5 mm) the historical average (991.7 mm), except for November 2022. The opposite was observed in the dry period - April to September - (264.6 mm), slightly below the historical average (282.2 mm), with emphasis on July 2022 when there was no rain.

Throughout the research, throughfall varied from 1.7 to 62.8 mm, interception from 0.1 to 12.1 mm and stemflow from 0 to 2.7 mm. It should be noted that there were events in which the stemflow water storage plastic containers overflowed and for this reason the maximum value recorded for this process was 2.7 mm. Table 3 shows the results of the distribution of rainfall for each month and the totals for a year.

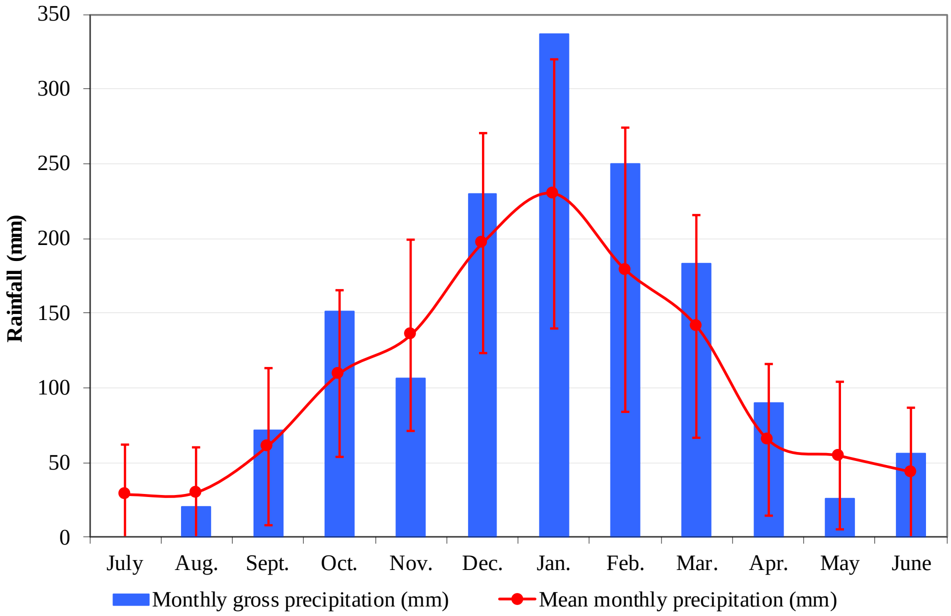

Figure 6. Monthly gross precipitation (from July 2022 to June 2023) compared to mean monthly precipitation (circles), with respective standard deviations (vertical bars) from 1917 to 2023 recorded at the meteorological station of the "Luiz de Queiroz" College of Agriculture – University of São Paulo, 10 km from the experimental area.

Figura 6. Precipitação total mensal (julho de 2022 a junho de 2023) comparada à precipitação média mensal (círculos), com respectivo desvio padrão (barras verticais) de 1917 a 2022, registradas no posto meteorológico da Escola Superior de Agricultura "Luiz de Queiroz" – USP, à 10 km da área experimental.

Table 3. Monthly and annual values (± standard deviation) of gross precipitation (P), throughfall (Tf), stemflow (Sf), net precipitation (Np) and interception loss (I). Period from July 1, 2022 to June 30, 2023.

Tabela 3. Valores mensais e anual (± desvio padrão) de precipitação (P), transprecipitação (Tf), escoamento pelo tronco (Sf), precipitação efetiva (Np) e interceptação (I). Período de 1º de julho de 2022 a 30 de junho de 2023.

