

Artigos

Interception and surface runoff in different regeneration stages of Atlantic Forest, southern Brazil

Interceptação e escoamento superficial em diferentes estágios de regeneração da Floresta Atlântica, sul do Brasil

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ABSTRACT

In natural regeneration, vegetation goes through different stages over time, each of them with different conditions to drain the precipitated water to the soil surface. The aim of this study was to evaluate interception loss, throughfall, stemflow and surface runoff in early and advanced stages regeneration at evergreen rainforest subtype sites within the Atlantic Forest, located in the Serra do Itajaí National Park, in southern Brazil. Rainfall was sampled by three rain gauges and throughfall was measured using "U" type gutters. The stemflow was measured in 24 trees per stage (i.e., 48 trees in total). The interception loss was calculated as the difference between rainfall and the sum of the throughfall plus stemflow. The surface runoff was evaluated using metal rails. Vegetation in the initial stage is a composition of 7 species with a basal area of 5.01 m².ha⁻¹ and advanced stage site consists of 28 species with a basal area of 34.7 m².ha⁻¹. Throughfall records were 81.7% in the initial and 74.1% in the advanced regeneration stages. The stemflows registered were 5.93% in the initial stage and 0.54% in the advanced stage while the interception losses were respectively 13.2% and 25.8%. Surface runoffs observations were 11.1% in the initial stage and 10.7% in the advanced stage. Statistically significant differences were found between the regeneration stages for the stemflow and for the interception loss parameters. The study showed that, for some hydrological processes, the behavior of the precipitated water differs for the stage of vegetation regeneration. The regeneration stage does not influence the surface runoff, demonstrating that after a few years of vegetation regeneration, this hydrological process is equivalent to vegetation in an advanced stage.

Keywords: Hydrological Process; Throughfall; Stemflow; Initial and Advanced Regeneration Stage

RESUMO

A vegetação em regeneração passa por diferentes estágios ao longo do tempo, cada um com diferentes condições para o escoamento da água precipitada até a superfície do solo. O objetivo deste estudo foi avaliar a interceptação, a precipitação interna, o escoamento pelo tronco e o escoamento superficial em estágios inicial e avançado de regeneração na Floresta Ombrófila Densa Montana no Parque Nacional da Serra do Itajaí em Indaial/SC. A precipitação externa foi amostrada por três pluviômetros e a precipitação interna foi medida através do uso de calhas do tipo "U". O escoamento pelo tronco foi medido em 24 árvores por estágio de regeneração. A perda por interceptação foi calculada pela diferença entre a precipitação total e a soma da precipitação interna e do escoamento pelo tronco. O escoamento superficial foi medido utilizando calhas de metal. A vegetação arbórea do estágio inicial é composta por 7 espécies com área basal de 5,01 m².ha⁻¹ e do estágio avançado é composta por 28 espécies com área basal de 34,7 m².ha⁻¹. A precipitação interna foi de 81,7% da precipitação externa no estágio inicial e 74,1% no estágio avançado. O escoamento pelo tronco foi de 5,93% no estágio inicial e 0,54% no estágio avançado. A perda por interceptação foi de 13,2% no estágio inicial e 25,8% no estágio avançado. O escoamento superficial foi de 11,1% no estágio inicial e 10,7% no estágio avançado. Foram encontradas diferenças estatisticamente significativas entre os estágios de regeneração para o escoamento pelo tronco e para a perda por interceptação. O estudo mostrou que, para alguns processos hidrológicos, o estágio de regeneração da vegetação difere no caminho que a água precipitada. No caso do escoamento superficial, o estágio de regeneração não influencia, demonstrando que, após alguns anos de regeneração da vegetação, este processo hidrológico é equivalente à vegetação em estágio avançado.

Palavras-chave: Processos hidrológicos; Precipitação interna; Escoamento pelo tronco; Estágio inicial e avançado de regeneração

1 INTRODUCTION

Interception occurs when rainwater reach the treetops. Shortly after interception, the rainwater reaches the ground by throughfall and stemflow, while portion of rainwater is intercepted and returns to the atmosphere as evaporation (ARCOVA *et al.*, 2003). Throughfall is the part of the precipitation that crosses the vegetation, directly or by drip (ARCOVA *et al.*, 2003; LORENZON *et al.*, 2013), reaching the soil, after a little part is lost by interception of the litter, present in most of the forests. Stemflow is the portion of rainfall water that reaches the surface of the forest floor running down the trunk. The stemflow typically represents a small part of the precipitation (CROCKFORD; RICHARDSON, 2000; SALEMI *et al.*, 2013).

Interception has been evaluated in different forest typologies, such as natural forest and in plantations (GHIMIRE *et al.*, 2012; FAN *et al.*, 2014), altitudinal gradient forests (GOMEZ-PERALTA *et al.*, 2008), Mediterranean oak forests (*Quercus ilex*) (RODRIGO; ÁVILA, 2001), shrub xerophytic ecosystems (ZHANG *et al.*, 2015), to name a few. The interception loss may represent up to 18.6% of rainfall in tropical rain forests (ARCOVA *et al.*, 2003) and to 40.2% in lower montane tropical forest (FLEISCHBEIN *et al.*, 2006). However, to present information about interception loss in a representative way, it is necessary to acknowledge precipitation characteristics and local factors that interfere in this process, such as wind parameters as well as canopy attributes (JACKSON, 1975; MARIN *et al.*, 2000).

Most of the studies dedicated to hydrological cycle components related to mature forests. Gomez-Peralta *et al.* (2008) studied rainfall and cloud-water interception in tropical montane forests in the Andes of Peru; Limousin *et al.* (2008) modelled rainfall interception and throughfall in a Mediterranean ecosystem. However, fewer researches have been conducted in initial succession stage forests, where pioneer species, shrubs and sparse trees prevail (ALVES *et al.*, 2007; TOGASHI *et al.*, 2012; LORENZON *et al.*, 2013). Within the Atlantic rainforest specifically, vegetation in initial regeneration stages has been analyzed in the following phytogeographic subdomains: semideciduous forest (ALVES *et al.*, 2007; LORENZON *et al.*, 2013), Araucaria Forest (THOMAZ, 2005), evergreen rainforest (TOGASHI *et al.*, 2012).

