*Original Research Article*

# Linear regression of incident precipitation explains the throughfall, stemflow and interception by the eucalyptus canopy under different fertilization management

.

## ABSTRACT

The present work aims to quantify the precipitation partition after interaction with the *Eucalyptus urophylla* canopy under two fertilization treatments. The experimental design was completely causalized with two fertilization treatments. Each plot had a dimension of 30 m x 60 m, and the spacing of the seedlings was 3 m x 2 m. The study was developed in a sandfield core located in the municipality of Maçambará, state of Rio Grande do Sul, Brazil. The duration of the study was one year (from April 2017 to March 2018). Biweekly over twelve months the volume of precipitation was quantified. The experiment consists of two fertilization treatments in a *Eucalyptus urophylla* stand: T1 with smaller and T2 greater fertilization. In each treatment 3 throughfall collectors were installed at one meter of the soil level and three stemflow collectors. In the open area 3 collectors of the incident precipitation were installed 1.5 meters from the ground level. The percentages of the throughfall, stemflow and canopy interception in relation to the incident precipitation were 95.3; 1.3 and 4.3% for treatment 1 and 91.7; 3.2 and 6.2% for treatment 2. The coefficients of determination for throughfall, stemflow and canopy interception were 0.99; 0.96 and 0.85 for treatment 1 and 0.99; 0.97 and 0.89 for treatment 2. The graphical analysis of the regression residues shows independence of the errors. The fertilization management described for treatment 2 results in a greater interception of rainfall due to the greater amount of biomass of the canopy.

*Keywords: Regression analysis; hydrology; seasonality; fertilization.*

## 1. INTRODUCTION

Erosion has a positive correlation with the average annual precipitation (with adjustment $R^2$ 0.97 and $p = 0.01$) in a study considering various areas of Brazil [1,2]. The soil without plant cover becomes susceptible to increase of the same, as it is the case of sandfield in the western border of the state of Rio Grande do Sul.

Faced with this problem, since the 70s, technicians, public entities, universities and rural producers have discussed ways of controlling the expansion of these areas with a focus on wind agent control [3]. According to Souto [3], in the municipality of Alegrete in the south of Brazil a project was installed in which native and exotic tree species were planted. At that time, the species of *Eucalyptus* sp. and *Pinus* sp. were the most adapted.

During precipitation events, a portion of rainwater, to reach the treetops, is intercepted with subsequent evaporation to the atmosphere [4]. Another part crosses the canopy and precipitates in the interior of the stand to be called throughfall [5]. Rainwater that does not satisfy any of the above provisions, flows through the leaves, being led to the branches, branches and finally flows through the trunk of the tree, and is thus called the stemflow [6,7].

Several factors influence the rainfall partition. Among the abiotic factors, we highlight the quantity, duration and intensity of rainfall, relief, wind speed, season of the year, among others [8,9,10,11]. As for biotic factors should be highlighted the structure and the degree of closing the canopy, species and age [12].

The quantification of the incident precipitation on the different partitions is important for the understanding of the hydrological cycle [13]. In addition to interception that reduces the amount of water reaching the soil surface [14], tree canopies reduce the speed and impact of rain, promote wind barriers, and increase the amount of water infiltrating the soil through the roots.

Studying the precipitation partition the seventh to the eighth year, Momolli et al [11] concluded that 99, 90 and 52% of the throughfall, stemflow and canopy interception are explained from the incident precipitation. Monitoring carried out in *Eucalyptus dunnii* at different ages shows that as the age of stand increases, the percentage of throughfall decreases and the canopy interception increases [15,16,11].

Sandy soils are easily disaggregated by the impact of raindrops when compared to clay soils, thus increasing the probability of erosion [17,18]. Given the importance of this study, the objective is to quantify the incident precipitation, throughfall, stemflow and canopy interception of a *Eucalyptus urophylla* stand under different fertilization management.

## 2. MATERIAL AND METHODS

### 2.1 Characterization of the experimental area

The work was developed in a sandfield area in the municipality of Maçambará-RS, under the geographic coordinates 29º 02 '32.67 "S and 55º 19' 40.44" W, at an average altitude of 191 meters in relation to the average level of the seas. The sand accumulation extends over a perimeter of 6.55 km, representing an area of 82 hectares. In Figure 1 we can observe the location of the experiment and the exposed soil area, totally devoid of vegetation (A), and just above the presence of ravines and gullies (B).

