

CARACTERÍSTICAS MORFOLÓGICAS DO CAULE E ESCOAMENTO PELO TRONCO EM FLORESTA DE TERRA FIRME NA AMAZÔNIA (AMAPÁ, BRASIL)

LORENA PIMENTEL PINHEIRO¹; VANDRESSA DANDARA ALMEIDA DAMASCENO¹; KELLY CRISTINA TONELLO²; CÉSAR DE OLIVEIRA FERREIRA SILVA³ E JULIETA BRAMORSKI¹

¹ *Department of Environment and Development. Federal University of Amapá, Rod. Josmar Chaves Pinto, km 02, Macapá, AP, 68903-419. email: lorenagarcezpinheiro@gmail.com; dandara7580@gmail.com; bramorski@gmail.com. ORCID (0009-0003-2355-7661; 0000-0003-3829-123X; 0009-0008-9146-1844).*

² *Department of Environmental Sciences, Federal University of São Carlos, Rod. João Leme dos Santos, s/n, Km 110, Sorocaba, SP, 18052-780. email: kellytonello@ufscar.br. ORCID (0000-0002-7920-6006).*

³ *Stormgeo, Avenida Mutinga, 4935, CEP 05110-903, São Paulo, SP, Brasil. email: cesar.of.silva@unesp.br. ORCID (0000-0002-5152-6497)*

1 RESUMO

O escoamento pelo tronco (ETr) constitui um componente da partição da precipitação e contribui para a redistribuição localizada da água no ambiente florestal. Este estudo avaliou a associação entre características morfológicas dos indivíduos, variáveis dendrométricas, umidade medida no tronco e volume de ETr em uma floresta de terra firme no Amapá, Brasil. Foram monitorados 52 indivíduos entre janeiro e setembro de 2023. O volume de ETr e as variáveis dendrométricas foram descritos, e as associações lineares foram exploradas pelo coeficiente de correlação de Pearson. A área da copa apresentou associação positiva com o volume total de ETr ($r = 0,371$), enquanto a área basal ($r = -0,305$) e o CAP ($r = -0,297$) apresentaram associações negativas. A umidade medida no tronco apresentou associação linear muito fraca com o ETr ($r = -0,039$). Na descrição por categorias de casca, indivíduos classificados como casca lisa apresentaram maior volume médio observado, seguidos por indivíduos com casca rugosa e escamosa. Esses padrões são descritivos e devem ser interpretados considerando a natureza observacional da amostra, a possível dependência entre observações e a ausência de testes formais de comparação entre grupos.

Palavras-chave: Hidrologia florestal; Partição da precipitação; Escoamento pelo tronco; Morfologia vegetal.

PINHEIRO, L. P.; DAMASCENO, V. D. A.; TONELLO, K. C.; SILVA, CÉSAR de O. F., BRAMORSKI, J.

STEM MORPHOLOGICAL CHARACTERISTICS AND STEMFLOW IN A TERRA FIRME FOREST IN THE AMAZON (AMAPÁ, BRAZIL)

2 ABSTRACT

Stemflow (ETr) is a component of rainfall partitioning that contributes to the localized redistribution of water in forest environments. In this study, associations between individual morphological traits, dendrometric variables, stem moisture readings and stemflow volume in

a terra firma forest in Amapá, Brazil, were evaluated. Fifty-two individuals were monitored from January to September 2023. Stemflow volume and dendrometric variables were described, and linear associations were explored using Pearson's correlation coefficient. Crown area was positively associated with total stemflow volume ($r = 0.371$), whereas basal area ($r = -0.305$) and circumference at breast height ($r = -0.297$) were negatively correlated. Stem moisture reading showed a very weak linear association with stemflow ($r = -0.039$). In the descriptive comparison by bark category, individuals classified as having smooth bark had the highest observed mean volume, followed by those classified as having rough and scaly bark. These patterns are descriptive and should be interpreted in light of the observational design, possible dependence among observations and the absence of formal tests comparing groups.

