Ambiente & Água - An Interdisciplinary Journal of Applied Science
ISSN 1980-993X – doi:10.4136/1980-993X
www.ambi-agua.net
E-mail: ambi.agua@gmail.com

Partial exclusion of precipitation: throughfall, stemflow and canopy interception in Eucalyptus plantations in southern Brazil

ARTICLES doi:10.4136/ambi-agua.2645

Received: 04 May 2021; Accepted: 13 Aug. 2021

Gian Carlos Poleto[1]; Dione Richer Momolli[1*]; Mauro Valdir Schumacher[1]; Aline Aparecida Ludvichak[1]; Kristiana Fiorentin dos Santos[2]; James Stahl[3]; Clayton Alcarde Alvares[4]

[1]Departamento de Ciências Florestais. Universidade Federal de Santa Maria (UFSM), Avenida Roraima, n° 1000, CEP: 97105-900, Santa Maria, RS, Brazil. E-mail: gianpoleto@gmail.com, mvschumacher@gmail.com, aline_lud@yahoo.com.br
[2]Departamento de Engenharia Florestal. Universidade Regional de Blumenau (FURB), Rua São Paulo, n° 3250, CEP: 89030-000, Blumenau, SC, Brazil. E-mail: kristianafiorentin@gmail.com
[3]Klabin S.A., Unidade de Monte Alegre, Avenida Brasil, n°26, CEP: 84275-000, Telêmaco Borba, PR, Brazil. E-mail: jstahl@klabin.com.br
[4]Suzano Papel e Celulose, Estrada Limeira, n°391, CEP: 13465-970, Limeira, SP, Brazil. E-mail: calcarde@suzano.com.br
[*]Corresponding author. E-mail: dionemomolli@gmail.com

ABSTRACT

Hydrological behavior in reforested watersheds is different from that under other forms of cover. The variation may be related to aspects intrinsic to species, planting density, physiological maturity, management system and climatic conditions. Periodically, climatic anomalies such as the case of La Ninã are observed, and these are responsible for the alteration of the rainfall regime and consequently generate water deficits in the southern region of Brazil. Water deficit is responsible for reducing growth and productivity for the Eucalyptus genus, in addition to causing changes in hydrological behavior in reforested watersheds. Accordingly, this study compared the partition of rainfall in throughfall, stemflow and canopy interception of eucalyptus trees submitted or not to partial exclusion of precipitation. In the open field, 3 rainfall collectors were installed, and in the stand, for each rain exclusion treatment, 9 throughfall collectors and 9 stemflow collectors were installed. Every two weeks for 12 months, the volume of the collectors was measured. The quantified precipitation was 1627 mm over a year. In the treatment without exclusion, 84.8, 2.9 and 12.3% referred to throughfall, stemflow and canopy interception, respectively, while in the treatment excluding rainfall 80.6, 2.3 and 17.2% referred to throughfall, stemflow and canopy interception. The regression adjustments for throughfall and stemflow showed satisfactory R^2 coefficients.

Keywords: hydrology, sustainability, watershed.

Exclusão parcial da precipitação pluviométrica: precipitação interna, escoamento pelo tronco e interceptação em plantações de eucalipto no sul do Brasil

RESUMO

O comportamento hidrológico em microbacias reflorestadas é diferenciado de outras formas de cobertura. A variação pode estar relacionada tanto à aspectos intrínsecos à espécie, densidade de plantio, maturidade fisiológica, sistema de manejo e às condições climáticas. Periodicamente anomalias climáticas como o caso do La Ninã são constatadas e essas, são responsáveis pela alteração do regime pluviométrico e consequentemente geram déficits hídricos na região sul do Brasil. O déficit hídrico é responsável pela redução do crescimento e da produtividade para o gênero *Eucalyptus*, além de provocar alterações no comportamento hidrológico em bacias hidrográficas reflorestadas. Por conta disso, o objetivo do estudo foi comparar a partição da precipitação pluviométrica em precipitação interna, escoamento pelo tronco e interceptação pela copa das árvores de eucalipto submetidas ou não à exclusão parcial da precipitação. Foram instalados 3 coletores de precipitação em área aberta, e no interior do povoamento, para cada tratamento de exclusão de chuva, 9 coletores de precipitação interna e 9 coletores de escoamento pelo tronco foram instalados. Ao longo de 12 meses, quinzenalmente, o volume dos coletores era aferido. A precipitação quantificada foi de 1627 mm ao longo de um ano. No tratamento sem exclusão, 84.8, 2.9 e 12.3% referiram-se à precipitação interna, escoamento pelo tronco e interceptação pela copa respectivamente, enquanto que no tratamento com exclusão da precipitação 80.6, 2.3 e 17.2% referiram-se à precipitação interna, escoamento pelo tronco e interceptação. Os ajustes da regressão para precipitação interna e escoamento pelo tronco mostraram bons coeficientes R^2.

Palavras-chave: bacia hidrográfica, hidrologia, sustentabilidade.

1. INTRODUCTION

The forestry sector holds a prominent position in the Brazilian economy. Planted forests occupy 7.83 million hectares of the country, and the genus *Eucalyptus* represents 72% of this area. Even with the large area occupied, industrial forest plantations cover about 0.92% of the Brazilian territory. Paper and cellulose commodities are the second-most exported products of Brazil (IBÁ, 2019).

Extensive areas occupied by forest plantations are able to modify the hydrological balance (Ferraz *et al.*, 2019). In addition to the interception of rainfall through the canopy of trees, the rapid growth of the *Eucalyptus* genus increases water consumption, losing it to the atmosphere through transpiration (Rodríguez Suarez *et al.*, 2014; Jackson *et al.*, 2005). Comparing two paired watersheds, Reichert *et al.* (2017) concluded that the interception in a *Eucalyptus* plantation is greater when compared to an area of pasture or natural grassland.