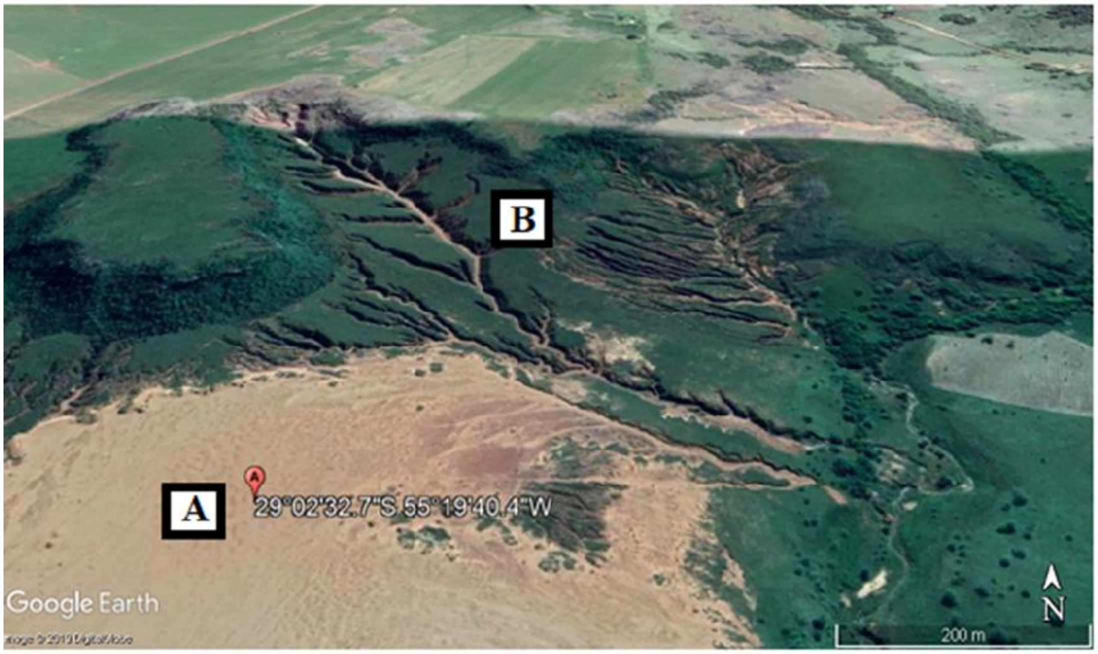


**Figure 1: Location of the experiment (A) and erosion grooves (B). [19]**

For the planting of the *Eucalyptus urophylla* seedlings, the soil was subsoiled at 30 cm depth. The initial density was 1666 $ha^{-1}$ plants spaced 3 m x 2 m. The design was completely causalized with 2 fertilization treatments. The plots had dimensions of 60 m x 30 m with 300 trees in each. Treatment 1 was the one that received natural phosphate base, the lowest amount of nutrients and applications until 120 days after planting. Treatment 2 received triple superphosphate, with fertilization occurring up to 420 days after planting and a higher nutrient load when compared to T1. The detailed fertilization description can be found in Table 1.

**Table 1. Formulations and application times of fertilizers in *Eucalyptus urophylla* stands in sandfield.**

| Fertilization | Days after planting | Formulation | Amount of fertilizer (g $plant^{-1}$) | |
|---|---|---|---|---|
| | | | T1 | T2 |
| Base | 0 | ST* | - | 300 |
| Base | 0 | FN* | 250 | - |
| Start | 30 | NPK 06-30-06 | 60 | 96 |
| Start | 30 | KCl | 165 | 165 |
| 1ª coverage | 75 | NPK 22-00-18 | 66 | 108 |
| 2ª coverage | 120 | NPK 22-00-18 | 66 | 108 |
| 2ª coverage | 120 | NPK 10-25-25 | - | 137 |
| 3ª coverage | 180 | NPK 06-30-06 | - | - |
| 3ª coverage | 180 | FTE (micro) | - | 102 |
| 4ª coverage | 300 | NPK 06-30-06 | - | 48 |
| 4ª coverage | 300 | NPK 22-00-18 | - | 48 |
| 4ª coverage | 300 | FTE (micro) | - | 48 |
| 5ª coverage | 420 | NPK 06-30-06 | - | 48 |
| 5ª coverage | 420 | NPK 22-00-18 | - | 48 |
| 5ª coverage | 420 | FTE (micro) | - | 48 |
| Total of Nutrients (kg $ha^{-1}$) | | | | |

| | | | |
|---|---|---|---|
| | N | 54,4 | 156,4 |
| | $P_2O_5$ | 30,0 | 153,0 |
| | $K_2O$ | 45,6 | 169,8 |
| | ST* | - | 225,0 |
| | FN* | 120,6 | - |
| | Ca | - | 24,9 |
| | S | - | 20,0 |
| | B | - | 6,3 |
| | Cu | - | 2,8 |
| | Mn | - | 7,0 |
| *ST= triple superphosphate | Mo | - | 0,4 |
| *FN= natural phosphate | Zn | - | 31,5 |

Inventory data at 2 years of age show that for treatment 1 and 2 the basal area was 5.88 and 10.53 $m^2$ respectively. The volume of wood was 23.6 and 56.5 $m^3$ $ha^{-1}$. Table 2. With respect to biomass, there was an increment of 34.2 and 57.9% of leaf and branch of treatment 1 for treatment 2 respectively. These data show the response of the stands to fertilization.

**Table 2. Forest inventory of the plots and biomass of leaves and branches in *Eucalyptus urophylla* stands at 2 years of age.**

| Treatment | DBH | High | Basal | N | Vol | Leaf | Branches |
|---|---|---|---|---|---|---|---|
| | cm | m | $m^2$ $ha^{-1}$ | Plants $ha^{-1}$ | $m^3$ $ha^{-1}$ | kg $ha^{-1}$ | |
| T1 | 6,71 | 7,10 | 5,88 | 1666 | 23,60 | 2,67 | 1,82 |
| T2 | 9,01 | 9,60 | 10,53 | 1659 | 56,50 | 4,06 | 4,32 |
| (T2-T1) | 2,30 | 2,50 | 4,65 | -7,0 | 32,90 | 1,39 | 2,50 |
| (T2-T1) % | 25,5 | 26,0 | 44,2 | -0,4 | 58,2 | 34,2 | 57,9 |

The soil of the experimental area is predominantly of sandy texture with average percentage of 83.4, 3.4, 2.7 and 10.4% for coarse sand, fine sand, silt and clay respectively. Regarding the chemical attributes, the average content of organic matter up to 2 meters deep was very low, 0.2%. The base saturation (V) 4.2% indicates to be a dystrophic, low fertility natural soil [20].