Infiltration and runoff in forest ecosystems are also a very important field of study, considering, for example, that soil capacity of water infiltration is higher in forest covered areas when compared to pasture and agriculture covers (MCCULLOCH; ROBINSON, 1993), or that the removal of the first soil layer in forests environments make them vulnerable and unstable (BONELL, 1993). Because of its significance, runoff and its modification impact must be considered in ecosystem recovery practices, particularly under steep terrain slopes (MERINO-MARTÍN *et al.*, 2015).

Interception and surface runoff are hydrological processes that varies considering the different stages of vegetation regeneration and are highly dependent of local environment factors. The studies of interception of rainfall and runoff in forest environments serve to improve the management of water resources, as well as in the verification of possible impacts caused by climate change (WALLACE; MCJANNET, 2008). Thus, it is important to evaluate these parameters in qualitative and quantitative forms over different phytogeographic regions and under different environments conditions.

In this context, this paper aims to investigate interception loss, throughfall, stemflow, and surface runoff, comparing two distinct regeneration stages (initial and advanced) of Atlantic Forest in Santa Catarina, southern Brazil.

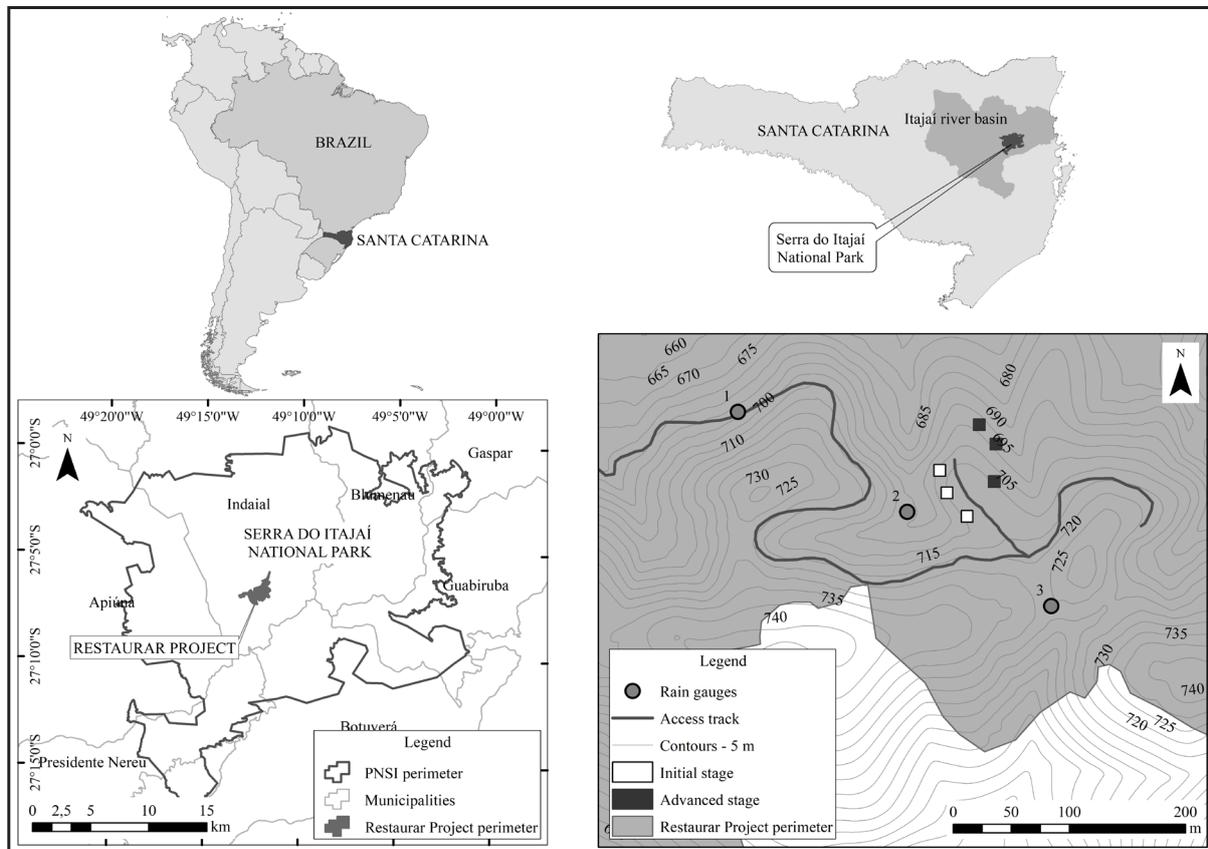
2 MATERIAL AND METHOD

2.1 Characterization of study area

The experimental area is located at the geographical coordinates 27°06'35"S and 49°11'51"W in the Serra do Itajaí National Park (SINP), Santa Catarina, southern Brazil (Figure 1). The altitude range between 700 and 730 m above sea level. The climate is defined as Cfa type according to Köppen climatic classification (ALVARES *et al.*, 2014). The average annual temperature is 22.1°C (\pm 3.5°C) computed on the basis of the climatic records for the period between 1992 and 2014 and the average annual precipitation is 1,742 mm (\pm 398 mm) on the basis of data registered in the period between 1981 and 2014, according to data from the Regional University of Blumenau (FURB) meteorological station (CEOPS, 2015) distant 26.6 km of the experimental area.

The vegetation is typified as subtropical upper hills evergreen broadleaved rainforest (OLIVEIRA-FILHO, 2015), belonging to the Atlantic Forest biome. The selected area includes initial and advanced successional stages.

Figure 1 Localization of study area



Source: Author (2021)

2.2 Characterization of vegetation

In order to characterize vegetation, a forest inventory was carried out. Three sampling units of 10 x 10 m, north/south oriented were established at each vegetation regeneration stage site, within hydrological experimental areas, meeting homogeneous geomorphological conditions, with identical slope and altitude. Trees with diameter at breast height (DBH) larger than 4 cm, at 1.3 m above ground level, were measured. The measurements included the diameter at breast height and the total height as well as botanical identification of the species.