Keywords: Forest hydrology; Rainfall partitioning; Stemflow; Plant morphology.

3 INTRODUCTION

In forest environments, incident precipitation is redistributed by vegetation in different components, including interception losses, throughfall, and stemflow. Stemflow (ETr) concentrates water and, potentially, solutes at the base of individuals, resulting in a spatially heterogeneous distribution of precipitation on the soil (Levia; Germer, 2015; Carlyle-Moses *et al.*, 2018). ETr generation results from the interaction between rainfall event characteristics, crown area and architecture (Santos *et al.*, 2020), branch connectivity (Costa *et al.*, 2025), orientation of structural elements (Collet *et al.*, 2011), and trunk and bark surface properties (Germer; Werther; Elsenbeer, 2010). Intensity, duration, volume, and antecedent moisture conditions can alter the onset and magnitude of flow, whereas roughness, wettability, storage capacity, and slope can modify the continuity of flow paths (Levia; Germer, 2015; Metzger *et al.*, 2019; Tonello *et al.*, 2021a, 2021b).

The variables evaluated in this study represent distinct structural levels: precipitation and atmospheric humidity are variables of the event or environment; crown area and architecture represent the potential interception surface; DBH, height, basal area, and inclination describe the individual; and bark texture and moisture reading represent characteristics of the trunk surface

(Jana; Dasgupta; Todaria, 2021). Visual bark classification is a morphological indicator and does not, by itself, equate to a direct measure of roughness, absorption, or wettability (Keim; Tromp -Van Meerveld; McDonnell, 2006). The moisture measured in the trunk should be interpreted as the reading produced by the instrument used in the study (Balieiro *et al.*, 2023). It does not automatically represent the internal water status of the tree, which would require specific physiological variables (Zhong *et al.*, 2022). A more restricted hydrological hypothesis is that the antecedent condition of the surface (Zhang *et al.*, 2021) or the crust may be associated with storage capacity (Pinheiro; Ferreira, 2022) and the continuity of flow paths (Xia; Liu; Luo, 2023).

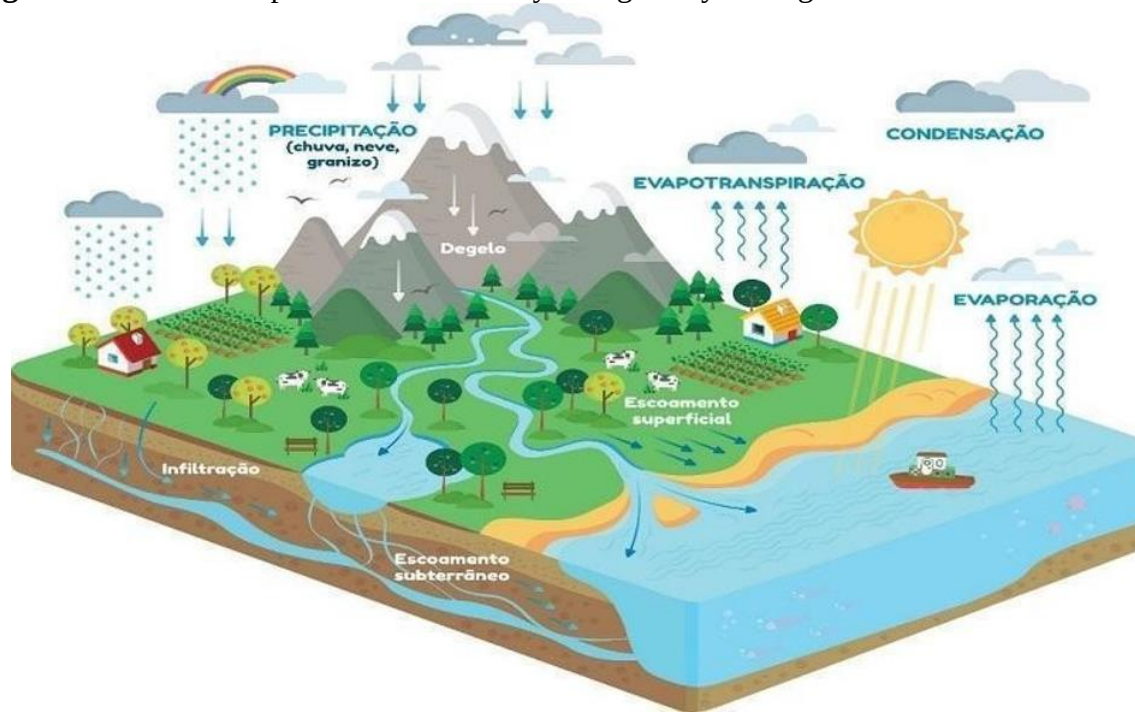
Although previous studies have linked ETr to canopy architecture, bark properties, and precipitation characteristics (Bredin *et al.*, 2020), assessments integrating dendrometric attributes, trunk texture and inclination, and a moisture measure in tropical upland forests of the Brazilian Amazon, particularly in Amapá, are still limited (De Lima; Tonello, 2023; Tonello *et al.*, 2021b). This gap is relevant because the direction and magnitude of the associations can vary across environments, individuals, and rainfall events.