The climate of the region is classified as being subtropical humid, with no dry season and hot summers (Cfa). The average annual rainfall is 1916 mm well distributed throughout the months of the year. The driest month presents mean precipitation> 40 mm. The average temperature of the coldest month is ≥ -3 ° C and <18 ° C and the temperature for the hottest month is ≥ 22 ° C. [21]. According to Flores et al. [22] the *Eucalyptus urophylla* species presents low climatic aptitude for the region.

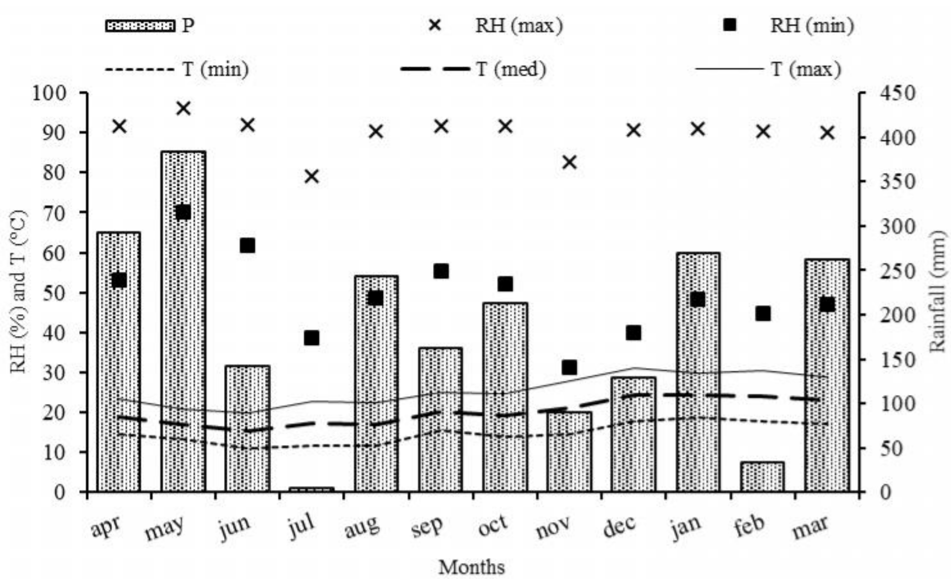


**Figure 2- Climatic diagram for the municipality of Santiago-RS, region of the study. Source: Agritempo[23].**

## 2.2 Measurement of precipitation, throughfall, stemflow an canopy interception

The quantification of the incident precipitation was carried out with 3 collectors with a capture diameter of 20 cm and storage capacity of 7 liters. The collectors were installed in open area about 50 meters from the stand at 1.5 meters from ground level.

The throughfall was quantified in the treatments T1 and T2 by means of the installation of 3 collectors, arranged in line, inter-row and diagonal positions of the trees. The collections were performed biweekly over 12 months. The equation for quantification of incident precipitation and throughfall (mm) can be described as follows:

$$P \text{ or } TF = V / A$$

Where: P = Incident precipitation; Tf = throughfall; V = volume of water (liters); A = catchment area (0.0314 m²)

The water flowing through the trunk was directed by a spiral gutter system around the trunk of the tree to a reservoir located at the base of the tree with a storage capacity of 60 liters. For the calculation of the stemflow was used the equation of Preuhsler et al. [24].

$$Sf = (V / g) \times (G / A),$$

Where: Sf = stemflow (mm), V = volume collected (liters) g = tree basal area (m²) G = basal area of trees in plot (m²) A = plot area (m²).

The canopy interception was calculated to the difference between the incident precipitation and the sum of the throughfall with the stemflow. The equation is described below by Krusche et al [25].

$$Ci = P - (Tf + Sf),$$

Where: C = canopy interception; P = incident precipitation; Tf = throughfall; St = stemflow.

## 2.3 Statistics and Data Analysis

Statistical analysis was performed using IBM SPSS 20.0 [26]. Regression equations were adjusted for throughfall, stemflow and canopy interception as a function of the incident precipitation variable. The distribution of the regression residues was then analyzed in order to validate the homogeneity of variance. The residues were presented in graphic form as a function of the variable analyzed.

Tukey's test on throughfall and stemflow was applied at ($P$ = .05) to compare if there was a statistical difference in the volume of water between the two treatments. Tukey's test was also applied in the incident precipitation at ($P$ = .05) to compare if there was statistical difference in rainfall volume between the months [26].

# 3. RESULTS

## 3.1 Distribution of incident precipitation, throughfall, stemflow, canopy interception

During the evaluated period the incident precipitation was 2050 mm, with throughfall of 1953 and 1880 mm for treatments 1 and 2, respectively. The throughfall in treatment 1 represented 95% of the incident precipitation, already for treatment 2 it represented 92%. The Tukey test showed a significant statistical difference between treatments for throughfall only in the months of October and March (Table 3).