The initial stage site is characterized by shrubby and arboreal open and discontinuous strata, reaching a maximum of 8 m height. The open forest shows

no litter and the soil cover is mainly herbaceous. At this stage, 43 plant individuals were found, distributed in 7 species, 6 genera and 4 families. The family with the highest floristic richness was Asteraceae, counting 3 species. The others were Bignoniaceae, Clethraceae and Primulaceae, with 1 specie each. The low species richness and the greater representativeness found for the Asteraceae family are typical characteristics of the initial vegetation regeneration stage in the region of Vale do Itajaí, Santa Catarina (KLEIN, 1980).

For the initial regeneration site tree metrics, average DBH of 49 stems was 6.1 ± 1.5 cm (Table 1), ranging from 4 to 9.6 cm, and average total height was 5.2 ± 1.1 m, ranging between 3.5 and 8 m. The vegetation density was $1,433 \text{ ind. ha}^{-1}$ and the most representative species was *Vernonanthura discolor* (58.1%). The basal area was $5.01 \text{ m}^2 \cdot \text{ha}^{-1}$, represented mainly by *Vernonanthura discolor* (52.4%).

In contrast, at the advanced stage site, the vegetation is characterized by a dense and continuous canopy, where the crowns overlap, with a maximum recorded height of 18 m. The soil surface is covered with thick litter. In the experiment, 70 individuals were found, distributed in 21 genera, 28 species and 16 families. The botanical families more widely represented were Lauraceae (6 species), Myrtaceae (5 species), Cyatheaceae, Fabaceae, Monimiaceae (2 species each), which stand for 61% of the total richness.

The average DBH of 77 stems was 11.4 ± 6.6 cm, ranging between 4.8 and 39.5 cm, and the average total height was 8.8 ± 4.7 m, ranging between 2.2 and 18 m. The vegetation density was $2,333 \text{ ind. ha}^{-1}$ and the most representative species was *Alsophila setosa* (xaxim), with greatest representation in individuals (37.1%). The basal area was $34.70 \text{ m}^2 \cdot \text{ha}^{-1}$, represented mainly by the species *Cryptocarya mandioccana* (22%), *Alsophila setosa* (16.5%), *Guatteria australis* (6.9%) and *Eugenia neoverrucosa* (6.6%).

Table 1 – Descriptive characteristics of the two vegetation regeneration stages analyzed

Regeneration stage	DBH (cm)	Height (m)	Basal area (m ² .ha ⁻¹)	Density (ind.ha ⁻¹)	Species
Initial	6.1 ± 1.5	5.2 ± 1.1	5.01	1,433.3	7
Advanced	11.4 ± 6.6	8.8 ± 4.7	34.7	2,333.3	28

Source: Author (2021)

2.3 Rainfall

Rainfall was measured using three rain gauges installed 1.5 m above the soil, with one rain gauge at less than 50 m distant from the vegetation sampling units and two located at 160 m. Such dispositions were adopted in order to guarantee the accuracy and for the verification of rainfall spatial distribution (Figure 1). The rain collected by gauges was conducted to and stored in 10 L containers. Rainfall and throughfall data were collected at weekly intervals from 13/oct/2014 to 12/oct/2015. All the measurements were taken manually using graduated 400 mL and 2000 mL test tubes.

2.4 Throughfall

Evaluation of throughfall was performed using a gutter system adapted from Gomez-Peralta *et al.* (2008), Limousin *et al.* (2008), Ghimire *et al.* (2012) and Fan *et al.* (2014). The gutter was composed by PVC pipes of 200 mm of diameter (divided in half along the length) with 2 m of length and 0.2 m of width (nominal dimensions), resulting in an area of 0.4 m². The ends of the pipes were sealed and the edges were sharpened to avoid splashes. For rainfall collection, the gutters were connected to a 50 L container.

Six gutters were placed in each vegetation stage, creating a total area of 2.4 m², corrected to the horizontal plane. These gutters were fixed 0.50 m above the soil surface as proposed by Ghimire *et al.* (2012). Throughfall for each regeneration stage was calculated as the sum of the volume collected by gutters divided by the total area.

This comparative analysis was performed with data from throughfall, stemflow, interception loss and surface runoff for the two stages of regeneration of the vegetation by the Mann-Whitney test ($\alpha = 0.05$).

2.5 Stemflow

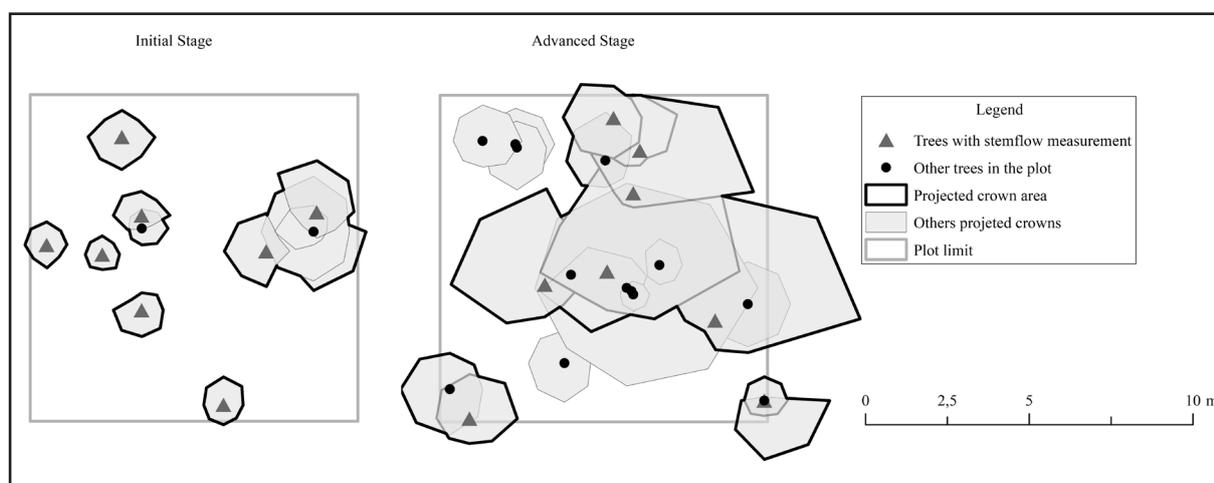
As proposed by Likens and Eaton (1970), collars of polyurethane foam were used for trees stemflow collection, installed around the tree trunk at 1.0 m height from the ground level as suggested by Limousin *et al.* (2008) and Ghimire *et al.* (2012). Sealant material was applied to the top of the collar to avoid infiltration. The water flow was conducted to a 25 L container. It was chosen 24 trees of each vegetation stage to receive the collars. These trees were selected according to: upright trunk, when possible; without the presence of another leaned trunk; without the presence of vines near the area where the collar is installed.