The partition of the rainfall in the area covered by vegetation is very dynamic. During precipitation, a portion of the water is intercepted by the canopy and immediately evaporated to the atmosphere (Llorens and Domingo, 2007). Part of the precipitation crosses the canopy and drips into the stand, being called "throughfall" (Navar, 2011). A portion flows from the leaves to the branches and trunk reaching the base of the tree, being called stemflow (Zhang *et al.*, 2016; Johnson and Lehmann, 2006). Knowledge of the partition of precipitation is important in studies of modeling the water balance of a watershed (Chaffe *et al.*, 2010), however, the percentage of interception by canopy varies according to characteristics inherent to the species and the site and, in the absence of this information, the interception is often neglected in hydrological-modeling studies (Savenije, 2004).

Considering the species in the present study, *Eucalyptus urophylla*, Arcova *et al.* (2018) reported 89.0%, 5.4% and 5.6% for throughfall, stemflow and canopy interception for a stand at 30-year-old, respectively. Souza *et al.* (2019) for the same species but at 1-year-old found 95.3; 1.3 and 4.3% for treatment with less fertilizer applied and 91.7; 3.2 and 6.2% for treatment with greater amount of fertilizers applied.

The importance of the partition of precipitation is discussed in several studies (Staelens *et* *al.*, 2006; Fan *et al.*, 2015); however, the difficulty in assessing the stemflow has caused great variations and still needs studies. Although it represents less relative contribution, the stemflow is responsible for supplying water and nutrients directly to the roots of the trees (Momolli *et al.*, 2019a; Zhang *et al.*, 2013; Bouillet *et al.*, 2002; Levia *et al.*, 2010). The precipitation event carries particles suspended in the atmosphere to the ground (Navar *et al.*, 2009). These particles, added to the interaction with the canopy (throughfall and stemflow), leach the different tissues of the plant, increasing the nutritional contribution (Bhat *et al.*, 2011; Schrumpf *et al.*, 2006). In addition, in areas of low natural fertility, nutrient input through precipitation may be the only source of nutrients (Dawoe *et al.*, 2018; Lu *et al.*, 2017).

Canopy interception is determined by biotic factors such as population age, morphophysiological aspects, height, contact surface of different plant species (Keim *et al.*, 2006) and by abiotic factors such as intensity and amount of precipitation, drop size, temperature and wind speed (Sulínski *et al.*, 2001; Momolli *et al.*, 2019b; Gerrits and Savenije, 2011; Bulcock and Jewitt, 2012). For Savenije (2004), in warm regions the percentage of water intercepted and returned to the atmosphere is more significant than in other climates. For the authors Crockford and Richardson (2000), high intercept values are the result of long rain events with low intensity, while small intercept values are the result of shorter and more intense rainfall indexes. In addition, the higher temperature favors evaporation and, consequently, the higher interception rates. Moderate wind contributes to the removal of water from the canopy and evaporation to the atmosphere; however, high winds provide the waterfall which initially was in the treetops. Figure 1 shows the scheme of the dynamic partition of rainfall in forested areas.

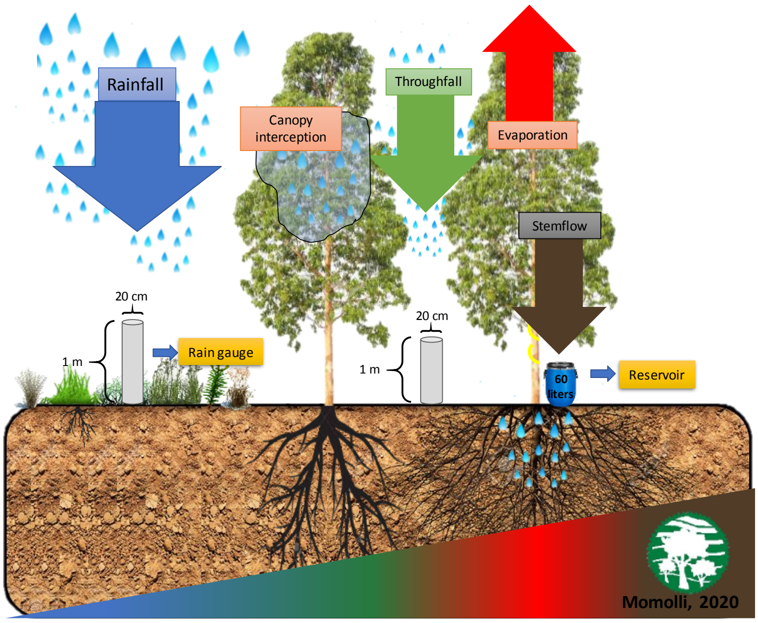

Figure 1. Scheme of the dynamic partition of rainfall in a reforested area.

The water regime in southern Brazil is determined by the atmospheric-oceanic phenomenon. When the cooling of ocean waters occurs in the equatorial Pacific, there is the phenomenon of “La Niña” that is responsible for the significant decrease in rainfall in this region. As a consequence, there is a loss of productivity of several crops, including *Eucalyptus* plantations. The reduction in precipitation can cause even greater impacts on the hydrological cycle of the watersheds considering that a greater part of the precipitation will be intercepted by the canopy without reaching the soil surface. Therefore, the present study evaluated the partition of precipitation in *Eucalyptus* stands with and without partial exclusion of throughfall.