The stemflow was 27.5 and 66.5 mm for T1 and T2, respectively. These values represent 1.3% and 3.2% of the incident precipitation. The Tukey test shows a statistical difference between the Sf treatments in most months, including the annual value.

The canopy interception was 4.3 and 6.2% for treatments 1 and 2, respectively. It was observed that the lower precipitation resulted in greater interception by the canopy, 9.1% and 17.6% for the T1 and T2 in the July month.

**Table 3. Partition incident rainfall precipitation over 12 months in *Eucalyptus urophylla* stand under different managements fertilization.**

| Months | P | Tf T1 | Tf T2 | Sf T1 | Sf T2 | Ci T1 | Ci T2 |
|---|---|---|---|---|---|---|---|
| | | | (mm) | | | (%) | |
| apr | 378,4 **A*** | 366,7 A** | 361,4 A** | 0,8 B | 3,3 A | 2,9 | 3,6 |
| may | 331,7 **B** | 302,8 A | 289,9 A | 5,5 B | 13,4 A | 7,0 | 8,5 |
| jun | 111,8 **F** | 102,0 A | 106,8 A | 2,3 A | 4,0 A | 6,8 | 0,9 |
| jul | 4,7 **J** | 4,1 A | 3,7 A | 0,1 A | 0,1 A | 9,1 | 17,6 |
| aug | 230,9 **E** | 223,6 A | 220,0 A | 3,3 A | 9,7 A | 1,7 | 0,5 |
| sep | 150,6 **F** | 146,5 A | 143,4 A | 3,7 A | 5,3 A | 0,2 | 1,2 |
| oct | 105,4 **G** | 103,0 **A** | 90,7 **B** | 1,4 B | 4,1 A | 1,0 | 10,1 |
| nov | 82,6 **H** | 75,3 A | 71,7 A | 1,1 B | 2,4 A | 7,5 | 10,2 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| dec | 75,3 **H** | 67,8 A | 69,5 A | 1,1 B | 2,0 A | 8,6 | 5,1 |
| jan | 282,2 **C** | 277,3 A | 250,0 A | 3,7 B | 10,9 A | 0,4 | 7,5 |
| feb | 34,9 **I** | 33,1 A | 32,4 A | 0,5 A | 0,9 A | 3,8 | 4,4 |
| mar | 261,4 **D** | 250,9 **A** | 240,1 **B** | 3,9 B | 10,2 A | 2,5 | 4,2 |
| Total | 2049,8 | 1953,2 A | 1879,6 A | 27,5 B | 66,5 A | - | - |
| % | 100,0 | 95,3 | 91,7 | 1,3 | 3,2 | 4,3 | 6,2 |

** Different letters in the column of incident precipitation (P) statistically differ to (P = .05)in the Tukey test. ** Different letters in the line between the treatments in the throughfall (Tf) and between treatments in the stemflow (Sf), statistically differ to (P = .05) in the Tukey test.*

### 3.2 Regression analysis

The regression analyses for throughfall, stemflow and canopy interception as a function of the incident precipitation were all linear (Figure 3). In relation to the throughfall, the adjustments were 0.998 and 0.993 for the T1 and T2, respectively. The stemflow presented adjustments of 0.96 and 0.97 for T1 and T2, respectively. The intercept adjustments by the canopy were inferior if compared to the previous partitions, however the adjustments can also be considered good. $R^2$ values were 0.85 and 0.89 for T1 and T2, respectively.

For the linear regression assumptions to be verified, the residuals of the dependent variables were plotted as a function of the independent variable as can be observed in Figure 4. The figure shows that the assumptions are satisfactorily met for all treatments in all partitions of precipitation.

The graphical distribution of the residuals is satisfied when the points on the graph are distributed randomly around the line. This characteristic corresponds to zero residue. Graphically there is the formation of a stain of uniform width without distinction of any pattern.