The stemflow was normalized by the crown area, that was considered as the stemflow catchment area, adopting the methodology of Marin *et al.* (2000). Each tree crown was modeled by a polygon resulting from the horizontal projection on the forest floor. In order to evaluate the area of these polygon, the radius of it was measured in eight directions (0, 45, 90, 135, 180, 225, 270 and 305 degrees). The crown area may be composed of a single tree canopy or composed with other adjacent trees canopy which were superimposed and may contribute to the stemflow measured. From the location of each tree (coordinates, axis x and y), the total crown area for each sampling unit could be modelled (Figure 2). Finally, the stemflow of the stage of vegetation was determined by the sum of the collected stemflow volume for all the trees in each regeneration stage, divided by the catchment area (Equation 1).

$$Sf = \frac{\sum V}{\sum A} \quad (1)$$

In where: Sf is the flow through the trunk, mm; V is the volume collected by all trees for each regeneration stage, L; A is the catchment area according to the trees canopy of each regeneration stage, m²; Stemflow data was collected at weekly intervals from 4/dec/2014 to 12/oct/2015.

Figure 2 – Diagram of the projected crown area evaluation



Source: Author (2021)

2.6 Interception loss

Canopy interception loss was calculated as the difference between the total precipitation and the sum of throughfall and stemflow (CROCKFORD; RICHARDSON, 2000; RODRIGO; ÁVILA, 2001; GOMEZ-PERALTA *et al.*, 2008), expressed either in mm or in percentage (%). Canopy interception loss was calculated from 4/dec/2014 to 12/oct/2015, just for the same period as for throughfall and stemflow were observed together.

2.7 Surface Runoff

The surface runoff was determined using gutter collectors made of galvanized metal sheets of 2 mm thickness, with 0.75 m wide, 1.0 m in length and 0.35 m high dimensions, resulting in a nominal surface area of 0.75 m², as adapted from Parchen *et al.* (2011). The collectors were buried 15 cm deep in the soil, thereby isolating the measurement area surface runoff from the external area.

For each regeneration stage site, three collecting gutters were installed taking care not to affect soil structure (PARCHEN *et al.*, 2011; SALEMI *et al.*, 2013). At the bottom of the gutters, a hose leads the water, by gravity, to a 25 L container. The surface runoff in each regeneration stage was calculated as the sum of the volume

collected by gutters divided by the sum of the gutter areas. Surface runoff data was collected at weekly intervals from 4/dec/2014 to 12/oct/2015.

3 RESULTS AND DISCUSSION

3.1 Rainfall

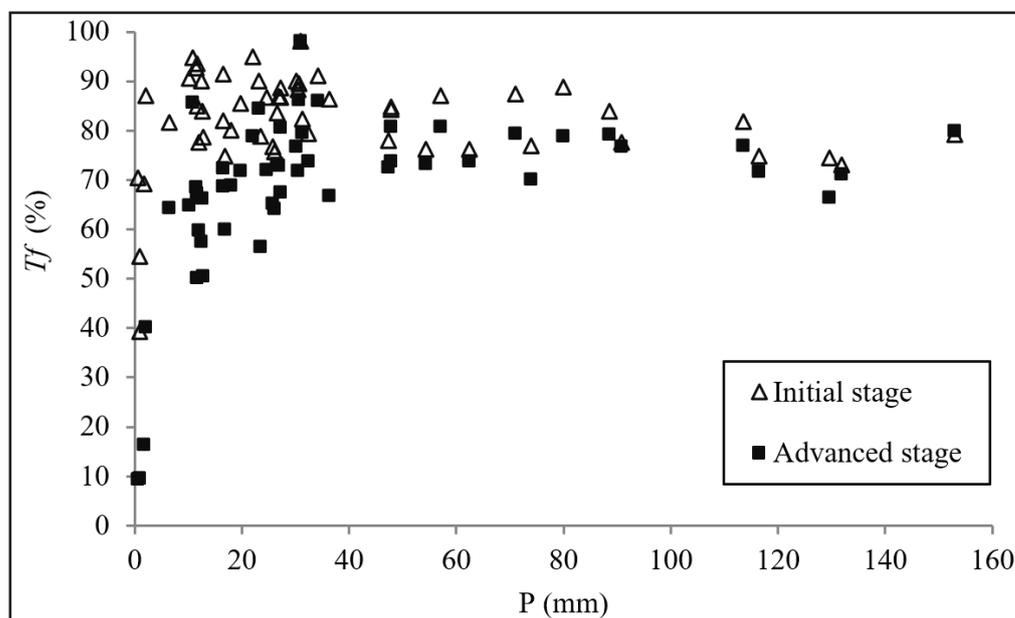
Rainfall from 13/oct/2014 to 12/oct/2015 was 2,079.8 mm, registered in 54 weekly intervals. Three weekly intervals obtained rainfall less than 1 mm and five weekly intervals with more than 100 mm. The rainfall registered was 19.4% larger in relation to historical average precipitation (1,742.0 mm) for city of Blumenau/Brazil with 34 years of observation (CEOPS, 2015).

3.2 Throughfall

Throughfall was measured using the same period as rainfall. Throughfall for the initial stage site was 1,699.0 mm (81.7% of the rainfall) whereas for the advanced stage site was 1,540.6 mm (74.1% of the rainfall). Although there is a difference of 7.6% (129.8 mm) of the rainfall at the end of the monitoring, statistical difference ($p=0.33$) among the population medians of throughfall was not detected. The throughfall percentage varies according to the precipitation recorded in the periods, as can be seen in Figure 3.