2. MATERIALS AND METHODS

2.1. Characterization of the experimental area

The experimental area is located in a Cfb climate (temperate climate), with an average annual temperature of 18.8ºC and an average annual precipitation of 1,646 mm, according to the Köppen classification (Alvares *et al.*, 2014). According to Flores *et al.* (2016) the species *E. urophylla* is classified as having a low climatic suitability for the study region.

Figure 2 shows meteorological data for the period from July 2017 to June 2018, obtained from the meteorological station located at the company Klabin SA in Telêmaco Borba – PR – Brazil at 880 m altitude, 24°12'40.6" S and 50°33'29.2" W. The distance between the experimental area and the weather station is approximately 3.4 km in a straight line.

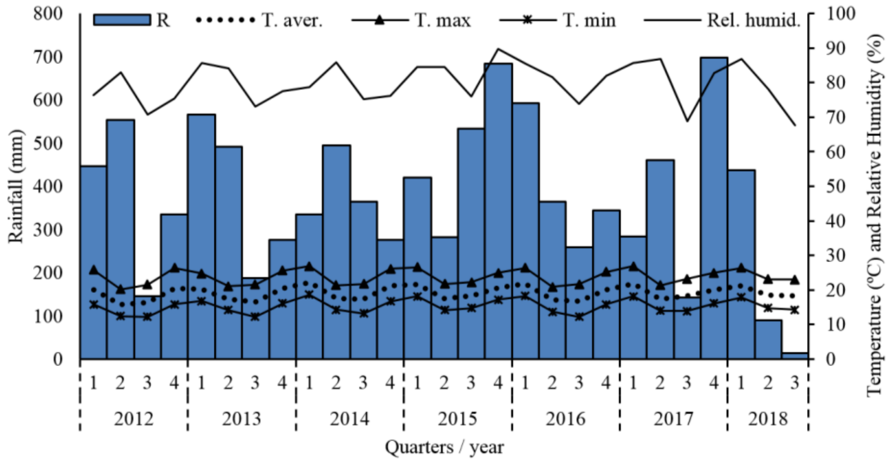

Figure 2. Meteorological data for the municipality of Telêmaco Borba, PR, from the planting of seedlings to the study period.

In March 2017, dendrometric characterization was performed, measuring the height and diameter at breast height (DBH) of all trees. According to Table 1, the mean DBH and the total height in the Excluding (E) treatment were 16.80 cm and 28.60 m, respectively. For the Without exclusion (WE) treatment, the mean DBH was 17.30 cm and the total height 28.80 m. The volume per hectare in the E and WE treatment was 346.17 and 365.07 m³ ha^{-1}, respectively.

Table 1. Characterization of the dendrometric variables of the hybrid stand of *Eucalyptus urophylla* x *E. sp.*, at 62 months of age, established in Telêmaco Borba, PR.

Variables	Excluding (E)	Without exclusion (WE)
Average diameter (cm)	16.78 ± 1.38 b*	17.34 ± 1.81a
Average height (m)	28.57 ± 1.09 a	28.35 ± 1.67 a
Basal plot (m²)	1.74 ± 0.02b	1.84 ± 0.02a
Plot volume (m³)	24.92 ± 0.32 a	26.29 ± 0.34 a
Basal area (m² ha^{-1})	24.13 b	25.52 a
Volume (m³ ha^{-1})	346.17 a	365.08 a
Leaf area index (LAI)	2.95	2.82

2.2. Experimental design

The study belongs to the TECHS project (Tolerance of *Eucalyptus* Clones to Hydric, Thermal and Biotic Stresses). The experiment was carried out in a completely randomized design, with 720 m² plots of eight lines with ten plants each in spacing of 3 m x 3 m (1,111 trees ha^{-1}). For the hybrid *E. urophylla* x *E. sp.* two treatments of the water regime were defined:

one receiving 100% of the throughfall (WE) and the other receiving only 70% of the throughfall (E). For the treatment (E), that received 70% of the precipitation, a system of partial exclusion of the throughfall was used with plastic gutters that prevent the precipitation reaching the ground. A schematic representation of the precipitation exclusion treatment (E) can be seen in Figure 3. This technique is based on the coverage between the planting lines covering 216 m² of the area of each treatment, being the equivalent to 30% of the plot area (Binkley *et al.*, 2017).