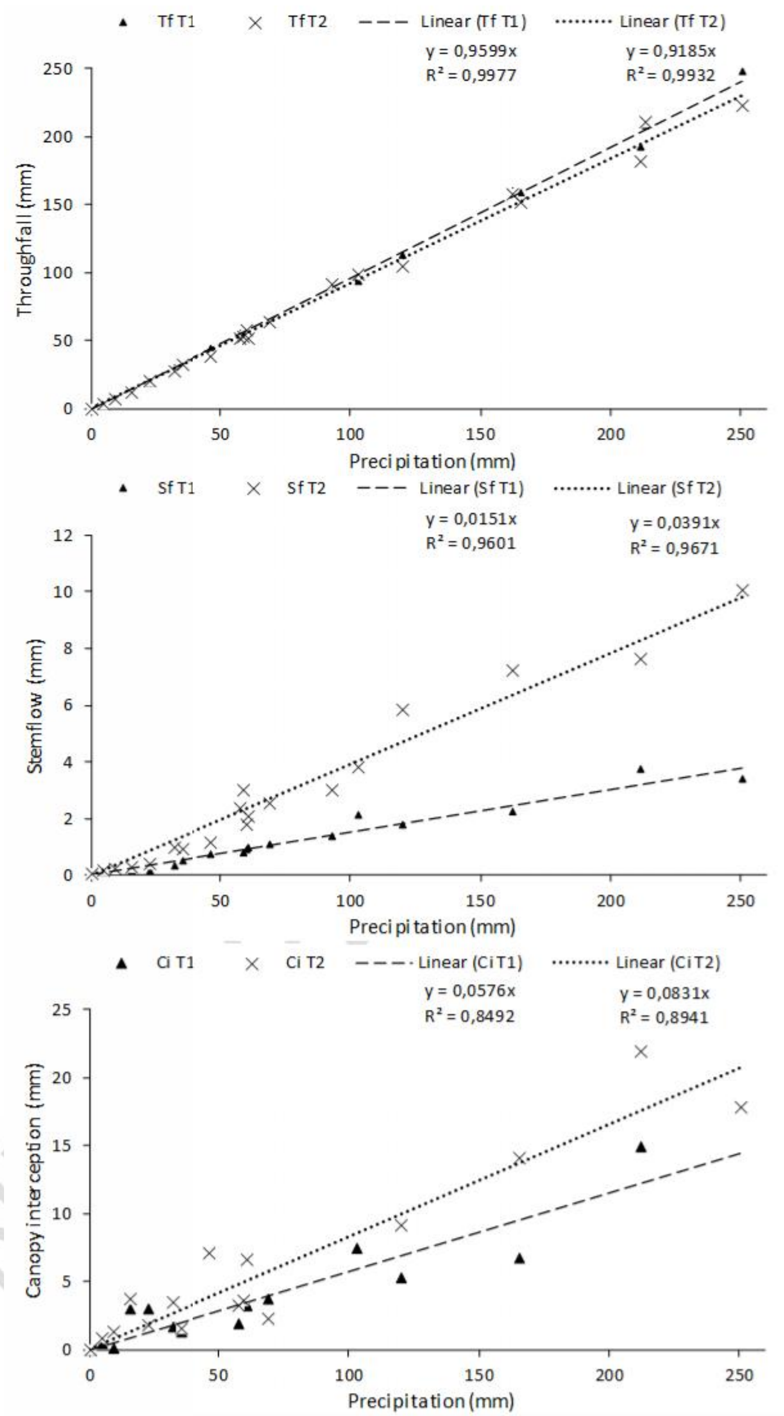


**Figure 3. Regression analysis for the different treatments in the throughfall, stemflow and canopy interception in *Eucalyptus urophylla* stands, as a function of the incident precipitation.**