For precipitations below 40 mm, a greater throughfall variation in the advanced stage site was observed, without a discernible trend. This is indicative that vegetation cover is not the only influencing variable on throughfall. Throughfall may well be associated with factors such as precipitation characteristics (CROCKFORD; RICHARDSON, 2000) or with environmental variables like wind (MARIN *et al.*, 2000). Excluding the lowest precipitations (< 5 mm), throughfall in the initial stage showed a relatively constant percentage, which can be explained by tree crowns with similar canopy structure at this regeneration stage of vegetation (CLARK, 1996). Another important information is the lower canopy storage capacity in the initial stage in relation that advanced stage.

Figure 3 – Throughfall (T_f) percentages as a function of precipitation (P) for Atlantic Forest in Indaial/SC



Source: Author (2021)

Throughfall percentage in the advanced regeneration stage found in this study was higher than the values obtained in similar forests by Edwards (1982) in New Guinea (68%), Cavelier *et al.* (1997) in Panama (62.8%), Fleischbein *et al.* (2006) in Ecuador (58.8%) and Salemi *et al.* (2013) in São Paulo, Brazil (67.6%). The divergencies in altitude with regards to our experiment could have contributed to this discrepancy, (i.e., our trials were located at lower altitude ± 715 m). Nonetheless, altitude is not the only variable to be considered to justify such differences. A lower altitude does not mean to obtain a greater percentage of internal precipitation, since Edwards (1982) measured 2,400 m altitude and obtained 68% in internal precipitation, whereas Fleischbein *et al.* (2006) at 1900 m obtained 58%.

Arcova *et al.* (2003) studied an area of upper hills rain evergreen forest, at a 1,050 m elevation, close to the study site of Salemi *et al.* (2013) and found a throughfall percentage of 81.2% of the rainfall. This confirms that, at least for throughfall, even in nearby areas, results might significantly disagree, since the values may be influenced by highly local meteorological characteristics (JACKSON, 1975).

In our case, the found throughfall for the initial stage site (81.7%) exceeded the values of the above cited researches. On the other side, Togashi *et al.* (2012) evaluated the throughfall in Atlantic lowland evergreen rainforest, also for an initial successional stage (8 years old) and found a throughfall percentage of 94% of the rainfall. The same authors simultaneously evaluated the vegetation at an advanced stage site: the throughfall was 75%. Moura *et al.* (2012), who also evaluated the throughfall in Atlantic lowland evergreen rainforest in advanced successional stage, found the percentages of 93.3% and 72.1% for rainy and less rainy period, respectively. Similarly, Marin *et al.* (2000) evaluated the throughfall in four ecosystems of the Amazon rainforest and concluded that the differences found can be partially attributed to forest structure features. The sedimentary plain forest showed the highest throughfall percentage (87.2%), related to rainfall, whereas the lowest corresponded to the flood plain forest.

Fan *et al.* (2014) measured the throughfall in a forest dominated by the species *Banksia aemula*, with 6.82 m (± 0.28) of average canopy height and found throughfall value of 83.2%. This value is close to our throughfall in the initial regeneration stage site, where the average tree height was 5.2 m (± 1.1), despite the differences in species composition between the two experiments.

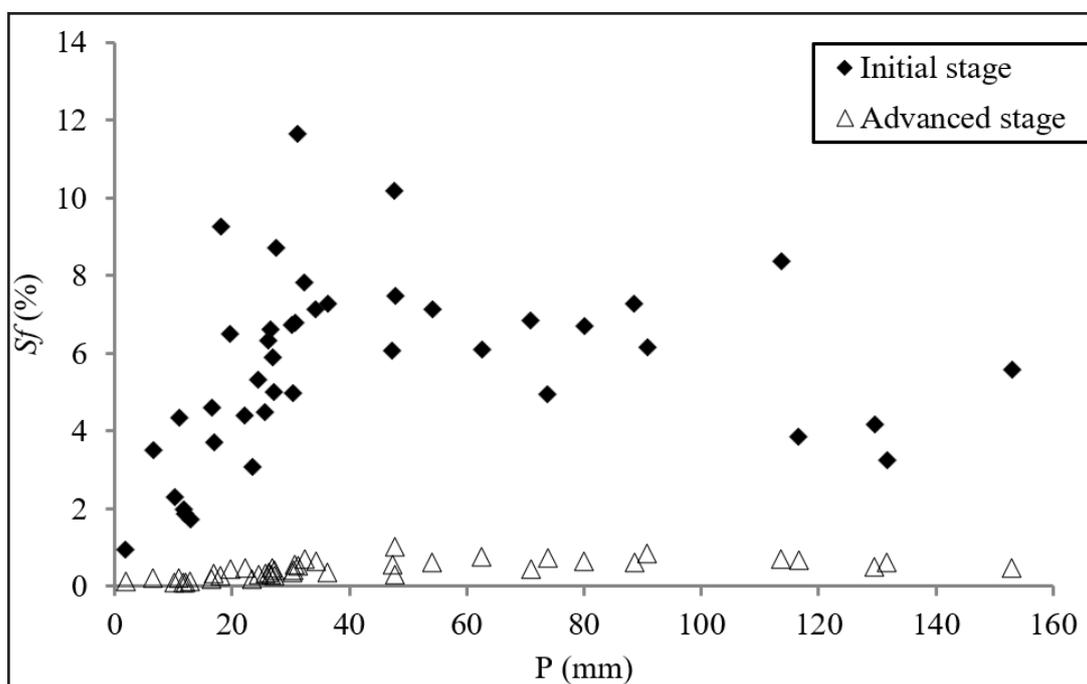
3.3 Stemflow

The accumulated stemflow for initial stage was 112.8 mm (5.93% of the rainfall), while for the advanced stage site was 10.3 mm (0.54%). As can be seen in Figure 4, the stemflow (%) in the initial stage in relation to precipitation shows a larger dispersion compared to the advanced stage, which varied around 0.54%. The stemflow for the initial stage showed a minimum participation of 0.96% and 11.6% of the maximum precipitation.