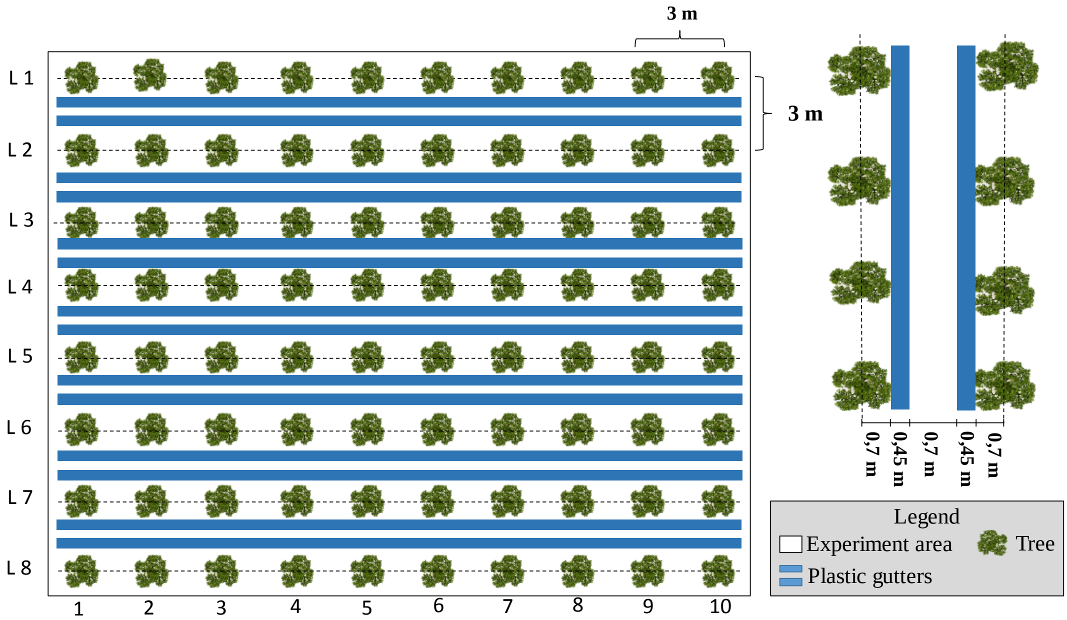

Figure 3. Representative scheme of the partial precipitation exclusion treatment (E), with dimensions and spacing.

The monitoring of the partition of precipitation under the two rainfall regimes occurred from July 2017 to June 2018. The sampling of this experiment was started when the stand was 66 months old. For the (E) treatment, a partial exclusion system of throughfall was used, installed when the stand completed one year of age.

2.3. Measurement of rainfall, throughfall and stemflow

To quantify the rainfall (R), three collectors with a 20 cm catchment diameter were installed in an area adjacent to the eucalyptus stand at a height of 1.5 m above ground level. Straps with steel wires were placed in order to prevent birds from using the collectors as perches.

For the evaluation of throughfall (Tf), nine collectors per treatment were installed, with a collection diameter of 20 cm and height of 1 m from the ground level, systematically distributed along the line, between the lines and diagonally between four trees. Collections were started at 66 months of age.

The stemflow quantification (Sf) occurred with the installation of nine sets formed by a plastic hose with a diameter of one inch and a reservoir for water storage. The hose was cut longitudinally and then it was installed in a spiral shape on the tree trunk. This configuration allowed the water to drain through the trunk and be stored in the reservoir. Fortnightly, the values of rainfall (R), throughfall (Tf) and stemflow (Sf) were measured. To obtain the values of precipitation and throughfall in millimeters, the following Equation 1 was used:

$$R = V/a \quad (1)$$

Where:

R = rainfall (mm);

V = volume collected (L);

a = collector area (m^2).

The values of stemflow were obtained using the following expression, used by Preuhsler *et al.* (2006) Equation 2:

$$Sf = \left(\frac{V}{g}\right) * \left(\frac{G}{A}\right) \tag{2}$$

Where:

Sf = stemflow (mm);

V = volume collected (L);

g = basal area of the tree (m^2);

G = basal area of the plot (m^2);

A = plot area (m^2).

For the canopy interception calculation, the expression was used Equation 3:

$$I = \frac{R-(Tf+Sf)}{R} * 100 \tag{3}$$

Where:

I = canopy interception (%);

R = rainfall (mm);

Tf = throughfall (mm);

Sf = stemflow (mm).

The rainfall and throughfall collectors were composed of plastic bottles with a capacity of 2 liters, and the collections were carried out every 15 days. The throughfall collectors were arranged on the line, between the lines and diagonally between four trees.

2.4. Statistics and Data Analysis

Descriptive statistics are presented as the mean, percentage and coefficient of variation (%) for the quantities in each rainfall regime and each partition of precipitation. Statistical analysis was performed using IBM SPSS 20.0 (IBM, 2011). 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.

3. RESULTS AND DISCUSSION

3.1. Rainfall partitioning

According to the results obtained, the total rainfall (R), during the study period, was

1,627.25 mm. The month of December 2017 had the highest volume of R 371 mm, while the months of July 2017 and April 2018 registered the lowest volumes (0.00 and 21 mm) (Table 2).

Table 2. Values in (mm) of rainfall (R), throughfall (Tf), stemflow (Sf), canopy interception (I) and their respective variation coefficients (±) in (%) in the experimental area of the hybrid stand of *Eucalyptus urophylla* x *E*. sp.

Year	Month	R	Tf WE	Tf E	Sf WE	Sf E	I WE	I E
				mm			%	
2017	Jul	0 ± 0.0	0 ± 0.0	0 ± 0.0	0 ± 0.0	0 ± 0.0	0 ± 0.0	0± 0.0
	Aug	122 ± 1.8	100 ± 4.5	97 ± 3.1	4 ± 21.5	4 ± 14.7	18 ± 17.1	19 ± 7.2
	Sep	35 ± 0.5	28 ± 9.8	26 ± 4.4	2 ± 57.7	2 ± 33.8	16 ± 68.1	21 ± 6.6
	Oct	295 ± 0.7	262 ± 1.4	228 ± 1.6	11 ± 4.7	7 ± 25.0	11 ± 29.5	21 ± 5.4
	Nov	180 ± 5.4	157 ± 3.0	139 ± 6.0	8 ± 24.5	6 ± 15.4	9 ± 32.6	20 ± 13.3
	Dec	371 ± 2.5	320 ± 5.4	321 ± 1.7	8 ± 5.0	5 ± 8.3	12 ± 60.7	13 ± 7.9
2018	Jan	274 ± 1.2	218 ± 1.1	219 ± 2.0	5 ± 6.4	4 ± 10.8	22 ± 11.9	22 ± 0.6
	Feb	117 ± 0.9	105 ± 3.6	101 ± 3.1	3 ± 31.9	3 ± 4.0	15 ± 71.4	21 ± 4.7
	Mar	102 ± 0.9	83 ± 3.3	79 ± 1.5	4 ± 34.3	3 ± 37.0	15 ± 31.4	19 ± 7.1
	Apr	21 ± 5.8	17 ± 3.8	17 ± 5.1	1 ± 30.5	0 ± 17.3	13 ± 72.8	18 ± 7.9
	May	56 ± 0.7	44 ± 9.0	43 ± 0.4	2 ± 30.9	2 ± 33.1	28 ± 37.5	31 ± 3.7
	Jun	54 ± 1.5	43 ± 1.3	42 ± 5.2	1 ± 19.6	1 ± 41.7	22 ± 10.5	25 ± 7.0
Total (mm)		**1627** ± 2.0	**1379** ± 4.2	**1311** ± 3.1	**48** ± 24.3	**37** ± 21.9	**200** ± 40.3	**280** ± 6.5
%		**100**	**84.8**	**80.6**	**2,9**	**2,3**	**12.3**	**17.2**