Figure 1 presents a general representation of the hydrological cycle, while the present study focuses on the local

partitioning of precipitation and ETr (EPAL, 2023). The sampled area is located on the campus of the Federal University of Amapá

in Macapá, and the results should be interpreted on a local scale and within the monitored period.

Figure 1. Schematic representation of the hydrological cycle stages.



Source: EPAL (2023)

In the context of Amapá, terra firme forests offer a relevant environment for evaluating precipitation partitioning because of their heterogeneous structure and the occurrence of periods with different rainfall conditions (Balieiro *et al.*, 2023). Specific studies on the association between individual attributes and ETr in this region are still needed. The literature indicates that ETr can vary between individuals and morphological categories (Husch, Beers, Kershaw Junior, 2002; Levia, Frost, 2003; Wang *et al.*, 2008; Li *et al.*, 2009; Levia). *et al.*, 2010; Lorenzon, 2011; Wang *et al.*, 2011; Kunert *et al.*, 2019; Metzger *et al.*, 2019; Yin; Roderick, 2020; Moraes *et al.*, 2021; Pinos *et al.*, 2023) but also highlights the importance of controlling for or considering the characteristics of precipitation events (Tonello *et al.*, 2021a). Thus, differences in observed volume should not be interpreted as measures of efficiency

without a metric normalized by incident precipitation and, when pertinent, by canopy area (Almeida; Ferreira; Coudel, 2023).

ETr is a pathway for water transfer to the soil whose magnitude may be small in relation to total precipitation, although its spatial concentration may be relevant to the local distribution of water (Oliveira *et al.*, 2011). Quantifying the volume alone does not allow conclusions to be drawn about its effects on infiltration, soil moisture, or nutrient cycling (Levia; Germer, 2015; Pinos *et al.*, 2023). Physically, ETr results from the redistribution of precipitation by the canopy and branches, followed by the movement of water over the trunk (Reid; Lewis, 2009). Flow formation depends on rainfall characteristics; the connections between canopy elements; and the surface and geometric properties of the trunk, including storage, roughness, wettability, and inclination (Yang; Shao; Wei, 2019).

Among the individual attributes, crown area may represent a relatively large potential interception surface; DBH, height, and basal area describe size; inclination may alter the flow trajectory; and bark texture may be associated with the retention and continuity of runoff (Lima; Tonello, 2023). The observed associations may also reflect precipitation, atmospheric humidity, and other event conditions (Tonello *et al.*, 2021b). Therefore, interpretation must distinguish absolute ETr volume from relative measures, such as the proportion of precipitation converted to ETr (Almeida; Ferreira; Coudel, 2023).