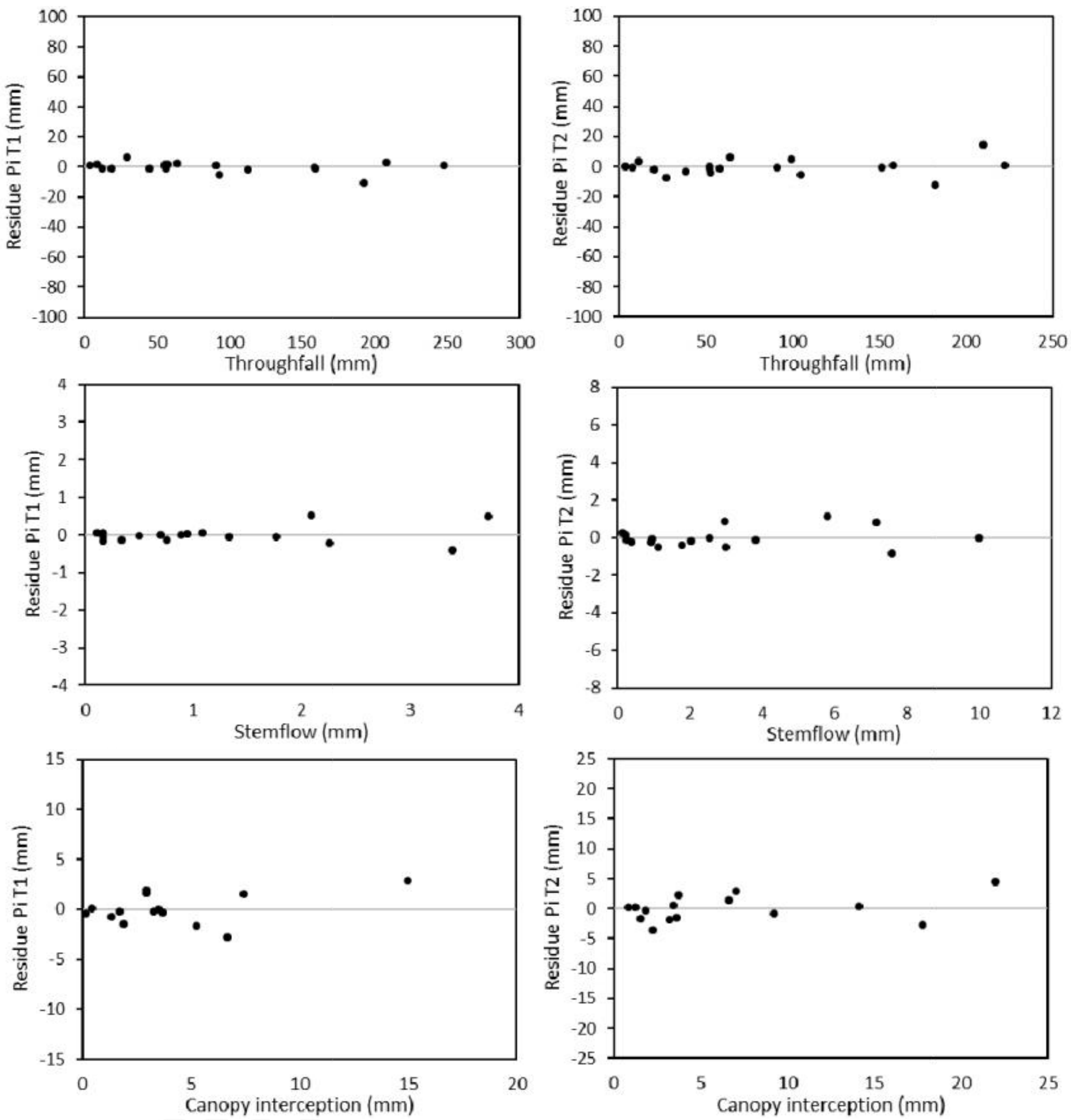


**Figure 4. Distribution of linear regression residuals for throughfall, stemflow and canopy interception in the different treatments in *Eucalyptus urophylla* stands.**

## 4. DISCUSSION

### 4.1 Distribution of incident precipitation, throughfall, stemflow, canopy interception

The precipitation over twelve months was 2050 mm, representing 7% above the historical average that is 1916 mm according to Alvarez et al [21]. These values can still be considered on average. The throughfall was 95.3 and 91.7% for T1 and T2, respectively.

Monitoring at different ages has been conducted in *Eucalyptus dunnii* stands in Alegrete municipality in southern Brazil. With the advancement of the stand age, there is a percentage reduction in the throughfall. Corrêa [15] found 91.6% of throughfall as function to the incident precipitation between 1.4 and 2.4 years of age. Between 4 and 6 years of age, Dick et al [16] found an average throughfall of 91.3%. In the same stand, between 7 and 8 years of age Momolli et al [11] show that the throughfall was smaller when compared to the other studies, being only 90.3%.These results can be explained by the maturity of the stand. With the growth in diameter occurs the closure of the canopy, intercepting greater amount of rain through its leaves and branches.

The throughfall is associated with the leaf area index, for this reason there was no statistical difference between the treatments for most of the evaluated months. As described in the methodology, the increase in the amount of leaves was only 34% in the treatment 2.

The stemflow represented 1.3 and 3.2% for treatments 1 and 2 respectively. Statistical difference was significant. T2 was on average 59.4% higher than T1. As discussed previously, T2 shows an increase in the order of 57.9% in tree biomass when compared to T1.

For Corrêa [15], Dick et al [16] and Momolli et al [11] values were 1.5, 1.1 and 0.8%, respectively. Comparing the results with other studies shows that as age increases, the percentages of stemflow tend to decrease. The explanation for the fact is that the calculation of the quantification in millimeters. For the stemflow is considered the relation of the basal area of the tree with the volume in liters.

The interception by the canopy was higher in treatment 2. This treatment received the largest amounts of fertilizers and presented the largest stocks of biomass of leaves, branches, stem and bark. In this sense, we can conclude that larger biomass above ground increase the intercept by the canopy, mainly as a function of the leaf area. Other studies indicate that the leaf area is directly related to the interception, as is the case of the work developed by Holder &Gibbes [27] that evaluated the canopy characteristics and the leaf area in several tree species.

Studies with different forest formations converge with the results found. Comparing interception by canopy in native forests and plantations with exotic species of *Pinus* and *Eucalyptus* in Chile, Soto-Schönherr and Iroumé [28] show that native forests intercept up to 50% more rainwater than plantations, considering the same basal area. The explanation is due to their lower canopy structure and closure degree of the plantations. In a native forest there are several stratifications while in a plantation there is only one stratum.

Older forest stands have greater interceptions by the canopy. The mean interceptions by the canopy of *Eucalyptus dunnii* were 6.9; 7,5 and 8,9% [15,16,11]. For other authors the intercept by the canopy is more related to the height and basal area of the trees of the stand [29]. For Laclau [30] evaluating the precipitation partition in *Eucalyptus* sp. from 6 to 9 years of age in Congo, the season of the year is the main factor that determines the interception by the canopy. During the wet season the interception values were only 3.9%, and during the dry season these values increased to 22.8%.

Studying the pluviometric precipitation partition in a 31-year *Japanese cypress*stand in central Japan, Sun et al. [31] show that the throughfall and stemflow represented 64.2; 10.6% of the precipitation incident. The canopy interception was 25.2%. These results differ from those found in our study. According to the authors, the density was 2198 trees per hectare, representing a basal area of 50.4 $m^2$ $ha^{-1}$. In addition, mean height and DBH were 16 m and 19.1 cm, respectively. Considering these facts, it is evident that the greater density of trees as well as greater dendrometric characteristics increased the values of the stemflow and canopy interception, reducing the throughfall.

### 4.2 Regression analysis

The regression analysis for the dependent variables, throughfall, stemflow and canopy interception had excellent linear adjustments: 0.99; 0.96 and 0.85 for treatment 1 and 0.99; 0.97 and 0.89 for treatment 2. Similar results were reported by Sun et al. [31]. The authors present $R^2$ of 0.99; 0.99 and 0.97.

Balieiro et al. [32] studied the partition of precipitation in *Eucalyptus grandis* stands at 5 years of age in the southeastern region of Brazil. The linear regression analysis showed adjustments of 0.99 and 0.93 for the throughfall and stemflow. Momolli et al. [11] also performed regression adjustments and found values of 0.99; 0.90 and 0.60 for throughfall, stemflow and canopy interception, respectively.