Where: ± variation coefficients (%); R = rainfall, Sf WE = throughfall in the treatment without exclusion; Sf E = throughfall in the treatment with partial exclusion; Tf WE = stemflow in the treatment without exclusion; Tf E = stemflow in the treatment with partial exclusion; I WE = canopy interception in treatment without exclusion; I E = canopy interception in treatment with partial exclusion.

Regarding throughfall, the WE treatment showed 1379 mm, equivalent to 84.8% of the precipitation. In contrast, the E treatment showed a lower value (1311 mm), corresponding to 80.6% of the precipitation. The volume collected for the Sf WE treatment was 48.40 mm, representing 2.9% of the rainfall. For the Sf E treatment, 37 mm was accumulated, corresponding to 2.3% of the rainfall. In the canopy interception, the lowest observed value was 200 mm (12.3%) for WE treatment, while in treatment E the value was 280 mm (17.2%).

The regression analyses for throughfall, stemflow and canopy interception as a function of precipitation in the WE treatment showed an adjustment R = 0.97; 0.73 and 0.34, respectively (Figure 4). For E treatment, the adjustment was R = 0.96; 0.67 and 0.59, for throughfall, stemflow and canopy interception, respectively.

Evaluating forest formations of *Eucalyptus cloeziana*, *Pinus* sp. and Seasonal Semideciduous Forest in Iperó, SP, Gasparoto *et al.* (2014) found that throughfall represents 76.2%, 85.1% and 84% of precipitation, respectively. Almeida *et al.* (2013), evaluating an *E. grandis* x *E. urophylla* stand in Minas Gerais, found that the canopy interception was 9%, this value being lower than that found in this work. Momolli *et al.* (2019b) studied the distribution of rainfall in an *E. dunnii* Maiden stand, aged 72 months in Alegrete, RS, and found an average canopy interception of 8.9% in one year of evaluation (1903 mm). Supangat *et al.* (2012) evaluating the behavior of rainwater after interaction with the canopy of six-year-old *Eucalyptus pellita* found an interception of 15.4%.

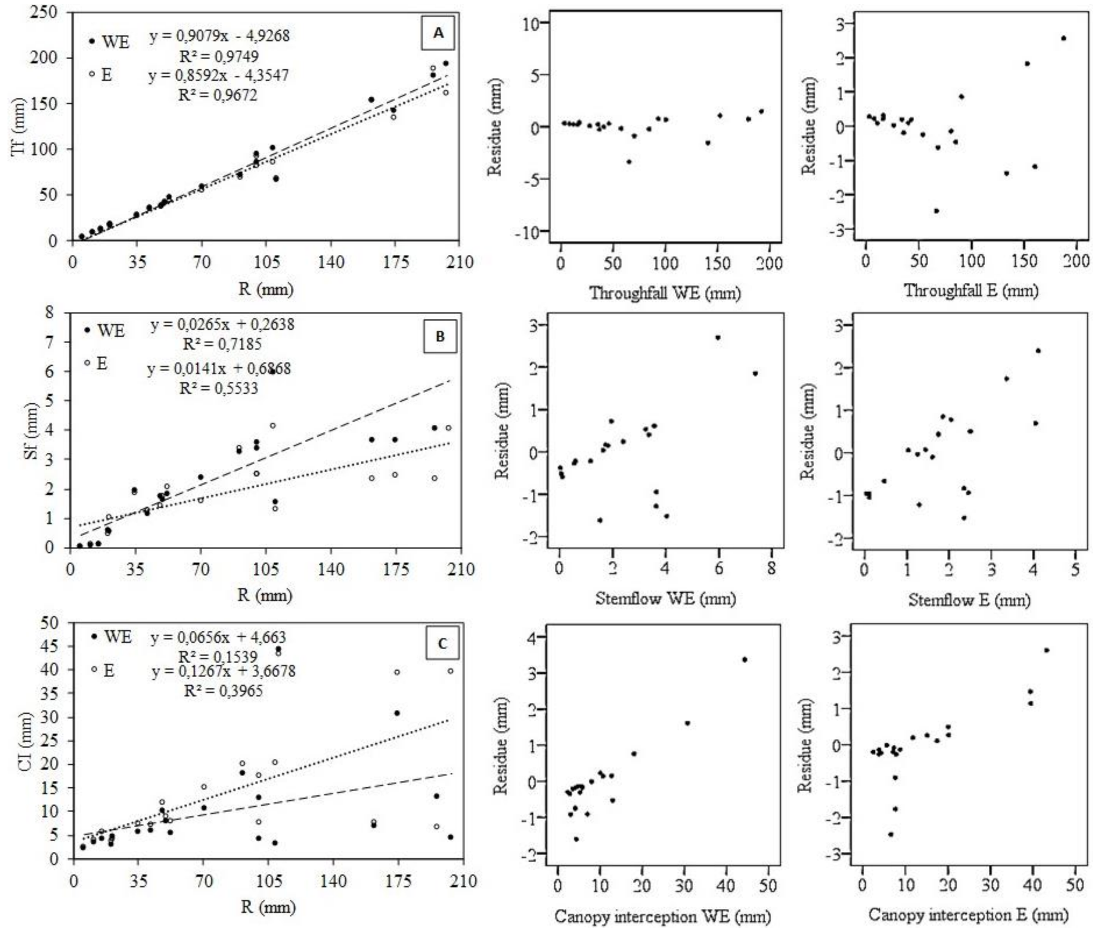

Figure 4. Relationship of throughfall (A); stemflow (B) and canopy interception (C), as function on precipitation and graphical distribution of the regression residuals.