The study was conducted in a specific area of upland forest on the campus of the Federal University of Amapá in Macapá. This local scale allows for the description of exploratory patterns at the site and during the evaluated period, without presupposing the representativeness of the entire Amazon. Despite advances in the literature, gaps remain regarding how dendrometric and morphological attributes are associated with ETr in the upland forests of Amapá, especially when the possible dependence between individuals, rainfall events, and bark categories is considered (Oliveira *et al.*, 2008). Investigating these associations can broaden the understanding of the local partitioning of precipitation

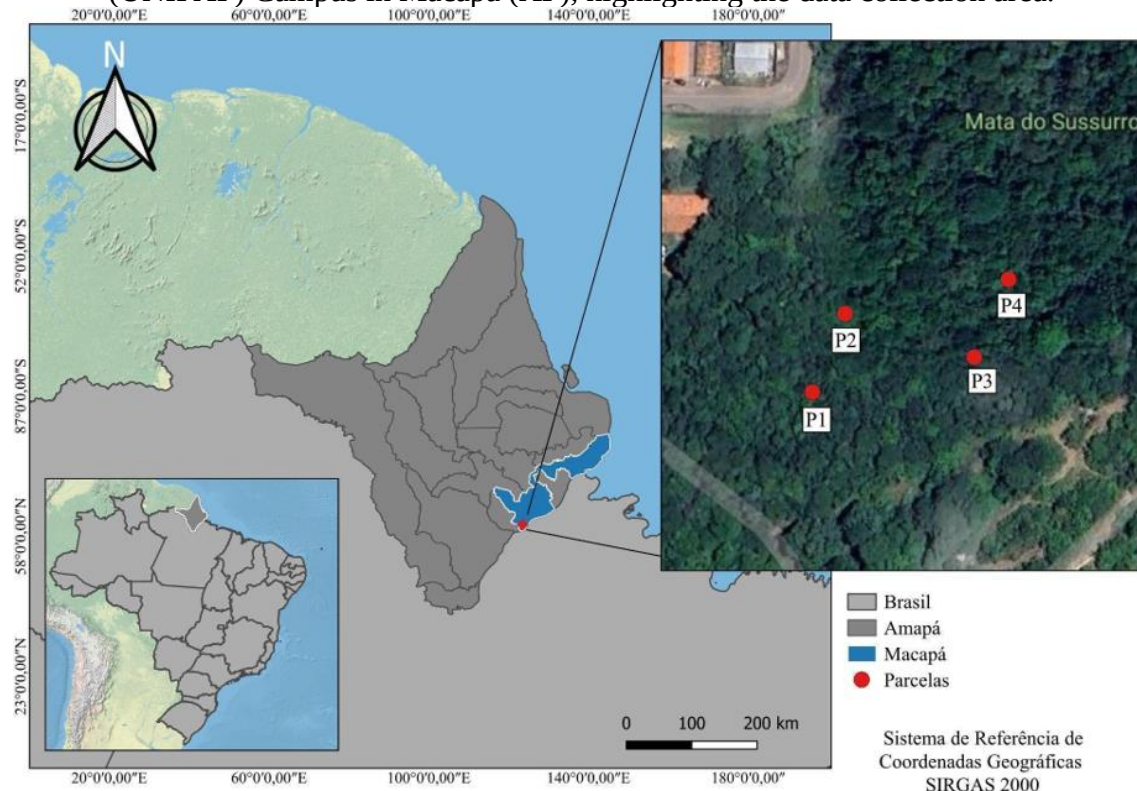
(Liang; Kosugi; Mizuyama, 2009), provided that the conclusions remain proportionate to the observational design and the bivariate analyses employed (Poudyal). *et al.*, 2004).

Thus, in this study, the associations between stem morphological characteristics, dendrometric variables, trunk moisture readings, and ETr volume in arboreal individuals from a terra firme forest in Amapá were evaluated. ETr volumes, observed differences between bark categories, and correlations between ETr and structural attributes were described. The exploratory hypothesis was that crown area would show a positive association with ETr volume, that size attributes could show linear associations with ETr, and that bark categories and inclination would be related to distinct patterns of observed volume.