Year	**Month**	**P**	**Tf**	**Sf**	**Np**	**I**	**Tf**	**Sf**	**Np**	**I**
		mm					**% Gross precipitation**			
2022	July	0.0	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00
	Aug.	20.8 ± 4.9	17.4 ±4.7	0.8 ±0.4	18.1 ±5.1	2.7 ±0.2	83.5	3.7	87.2	12.8
	Sept.	71.5 ± 3.7	54.9 ± 3.4	4.2 ± 0.5	59.1 ± 3.9	12.4 ± 1.2	76.8	5.9	82.7	17.3
	Oct.	151.1 ± 26.5	125.5 ± 23.2	5.5 ± 1.0	131.0 ± 24.1	20.1 ± 2.7	83.0	3.6	86.7	13.3
	Nov.	106.6 ± 21.1	82.1 ± 17.8	2.7 ± 0.8	84.8 ± 18.6	21.8 ± 2.5	77.1	2.5	79.5	20.5
	Dec.	229.8 ± 22.3	183.2 ± 18.4	10.9 ± 1.0	194.1 ± 19.3	35.6 ± 3.2	79.7	4.7	84.5	15.5
2023	Jan.	336.7 ± 17.3	270.9 ± 16.0	16.7 ± 0.8	287.5 ± 16.7	49.2 ± 1.4	80.4	5.0	85.4	14.6
	Feb.	250.3 ± 21.1	205.0 ± 18.4	9.3 ±1.0	214.3 ± 19.4	36.1 ± 2.7	81.9	3.7	85.6	14.4
	Mar.	183.0 ± 24.2	141.7 ± 20.0	7.6 ± 0.9	149.4 ± 20.8	33.6 ± 3.5	77.5	4.2	81.6	18.4
	Apr.	90.3 ± 9.7	70.7 ± 7.8	4.6 ± 0.5	75.3 ± 8.1	15.0 ± 2.0	78.3	5.1	83.4	16.6
	May	26.1	20.7	1.4	22.1	4.0	79.4	5.2	84.6	15.4
	June	55.8	51.6	2.1	53.7	2.1	92.5	3.8	96.3	3.7
Total		**1522.0 ± 19,7**	**1223.7 ± 17.0**	**65.7 ± 0.9**	**1289.4 ± 17.8**	**232.6 ± 2.5**	**80.4**	**4.3**	**84.7**	**15.3**

* There was no rain in the month of July 2022, and only one event in the months of May and June 2023.

* Não houve precipitação no mês de julho de 2022, e somente um evento nos meses de maio e junho de 2023.

For the annual period, throughfall was 80.4%, stemflow was 4.3% and interception was 15.3% in relation to gross precipitation. These percentages are compatible with the results of studies carried out on a global scale by Yue et al. (2021) whose median values were 73.0%, 3.2% and 21.8%, respectively. They are also consistent with results obtained in research carried out in different semideciduous seasonal forest conditions (Table 1). However, the percentage of 4.3% of stemflow determined in the present study is well above the average, but it is not unique, given that Vieira and Palmier (2006) found 10%. In a survey carried out by Levia and Germer (2015) around the world values of up to 9.5% were also cited.

Throughfall and stemflow constitute the two flows that transfer rainwater to the forest floor. Combined, they account for 70% to 90% of gross precipitation (Levia et al., 2011; Crockford and Richardson, 2000). The area recomposed with semideciduous seasonal forest species in this study is in the middle of this range, with net precipitation accounting for 84.7% of gross precipitation.

Throughfall, stemflow and interception reflected each month's precipitation (Figure 7). The percentage of loss due to interception fluctuated during the year, the exceptions were June with only one rain event (55.8 mm) and July with none. There was no significant difference between months for these variables.

Gross precipitation during the rainy season and dry season was 1,257.5 mm and 264.6 mm, respectively, confirming the pronounced seasonality of rain in the region. This seasonality influenced both throughfall, with 1,008.4 mm during the rainy season and 215.3 mm during the dry season, and stemflow measuring 52.7 mm and 13.0 mm, respectively. However, in terms of percentages, both throughfall and stemflow were higher in the dry period, 81.4% and 4.9%, compared to the rainy period at 80.2% and 4.2%, respectively. These differences were not statistically significant.

There was a significant difference in interception losses between the dry (13.7%) and rainy (15.6%) periods. These results differ from those found in the literature, where studies typically point to greater losses due to interception in the dry season (Giglio and Kobiyama, 2013; Cuartas et al., 2007; Arcova et al., 2003; Nalon and Vellardi, 1992; Coelho Netto et al. 1986). In the present study, the lower interception in the dry period was due to an atypical rainfall in the month of June, concentrated in a single event, which provided high throughfall (92.5%) and, consequently, the interception of only 3.7%.