Corrêa *et al.* (2019) evaluating a stand of *Eucalyptus dunnii* in Alegrete, RS at 16.5 months of age observed that the precipitation was 1,586 mm, with 7% being intercepted by the canopy of the stand. The throughfall corresponded to 98% of the effective precipitation, the remaining 2% referring to stemflow. For the same species, Dick *et al.* (2018) studied a four-year-old stand and for the first year of assessment found that the throughfall was 91.08% (1,033.29 mm) and the stemflow 0.91% (10.40 mm). In the second year, the throughfall corresponded to 91.48% (1,497.46 mm) and the stemflow 1.28% (20.98 mm). The authors associated these results with the leaf area index of the stand, since the canopy cover allowed greater passage of rainfall.

For the same species, Dick *et al.* (2018) studying a four-year-old stand, the throughfall was 91.08% (1033 mm) and the stemflow was 0.91% (10.4 mm). In the second year, the same authors found that the throughfall corresponded to 91.48% (1497 mm) and the stemflow of 1.28% (21 mm). The authors associated these results with the leaf area index of the stand. The lower density of the canopy allowed the precipitation to reach the forest floor.

Other works developed with the genus *Eucalyptus* sp. has shown high correlations between variables. In a stand of *Eucalyptus dunni* aged between 1.4 and 2.4 years, Corrêa *et al.* (2019) found correlations between rainfall and throughfall, stemflow and canopy interception in the order of 0.99, 0.83 and 0.53%, respectively.

In a stand of *Eucalyptus grandis*, Balieiro *et al.* (2007) found a correlation of R = 0.99 for throughfall and R = 0.93 for stemflow. Supangat *et al.* (2012) found *E. pellita* coefficients of determination (R^2) of 0.99; 0.77 and 0.29 for throughfall, stemflow and canopy interception, respectively. Gasparoto *et al.* (2014) evaluated *Eucalyptus cloeziana* and found a linear adjustment of R = 0.90 in the relationship between rainfall and throughfall.

Studying the partition of rainfall in a stand of *E. dunni* at 6 years of age, Momolli (2019b) found adjustments of 0.99; 0.90 and 0.60 for throughfall, stemflow and canopy interception. Many factors are involved in the variability of the data, including the spacing of the trees, the degree of canopy closure and the spatial distribution of the collectors as possible factors (Xiao and McPherson 2011).

According to Momolli (2019b) the volume of precipitation is an important factor of variability. In the precipitation, the variation coefficient was 16% and 5% in the precipitation volumes below 20 mm and above 180 mm. For stemflow, the increase in the volume of precipitation from 0.5 mm to 1.7 mm resulted in a decrease from 60% to 20% in the variation coefficient. The author concludes that the increase in precipitation volumes decreases CV%.

4. CONCLUSION

The linear regression of the throughfall and stemflow as a function of the incident precipitation, presented adjustments of 97% and 72% without exclusion treatment and 97% and 55% in exclusion treatment. In addition, the analysis of the graphical distribution of the residues showed homogeneous behavior around the mean zero and without bias.

The regression model of throughfall and stemflow as a function of precipitation presented satisfactory adjustments. The higher leaf area index in the treatment excluding partial precipitation explains the greater canopy interception.

The treatment in which there is a 30% reduction in precipitation caused an increase from 12.3% to 17.2% in the interception of trees. This is attributed to the water-holding capacity of the canopy. This information is important because it can be used in projections of hydrological models during periods of the La Ninã phenomenon or even due to climate changes.

5. ACKNOWLEDGEMENTS

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil (CAPES) – Finance Code 001.

6. REFERENCES

ALMEIDA, A. Q.; RIBEIRO, A.; LEITE, F. P. Modelagem do balanço hídrico em microbacia cultivada com plantio comercial de *Eucalyptus grandis* x *Eucalyptus urophylla* no leste de Minas Gerais, Brasil. **Revista Árvore**, v. 37, n. 3, p. 547-556, 2013. https://doi.org/10.1590/S0100-67622013000300018

ALVARES, C. A. *et al.* Köppen's climate classification map for Brazil. **Meteorologische Zeitschrift**, v. 22, n. 6, p. 711-728, 2014. https://doi.org/10.1127/0941-2948/2013/0507

ARCOVA, F. C. S.; RANZINI, M.; CICCO, V. Partitioning of rainfall in experimental plantations of *Eucalyptus urophylla* and *Pinus elliottii*. **Floresta**, v. 48, n. 3, p. 383-392, 2018. http://dx.doi.org/10.5380/rf.v48i3.55492

BALIEIRO, F. C.; FRANCO, A. A.; FONTES, R. L. F.; DIAS, L. E.; CAMPELLO, E. F. C.; FARIA, S. M. Evaluation of the throughfall stemflow nutrient contents in mixed and pure plantations of *Acacia mangium*, *Pseudosamenea guachapele* and *Eucalyptus grandis*. **Revista Árvore**, v. 31, n. 2, p. 339-346, 2007. https://doi.org/10.1590/S0100-67622007000200017