The largest stemflow at the initial stage may be related to the dynamics of canopy and to the distance between the tree crown and the collector. Stemflow collectors were made with an average width of 1.28 ± 0.4 cm in the trees of the initial stage and an

average width of 2.06 ± 0.55 cm in the advanced stage. These collectors were, in part, thinner than those manufactured by Marin *et al.* (2000). Thus, larger collectors may increase the possibility of raindrops that fall close to the stem of the tree (CROCKFORD; RICHARDSON, 2000).

Figure 4 – Stemflow (Sf) percentages as a function of total precipitation for Atlantic Forest in Indaial/SC



Source: Author (2021)

The comparative analysis between the stemflow (mm) for both regeneration stages resulted in significant differences between population medians ($p < 0.05$), as could have been expected.

In order to test if the difference would be related to the normalization method, the stemflow data were also explored considering two other methods for calculate the catchment area: a) the area of each tree crown with the installed collection device; and b) the area of the parcel (300 m^2). A comparison of three methods area showed in Table 2.

The method considering only the stem of each tree crown area obtained the biggest result for the initial stage and practically the same value for the advanced stage. Considering the area of the parcel as a catchment area for disposal by the stem, the result of the initial stage (14.7 mm) significantly reduced compared to previous results. The stemflow of the advanced stages also reduced to 6.8 mm. This result was expected due to the increase of the areas considered in the calculation of the stemflow.

Table 2 – Comparison between different methodologies of the calculation of the catchment area of stemflow

Stemflow methods	Initial stage	Advanced stage
Crown area with adjacent canopy (methodology)	112.8 mm (5.93%)	10.3 mm (0.54%)
Crown area of each tree	154.3 mm (8.12%)	10.5 mm (0.55%)
Plot area	14.7 mm (0.77%)	6.8 mm (0.36%)

Source: Author (2021)

Although the stemflow difference between regeneration stages was 7.9 mm (14.7-6.8) for plot area method, there were significant differences between the population means ($p < 0.05$).

In this study, the stemflow of the initial stage was 112.8 mm (5.93%), which is even greater than in the advanced stage (0.54%). Some authors have calculated the stemflow through the average of the flow between the trees (CAVELIER *et al.*, 1997; ZHANG *et al.*, 2015), thereby individually characterizing the catchment area for each tree. On another study, Fan *et al.*, (2014) estimated stemflow by the average volume collected according to the number of trees by DBH classes. Still, other authors used the sampling plot area as the stemflow catchment area (ARCOVA *et al.*, 2003; ALVES *et al.*, 2007; LORENZON *et al.*, 2013), although they didn't specify how to consider/treat those trees whose crowns expand beyond the plot boundaries.

Regardless the area considered for stemflow catchment, the percentage of this variable is relatively small in most forest environments: less than or equal to 1%

(EDWARDS, 1982; ARCOVA *et al.*, 2003; FLEISCHBEIN *et al.*, 2006; GOMEZ-PERALTA *et al.*, 2008) or even a little more significant, as the 2.4% value found by Moura *et al.* (2012). These values were found in forest ecosystems with advanced regeneration stage characteristics and are at all rates consistent with the percentage found in this study (0.54%).

Contrasting advanced regeneration stage, the initial stage presented a high percentage (5.93%) for stemflow. Some researches agree, having found stemflow percentages above 5%, as in the cases of *Quercus ilex* forests where stemflow were 5.3% (RODRIGO; ÁVILA, 2001), and 12.5% (LIMOUSIN *et al.*, 2008). The average tree height was 6.4 and 5.5 m respectively in these studies, similar to the average tree height (5.2 ± 1.1 m) found in this study.

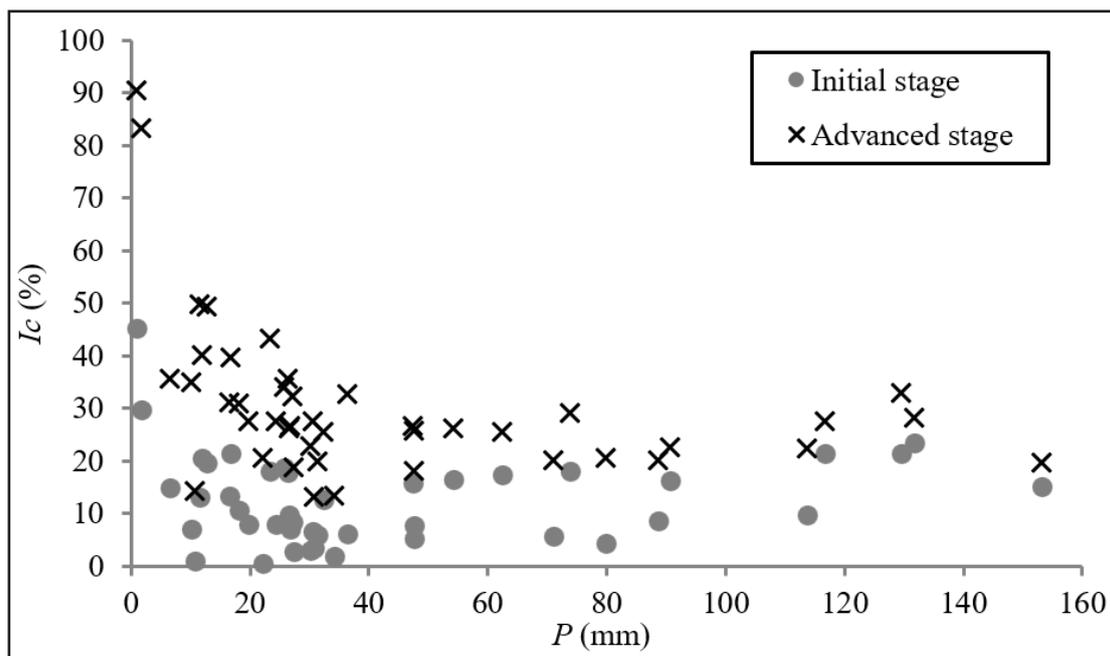
Beyond a lower canopy height when compared with the trees of advanced regeneration stage forests, other factors may be associated to large stemflow at an initial successional stage. For instance, Crockford and Richardson (2000) show that thick tree barks fosters a greater absorption, therefore resulting in smaller flow yields, as opposed to smoother and thinner barks and canopy openings, which make it easier for rainwater to reach the trunk at a wider rain angle spectrum, which is in turn influenced by wind intensity and directions.