A study with the same species *Eucalyptus urophylla*, at the age of 30, in the southeast region of Brazil was developed by Arcova et al. [33]. Over 3 years of monitoring, the researchers showed that the canopy interception was 5.6%, stemflow of 5.4% and throughfall of 89%. Regression analysis shows linear adjustments of $R^2$ 0.99 and 0.70 for throughfall and stemflow.

The throughfall was evaluated in Semidecidual forest, *Eucalyptus cloeziana* and *Pinus* sp. and according to Gasparoto et al. [34] the values found were 76; 85 and 84% of the incident precipitation. Linear regressions showed adjustments of $R^2$ 0.74; 0.90 and 0.90, respectively.

For a study developed by Shinzato et al. [35] evaluating a stand of *Eucalyptus cloeziana* at 15 years, flow through the trunk represented values similar to the present study: 0.98%. Based on linear regression the authors found adjustments of $R^2$ 0.71.

## 5. CONCLUSION

In a sandfield, the fertilization management described for Treatment 2 results in a greater interception of rainfall due to the higher amount of biomass of the canopy. This canopy interception reduces the amount of rainfall that reaches the ground and protects the surface of the same against the direct impact of rainfall.

There was no significant statistical difference between the throughfall of the two treatments. Stemflow of Treatment 2 was significantly higher than Treatment 1, possibly due to a 58% increase in the number of branches.

The adjustments of the linear regression, the coefficients of determination for throughfall, stemflow and canopy interception were 0.99; 0.96 and 0.85 for Treatment 1 and 0.99; 0.97 and 0.89 for Treatment 2. The graphical analysis of the residues presented distribution with zero mean, constant variance and independence of the residues, and there was no evidence of violation of the assumptions.

## REFERENCES

1. Oliveira PTS, Wendland E, NearingMA. Rainfall erosivity in Brazil: A review. CATENA, 2013:100:139–147. https://doi.org/doi:10.1016/j.catena.2012.08.006

2. SilvaAM.Rainfall erosivity map for Brazil. CATENA.2004;57(3):251–259. https://doi.org/doi:10.1016/j.catena.2003.11.006

3. Souto JJ. Desertoumaameaça? Porto Alegre, RS, Secretaria de agricultura. 169 p. 1984. Portuguese.

4. Llorens P, Domingo F. Rainfall partitioning by vegetation under Mediterranean conditions. A review of studies in Europe. Journal of Hydrology.2007;335:37–54, https://doi.org/10.1016/j.jhydrol.2006.10.032

5. Navar J. Stemflow variation in Mexico’s northeastern forest communities: Its contribution to soil moisture content and aquifer recharge. Journal of Hydrology.2011;408(1):35–42, https://doi.org/10.1016/j.jhydrol.2011.07.006

6. Zhang Y, Wang X, Pan Y, Hu R. Variations of Nutrients in Gross Rainfall, Stemflow, and Throughfall Within Revegetated Desert Ecosystems. Water Air Soil Pollution. 2016;227(6): 183. https://doi.org/10.1007/s11270-016-2878-z

7. Johnson MS, Lehmann J. Double-funneling of trees: stemflow and root-induced preferential flow. Ecoscience.2006;13:324 – 333. https://doi.org/10.2980/i1195-6860-13-3-324.1

8. Salehi M, Zahedi Amiri G, Attarod P. et al. Seasonal variations of throughfall chemistry in pure and mixed stands of Oriental beech (*Fagus orientalis* Lipsky) in Hyrcanian forests (Iran). Annals of Forest Science. 2016;73:371–380. https://doi.org/10.1007/s13595-015-0525-2

9. Calder IR. Dependence of rainfall interception on drop size a replay to the comment by Uijlenhoet and Sticker. Journal Hydrology.1999;217:164–165. https://doi.org/10.1016/S0022-1694(99)00003-7

10. Sulinski J, Starzak R,Kucza J. Weryfikacjawzoruwyra_ zaja˛cegointercepcje˛ drzew w zale_znos´ci od nate˛ zeniaiczasutrwaniaopadudeszczu w warunkacheksperymentalnych. Acta Agraria et Silvestria. 2001;39:3–16. Polish

11. Momolli DR, Schumacher MV, Viera M, Ludvichak AA, Guimarães CC, Souza HP. Incident precipitation partitioning: throughfall, stemflow and canopy interception in *Eucalyptus dunnii* stand. Journal of Agricultural Science.2019;11(5)*(In press)*.

12. Zimmermann A, Zimmermann B. Requirements for throughfall monitoring: the roles of temperate scale and canopy complexity. Agricultural and Forest Meteorology.2014;189-190: 125–139, https://doi.org/10.1016/j.agrformet.2014.01.014

13. Rodriguez Suarez JA, Diaz-Fierros F, Perez R, Soto B. Assessing the influence of afforestation with*Eucalyptus globulus*on hydrological response from a small catchment in northwestern Spain using the HBV hydrological model. Hydrological Processes.2013;28(22):5561–5572. https://doi.org/10.1002/hyp.10061

14. ReichertJM, Rodrigues MF, Peláez JJZ, Lanza R, Minella JPG, Arnold JG, Cavalcante RBL. Water balance in paired watersheds with eucalyptus and degraded grassland in Pampa biome. Agricultural and Forest Meteorology.2017;237-238:282–295. https://doi.org/10.1016/j.agrformet.2017.02.014

15. Corrêa RS. Ciclagem de nutrientesem*Eucalypts dunnii* estabelecido no Bioma Pampa. 99 f. Tese (DoutoradoemEngenhariaFlorestal) - Universidade Federal de Santa Maria, Santa Maria, RS. 2011.Portuguese.