BHAT, S.; JACOBS, J.; BRYANT, M. The chemical composition of rainfall and throughfall in five forest communities: A case study in Fort Benning, Georgia. **Water, Air, & Soil Pollution**, v. 218, p. 323-332, 2011. https://doi.org/10.1007/s11270-010-0644-1

BINKLEY, D.; CAMPOE, O. C.; ALVARES, C.; CARNEIRO, R. L.; CEGATTA, Í.; STAPE, J. L. The interactions of climate, spacing and genetics on clonal Eucalyptus plantations across Brazil and Uruguay. **Forest Ecology and Management**, v. 405, p. 271-283, 2017. https://doi.org/10.1016/j.foreco.2017.09.050

BOUILLET, J. P.; LACLAU, J. P.; ARNAUD, M.; M'BOU, A. T.; SAINT-ANDRÉ, L.; JOURDAN, C. Changes with age in the spatial distribution of roots of Eucalyptus clone in Congo. **Forest Ecology and Management**, v. 171, p. 43-57, 2002. https://doi.org/10.1016/S0378-1127(02)00460-7

BULCOCK, H. H.; JEWITT, G. P. W. Field data collection and analysis of canopy and litter interception in commercial forest plantations in the KwaZulu-Natal Midlands, South Africa. **Hydrology Earth System Science,** v. 16, n. 10, p. 3717-3728. 2012. https://doi.org/10.5194/hess-16-3717-2012

CHAFFE, P. L. B.; KOBIYAMA, M.; YAMASHIKI, K.; TAKARA, K. Is interception information important for rainfall runoff modeling? **Annual Journal of Hydraulic Engineering**, v. 54, p. 73-78, 2010.

CORRÊA, R. S.; SCHUMACHER, M. V.; MOMOLLI, D. R.; BERGER, C. Aspectos da precipitação pluviométrica em um povoamento jovem de *Eucalyptus dunnii* no Bioma Pampa. **Advances in Forestry Science,** v. 6, n. 3, p. 717-721, 2019. http://dx.doi.org/10.34062/afs.v6i3.7617

CROCKFORD, R. H.; RICHARDSON, D. P. Partitioning of rainfall into throughfall, stemflow and interception: effect of forest type, groundcover and climate. **Hydrological Processes**, v. 14, n. 16 -17, p. 2903 –2920, 2000. https://doi.org/10.1002/1099-1085(200011/12)14:16/17%3C2903::AID-HYP126%3E3.0.CO;2-6

DAWOE, E. K.; BARNES, V. R.; OPPONG, S. K. Spatio-temporal dynamics of gross rainfall partitioning and nutrient fluxes in shaded-cocoa (*Theobroma cacao*) systems in a tropical semi-deciduous forest. **Agroforestry System,** v. 92, p. 397–413, 2018. https://doi.org/10.1007/s10457-017-0108-3

DICK, G.; SCHUMACHER, M. V.; MOMOLLI, D. R.; VIERA, M. Nutrient input via incident rainfall in a *Eucalyptus dunnii* stand in the Pama Biome. **Floresta e Ambiente**, v. 25, n. 3, 2018. https://doi.org/10.1590/2179-8087.055916

FAN, J. L.; OESTERGAARD, K. T.; GUYOT, A.; JENSEN, D. G.; LOCKINGTON, D. A. Spatial variability of throughfall and stemflow in an exotic pine plantation of subtropical coastal Australia. **Hydrological Processes,** v. 29, p. 793-804, 2015. https://doi.org/10.1002/hyp.10193

FERRAZ, S. F. B.; RODRIGUES, C. B.; GARCIA, L. G.; ALVARES, C. A.; DE PAULA LIMA, W. Effects of Eucalyptus plantations on streamflow in Brazil: Moving beyond the water use debate. **Forest Ecology and Management**, v. 453, n. 117571, 2019. https://doi.org/10.1016/j.foreco.2019.117571

FLORES, T. B. *et al.* ***Eucalyptus* no Brasil**: zoneamento climático e guia para identificação. Piracicaba: IPEF, 2016. 448p.

GASPAROTO, E. A. G. *et al*. Throughfall in different forest stands of Iperó, São Paulo. **Cerne**, v. 20, n. 2, 2014. https://doi.org/10.1590/01047760.201420021260

GERRITS, A. M. J.; SAVENIJE, H. H. G. Interception. *In*: PETER, W. (ed.). **Treatise on Water Science**. Oxford: Academic Press. 2011. p. 89-101. https://doi.org/10.1016/B978-0-444-53199-5.00029-4

IBÁ. **Relatório anual 2019**: ano base 2018. Brasília; São Paulo, 2019. p. 80.

IBM Corp. **IBM SPSS Statistics for Windows**, Version 20.0. Armonk, NY, 2011.