In an Atlantic semideciduous forest, the stemflow percentages for the initial and advanced stages were 0.38 and 0.77% respectively (ALVES *et al.*, 2007), and were neither differentiated statistically. In contrast, Lorenzon *et al.* (2013) in the same location as Alves *et al.* (2007) did find statistically different stemflow percentages between the initial (0.69%) and advanced (1.89%) successional stages. In their case, divergences were attributed to the research period, sampling techniques or even forest formations structural changes. In any case, the percentages found for the abovementioned authors are higher than the ones found in this study in the advanced successional stage site, albeit smaller than in initial stages. These differences could be attributed to case specific particularities regarding rainfall and vegetation structural features.

3.4 Interception loss

The interception loss by canopy was 250.6 mm (13.2%) in the initial stage of vegetation and 489.7 mm (25.8%) in the advanced stage. The percentages of interception loss in the advanced stage, for rain greater than 40 mm gets close to 20 %, but the same trend did not occur in the initial stage. Interception loss in initial stages is more dispersed than in advanced stages (Figure 5). Interception losses by canopy in the two stages resulted in differences between the median population statistics ($p < 0.05$).

Figure 5 – Relationship between precipitation and interception loss (I_c) of the two regeneration stages in Atlantic Forest in Indaial/SC



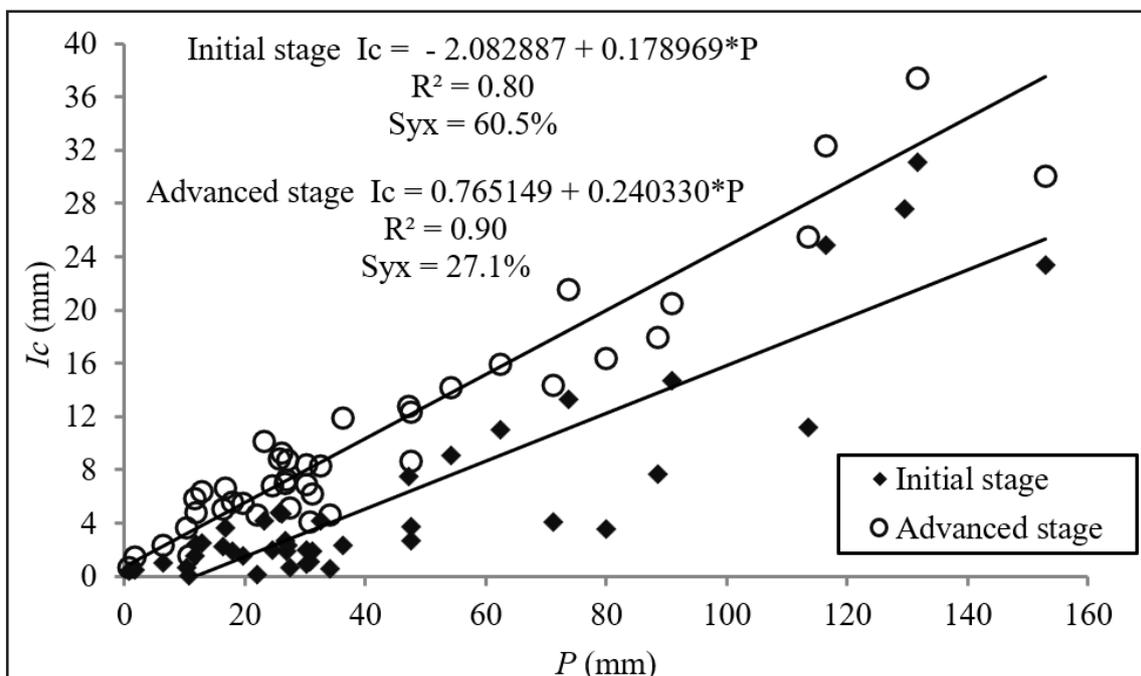
Source: Author (2021)

Canopy interception loss was lower in the initial regeneration stage (13.2%) than in the advanced stage site (25.8%). Other authors also found higher values of interception loss in advanced stages forest: e.g., 37.2% in Panama (CAVELIER *et al.*, 1997), 40.2% in Ecuador (FLEISCHBEIN *et al.*, 2006) and 32.4% in São Paulo, Brazil (SALEMI *et al.*, 2013). Arcova *et al.* (2003) in upper hills rain evergreen forest at 1,050

m above sea level, verified an interception loss percentage of 18.6%. In a lower hills rain evergreen forest located at 180 m above sea level, after 60 years of regeneration, the interception loss found by Togashi *et al.* (2012) was 25%, although it must be noted that stemflow was not measured in the study. These same authors evaluated 8 years old initial succession stage vegetation as well, finding an interception loss percentage of 6%.

Canopy interception loss and precipitation ratio (Figure 6) provided the highest determination coefficient ($R^2=0.90$) in the advanced stage that in the initial stage ($R^2=0.80$). The better performance of the advanced stage is even more evident in view of the lower residual standard error (27.1%) value in comparison to the one obtained for the initial stage (60.5%).

Figure 6 – Relationship between canopy interception loss (I_c) and precipitation for initial and advanced successional stages in subtropical upper hills rain evergreen broadleaved forest in Indaial/SC



Source: Author (2021)

A coefficient of determination $R^2=0.54$ was found by Lorenzon *et al.* (2013) when relating interception loss values and rainfall of initial regeneration stage of semideciduous forest. Likewise, in advanced regeneration stages, these authors found a R^2 value of 0.82. This value is very close to that one founded by Arcova *et al.* (2003) in an Atlantic rainforest in the rainy season ($R^2=0.82$). Assessing the relationship between precipitation and interception loss, Zhang *et al.* (2015) found determination coefficients of 0.30 and 0.41 in two xerophytic shrub ecosystems in multiple linear regression equations considering intensity, duration, and total precipitation variables. Therefore, these authors concluded that for the interception loss, other factors suchlike the canopy structure play a relevant role on partition of the rain share.