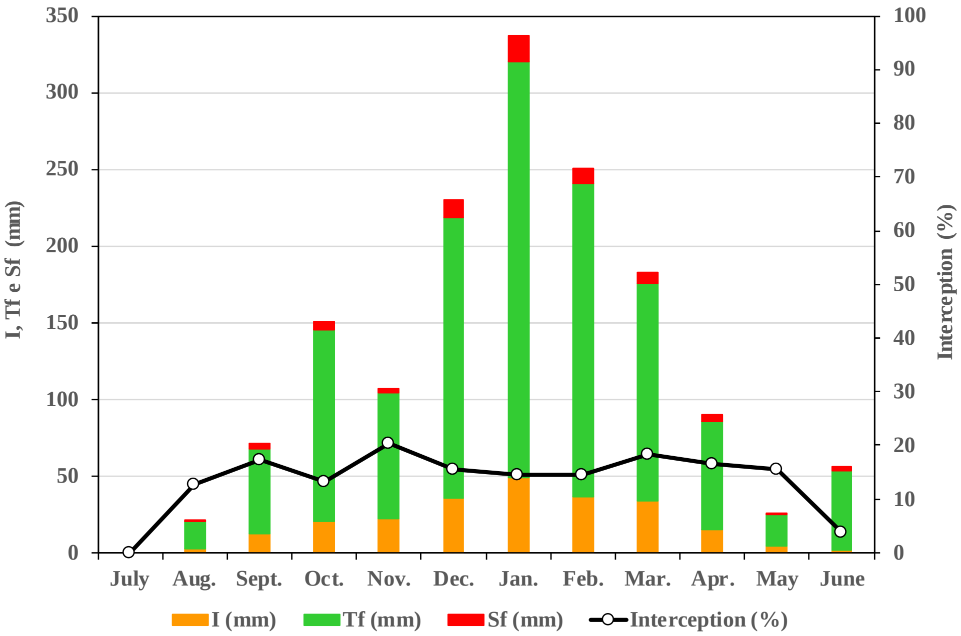

Figure 7. Seasonal variation in monthly stemflow, throughfall and interception in mm referring to the 1-year period (from July 2022 to June 2023). It is also shown the percentage of loss interception (black line and secondary y-axis).

Figura 7. Valores mensais em mm de escoamento pelo tronco, transprecipitação e interceptação referente ao período de 1 ano (julho de 2022 a junho de 2023). Também é mostrado a porcentagem de perda por interceptação (linha preta e escala no eixo secundário).

Linear regression analyses were performed with data on gross precipitation, interception, throughfall and stemflow (Figure 8). The regression lines indicated a high positive correlation for throughfall ($R^2 > 0.9$) and stemflow ($R^2 > 0.8$), and an average correlation for interception (R^2 close to 0.6). These results are in line with those of several studies carried out on the most different types of vegetation cover (Honda, 2013).

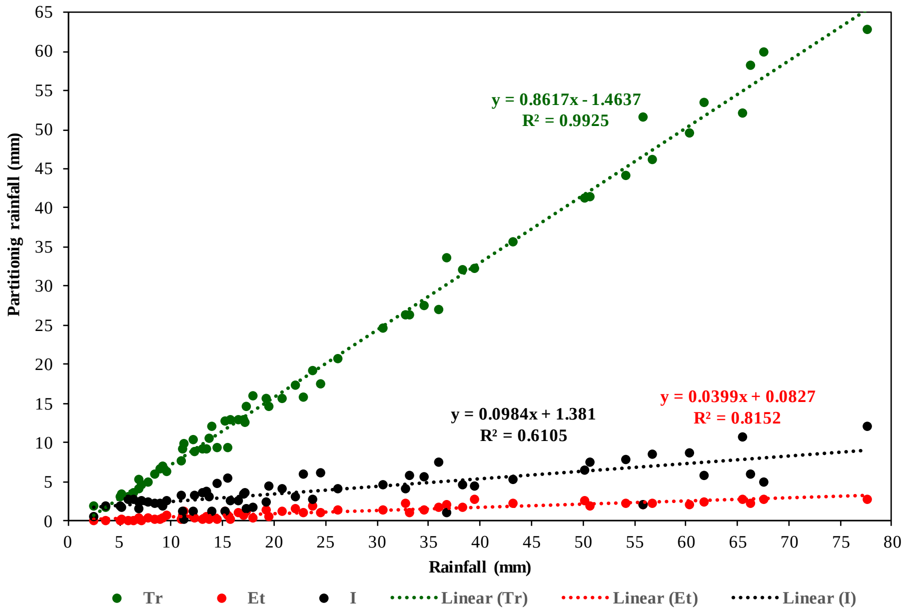

Figure 8. Relationship between gross precipitation and rainfall partitioning process: interception, throughfall and stemflow.

Figura 8. Relações entre a precipitação total e os processos de repartição da chuva: interceptação, transprecipitação e escoamento pelo tronco.

4 CONCLUSIONS

The 60 events recorded during the 1-year study period totaled 1,522.0 mm of gross precipitation (17.4% in the dry period), with 1,223.7 mm of throughfall, 65.7 mm of stemflow and 232.6 mm of interception, representing 80.4%, 4.3%, 15.3% of gross precipitation, respectively. There was a statistically significant difference in interception losses between the rainy and dry periods, and, contrary to what was found in the literature, with the highest values during the rainy season.

The results show that after approximately 70 years of vegetation restoration, the hydrological process of partitioning rainfall presents values compatible with those found in semideciduous seasonal forests.

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