JACKSON, R. B.; JOBBAGY, E. G.; AVISSAR, R.; ROY, S. B.; BARRET, D. J.; COOK, C. W.; MURRAY, B. C. Trading water for carbon with biological carbon sequestration. **Science**, v. 310, p. 1944-1947, 2005. https://dx.doi.org/10.1126/science.1119282

JOHNSON, M. S.; LEHMANN, J. Double-funneling of trees: Stemflow and root-induced preferential flow. **Ecoscience**, v. 13, p. 324-333, 2006. https://doi.org/10.2980/i1195-6860-13-3-324.1

LEVIA D. F.; KEIM, R. F.; CARLYLE-MOSES, D. E.; FROST, E. E. Throughfall and stemflow in wooded ecosystems. **Forest Hydrology and Biogeochemistry**: Synthesis of Past Research and Future Directions. Heidelberg: Springer-Verlag, 2010. (Ecological Series, 216). https://doi.org/10.1007/978-94-007-1363-5

LLORENS, P.; DOMINGO, F. Rainfall partitioning by vegetation under Mediterranean conditions: A review of studies in Europe. **Journal of Hydrology**, v. 335, p. 37-54, 2007. https://doi.org/10.1016/j.jhydrol.2006.10.032

LU, J.; ZHANG, S.; FANG, J.; YAN, H.; LI, J. Nutrient fluxes in rainfall, throughfall, and stemflow in Pinus densata natural forest of Tibetan Plateau. **Clean Soil Air Water**, v. 45, n. 1600008, 2017. https://doi.org/10.1002/clen.201600008

KEIM, R. F.; SKAUGSET, A. E.; WEILER, M. Storage of water on vegetation under simulated rainfall of varying intensity. **Advances in Water Resources**, v. 29, p. 974-986, 2006. https://doi.org/10.1016/j.advwatres.2005.07.017

MOMOLLI, D. R.; SCHUMACHER, M. V.; VIERA, M; LUDVICHAK, A. A.; GUIMARÃES, C. C.; SOUZA, H. P. Incident Precipitation Partitioning: The Canopy Interactions Enrich Water Solution with Nutrients in Throughfall and Stemflow. **Journal of Agricultural Science,** v. 11, n. 6, 2019a. https://doi.org/10.5539/jas.v11n6p351

MOMOLLI, D. R.; SCHUMACHER, M. V.; VIERA, M; LUDVICHAK, A. A.; GUIMARÃES, C. C.; SOUZA, H. P. Incident precipitation partitioning: throughfall, stemflow and canopy interception in *Eucalyptus dunnii* stand. **Journal of Agricultural Science,** v. 11, n. 5, 2019b. https://doi.org/10.5539/jas.v11n5p372

NAVAR, J.; GONZÁLEZ, J.M.; GONZALEZ, H. Gross precipitation and throughfall chemistry in legume species planted in Northeastern México. **Plant Soil,** v. 318, p. 15–26, 2009. https://doi.org/10.1007/s11104-008-9812-0

NAVAR, J. Stemflow variation in Mexico's northeastern forest communities: Its contribution to soil moisture content and aquifer recharge. **Journal of Hydrology**, v. 408, n. 1, p. 35-42, 2011. https://doi.org/10.1016/j.jhydrol.2011.07.006

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. Geneva: UNECE, 2006.

REICHERT, J. M.; RODRIGUES, M. F.; PELÁEZ, J. J. Z.; LANZA, R.; MINELLA, J. P. G.; ARNOLD, J. G.; CAVALCANTE, R. B.L. Water balance in paired watersheds with eucalyptus and degraded grassland in Pampa biome. **Agricultural and Forest Meteorology**, v. 237-238, p. 282-295, 2017. https://doi.org/10.1016/j.agrformet.2017.02.014

RODRÍGUEZ-SUÁREZ, J.; 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,** v. 28, n. 22, p. 5561-5572, 2014. https://doi.org/10.1002/hyp.10061

SAVENIJE, H. H. G. The importance of interception and why we should delete the term evapotranspiration from our vocabulary. **Hydrological Processes**, v. 18, n. 8, p. 1507-1511, 2004. https://doi.org/10.1002/hyp.5563

SCHRUMPF, M.; ZECH, W.; AXMACHER, J.; HERBERT V. M. LYARUU. Biogeochemistry of an Afrotropical Montane Rain Forest on Mt. Kilimanjaro, Tanzania. **Journal of Tropical Ecology**, v. 22, n. 1, p. 77-89, 2006. http://www.jstor.org/stable/4092145

SOUZA, H.; MOMOLLI, D.; LUDVICHAK, A.; SCHUMACHER, M.; MALHEIROS, A. Linear Regression of Incident Precipitation Explains the Throughfall, Stemflow and Interception by the Eucalyptus Canopy under Different Fertilization Management. **Journal of Experimental Agriculture International**, v. 33, n. 4, p. 1-11, 2019. https://doi.org/10.9734/jeai/2019/v33i430147

STAELENS, J.; DE SCHRIJVER, A.; VERHEYEN, K.; VERHOEST, N. E. C. Spatial variability and temporal stability of throughfall water under a dominant beech (*Fagus sylvatica* L.) tree in relationship to canopy cover. **Journal of Hydrology**, v. 330, p. 651-662, 2006. https://doi.org/10.1016/j.jhydrol.2006.04.032

SULÍNSKI, J.; STARZAK, R.; KUCZA, J. Weryfikacja wzoru wyra zajacego intercepcje drzew w zaleznosci od nate zenia i czasutrwania opadu deszczu w warunkach eksperymentalnych. **Acta Agraria et Silvestria**, v. 39, p. 3-16, 2001.

SUPANGAT, A. B. *et al.* Study of Rainfall Interception at *Eucalyptus pellita* Plantation Forest in Riau. **Agritech**, v. 32, n. 3, 2012.

XIAO, Q.; MCPHERSON, E. G. Rainfall interception of three trees in Oakland California. **Urban Ecosytems**, v. 14, p. 755-769, 2011. https://doi.org/10.1007/s11252-011-0192-5

ZHANG, Y.; WANG, X.; HU, R.; PAN, Y.; ZHANG, H. Stemflow in two xerophytic shrubs and its significance to soil water and nutrient enrichment. **Ecological Research**, v. 28, p. 567-579, 2013. https://doi.org/10.1007/s11284-013-1046-9

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,** v. 227, n. 6, p. 183, 2016. https://doi.org/10.1007/s11270-016-2878-z