The relationship between throughfall and precipitation (MARIN *et al.*, 2000; ZHANG *et al.*, 2015) usually is evidenced by high determination coefficients to linear regressions in hydrological studies. On the contrary, for other parameters like stemflow and interception loss, the determination coefficients related to precipitation are typically found to be lower than for throughfall, as is shown in Table 3.

Table 3 – Determination coefficients of throughfall, stemflow and interception loss in some ecosystems

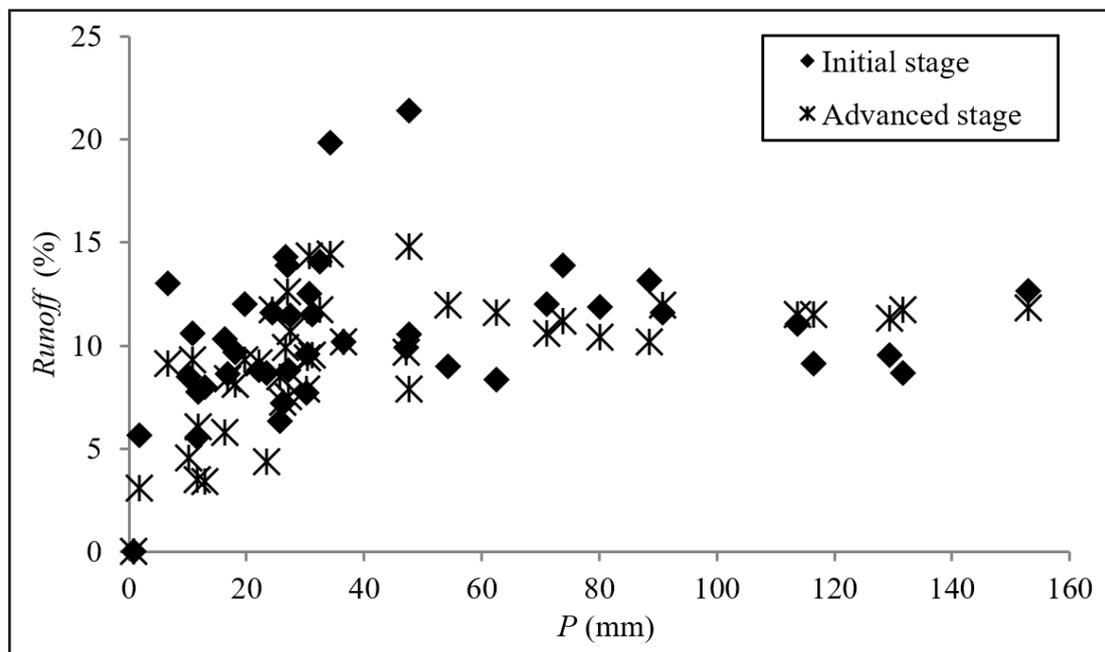
Biome / Ecosystem	Throughfall	Stemflow	Interception loss	Country	Reference
Atlantic rainforest rainy season	0.99	0.94	0.81	Brazil	Arcova <i>et al.</i> (2003)
Atlantic rainforest short rainy season	0.91	0.81	0.58		
Atlantic semideciduous forest. initial stage	0.99	0.93	0.54	Brazil	Lorenzon <i>et al.</i> (2013)
Atlantic semideciduous forest. advanced stage	0.99	0.91	0.82		
Colombian Amazonia – sedimentary plain. high and low terrace. flood plain	0.99	0.91 - 0.95	0.66 - 0.83	Colombia	Marin <i>et al.</i> (2000)
Xerophytic shrub - <i>Caragana korshinskii</i>	0.99	0.90	0.38	China	Zhang <i>et al.</i> (2015)
Xerophytic shrub - <i>Artemisia ordosica</i>	0.98	0.49	0.23		
Atlantic upper hills rain evergreen forest. initial stage	0.99	0.80	0.80	Brazil	This study
Atlantic upper hills rain evergreen forest. advanced stage	0.99	0.90	0.90		

Source: Author (2021)

3.5 Surface Runoff

The surface runoff in the initial stage site was 210.8 mm (11.1%) and at the advanced stage was 203.2 mm (10.7%). The comparative analysis of surface runoff data of the two regeneration stages did not detect significant differences between population medians ($p = 0.66$). This can be noticed in the surface runoff dispersion in relation to precipitation (Figure 7).

Figure 7 – Surface runoff for initial and advanced stages of the Atlantic Forest in Indaial/SC



Source: Author (2021)

Surface runoff in some periods was higher in the initial stage site (around 7% difference between the stages), and this could be attributed to a higher rainfall intensity, this assumption was not actually measured.

The surface runoff found this study are similar to those obtained by Parchen *et al.* (2011) in Araucaria forest in Paraná/Brazil (10.5%), in *Pinus* sp. reforestation (11.5%). The slopes in the areas of Parchen *et al.* (2012) were between 5 and 26% in

Araucaria forest in Paraná/Brazil and slopes of 18 and 38% in *Pinus* sp. reforestation. In this study, the average slope was 48% in the initial stage and 58% in the advanced stage. The difference in the slopes of the studies was not relevant in determining the surface runoff.

In our context, the absence of significant differences in surface runoff can be related to forest soils that present a high density of roots, leaves, branches and a more intense animal activity (BONELL, 1993).

4 CONCLUSION

The use of gutters instead of handmade rain gauges (interceptometers) was effective, because the sample area is larger than the conventional devices used in interception surveys. The gutters system reduces the number of containers installed to measure internal precipitation. However, with use of gutters a larger sample area is obtained, but it is reduced in the spatial assessment of internal precipitation.

Although the measurement of stemflow in forests of an advanced stage of regeneration may or may not be performed, in forests of an initial stage of regeneration it is necessary.

Stemflow results were important in differentiating rainfall interception by early stage regeneration vegetation compared to advanced stage.

The surface runoff was not significantly different between initial and in advanced successional stages, but we found evidence of that the presence of an initial stage vegetation facilitates surface runoff reduction when compared to other ground covers, like, for instance, agriculture.

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