16. Dick G, Schumacher MV, Momolli DR.Viera M. Nutrient Input via Incident Rainfall in a *Eucalyptus dunnii* Stand in the Pampa biome. Floresta Ambiente.2018;25(3) http://dx.doi.org/10.1590/2179-8087.055916

17. Le Bissonnais Y, Arrouays D. Aggregate stability and assessment of soil crustability and erodibility: II. Application to humic loamy soils with various organic carbon contents. European Journal of Soil Science.1997;48:39–48.

18. Valentin C, Bresson LM. Morphology, genesis and classification of surface crusts in loamy and sandy soils. Geoderma.1992;55:225–245.

19. Google Earth-maps. https://www.google.com.br/maps. Accessed in 20/03/2019.

20. SBCS-CQFS – Sociedade Brasileira de Ciência do Solo-Comissão de Química e Fertilidade do Solo – RS/SC. Manual de calagem e adubação para osEstados do Rio Grande do Sul e de Santa Catarina. 11ª ed. Solo – Núcleo Regional Sul. Porto Alegre. 2016, 376 p.Portuguese.

21. Alvares CA, Stape JL, Sentelhas PC, Gonçalves JLM,Sparovek G, Köppen's climate classification map for Brazil. MeteorologischeZeitschrift. 2013 http://dx.doi.org/10.1127/0941-2948/2013/0507

22. Flores TB, Alvares CA, Souza VC, Stape JL. *Eucalyptus* no Brasil: zoneamentoclimático e guia para identificação. Piracicaba: IPEF. 2016.Portuguese.

23. AGRITEMPO (2019). Dados meteorológicos – Santiago-RS. Campinas, 2019. Disponívelem: <http://www.agritempo.gov.br>. Acessoem: 14 feb. 2019.Portuguese.

24. Preuhsler T,Bastrup-Birk A,Beuker E. Manual on methods and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forests – Part VII: Meteorological Measurements. 32p. 2006.

25. Krusche AV, Ballester MVR, Leite NK. Hydrology and biogeochemistry of terra firme lowland tropical forests. DF. Levia et al., Eds., Forest Hydrology and Biogeochemistry, Ecological Studies. 216, Springer Science & Business Media, 2011;187-201, https://doi.org/10.1007/978-94-007-1363-5_9

26. IBM Corp. Released (2011). IBM SPSS Statistics for Windows, Version 20.0. Armonk, NY: IBM Corp.

27. Holder CD, Gibbes C. Influence of leaf and canopy characteristics on rainfall interception and urban hydrology. Hydrological Sciences Journal.2016;62(2):182–190. https://doi.org/10.1080/02626667.2016.1217414

28. Soto-Schönherr S, Iroumé A. How much water do Chilean forests use? A review of interception losses in forest plot studies. Hydrological Processes. 2016;30:4674–4686, https://doi.org/10.1002/hyp.10946

29. Dietz J, Hölscher D, Leuschner C, Hendrayanto. Rainfall partitioning in relation to forest structure in differently managed montane forest stands in Central Sulawesi, Indonesia. Forest Ecology and Management.2006;237(1-3):170–178. http://dx.doi.org/10.1016/j.foreco.2006.09.044

30. Laclau JP, Ranger J, Bouillet JP, Nzila JD, Deleporte P. Nutrient cycling in a clonal stand of *Eucalyptus* and an adjacent savanna ecosystem in Congo 1. Chemical composition of rainfall, throughfall and stemflow solutions. Forest Ecology and Management.2003;176: 105-119. https://doi.org/10.1016/S0378-1127(02)00280-3

31. Sun X, Onda Y, Kato H. Incident rainfall partitioning and canopy interception modeling for an abandoned *Japanese cypress* stand. Journal of Forest Research.2014;19(3):317–328. https://doi.org/10.1007/s10310-013-0421-2

32. Balieiro FC, Franco AA, Fontes RLF, Dias LE,Campello EFC, Faria SM. Evaluation of the throughfall stemflow nutrient contents in mixed and pure plantations of *Acacia mangium*, *Pseudosameneaguachapele* and *Eucalyptus grandis*. Revista Árvore. 2007;31(2):339-346.

33. Arcova FCS, Ranzini M, Cicco V. Partitioning of rainfall in experimental plantations of *Eucalyptus urophylla* and *Pinus elliottii*. Floresta.2018;48(3):383-392. http://dx.doi.org/ 10.5380/rf.v48i3.55492

34. Gasparoto EAG, Tonello KC, Shinzato ET, Valente ROA. Throughfall in different forest stands of Iperó, São Paulo. Cerne.2014;20(2):303-310. http://dx.doi.org/10.1590/01047760.201420021260

35. Shinzato ET, Tonello KC, Gasparoto EAG, Valente ROA. Escoamentopelotroncoemdiferentespovoamentosflorestaisna Floresta Nacional de Ipanema emIperó, Brasil. Scientia Forestalis.2011;39(92):395-402. Portuguese.