4 MATERIALS AND METHODS

The research was conducted in plots of upland forestland (Figure 2) located on the Campus of the Federal University of Amapá (UNIFAP) in the municipality of Macapá. The campus is situated on the Josmar Chaves Pinto Highway, km 02, in the Marco Zero do Equador neighborhood and occupies an area of 906,722.44 m².

Figure 2. Map showing the location of the study area on the Federal University of Amapá (UNIFAP) Campus in Macapá (AP), highlighting the data collection area.



Source: Authors (2025)

Fifty-two individual trees were selected and monitored in plots of upland forestland.

The selection considered the presence of individuals with a DBH greater than 15 cm, the possibility of installing the collectors, and the variation observed in the morphology of the trunks and crowns (Lorenzon; Dias; Tonello, 2015).

Individual taxonomic identification and sample distribution by species are not included in the presented database and, therefore, were not used as analytical variables.

For each individual, dendrometric variables, including the circumference at breast height (CBH), height, basal area, and crown projection area, were measured.

The diameter at breast height (DBH) was obtained from the circumference at breast height (CBH), and the individual basal area was calculated from the DBH

(Yang *et al.*, 2017) according to the equation presented below.

$$DAP = \frac{CAP}{\pi} \quad (1)$$

From this value, the individual basal area was determined by the expression:

$$AB_i = \frac{\pi DAP_i^2}{4} \quad (2)$$

This procedure is widely used in forest inventories and constitutes a fundamental metric for estimating the density and productivity of forest formations (Husch; Beers; Kershaw Junior., 2002; Yang *et al.*, 2017). The crown area (A) was calculated from measurements of the projected branch length from the center of the trunk to the tip, taken in four orthogonal directions (90° to each other). These measurements were used to form four

triangles whose individual areas were determined by the following equation:

$$A_{triangulo} = \frac{a b \text{ sen}90}{2} \quad (3)$$

where a and b represent two consecutive projections of the tree canopy. Considering that the sine of 90° is equal to 1, the equation can be simplified to the following equation:

$$A_{triangulo} = \frac{a b}{2} \quad (4)$$

The total crown area (A) corresponded to the sum of the areas of the four triangles formed. This procedure is adopted in forest mensuration studies and structural crown analyses, aimed at estimating competition, solar radiation interception, and hydrological processes (Hernández Ramos; Reyes Hernández; Beltrán Rodríguez, 2022; Husch; Beers; Kershaw Junior, 2002). The morphological characterization of the trunk was performed by visual inspection, and the bark texture was classified as smooth, rough, or scaly

(Schober; Boer; Schwarte, 2018). The trunk conformation was recorded as erect or inclined. These classifications are observational morphological indicators and do not replace continuous measurements of roughness, inclination, absorption, or wettability.

Total precipitation and stemflow data were collected from January to September 2023. Observations were organized by collection period, and ETr volume was treated as an absolute response variable. Precipitation was quantified using a manual rain gauge installed in an open area without vegetation cover near the study area (Figure 3a). The equipment was made with PVC pipes and fittings, following models described in the literature (Borges *et al.*, 2011).

ETr was measured using collectors attached directly to the individuals (Figure 3b). The collectors were molded with expanding polyurethane foam around the trunk, directing the water to collection containers. The collected volume was measured in the field using a 1,000 mL graduated cylinder.

Figure 3. (a) Open-air precipitation (total) rain gauge; (b) trunk flow collector



Source: Authors (2025)

Readings of trunk moisture and relative air humidity were collected. For this purpose, a digital penetration moisture meter (Moisture Meter) was used for the trunk

(Figure 4a), and a TASI TA8171 digital thermohygrometer was used for relative humidity and air temperature (Figure 4b).

Figure 4. (a) Digital penetration moisture meter; (b) digital thermohygrometer (model TASI TA8171)



Source: Authors (2025)

Moisture readings were treated as an instrumental indicator of trunk health, without direct interpretation of the internal water content.

After collection, the data were tabulated in spreadsheets using Microsoft Excel. Pearson's correlation coefficient (r) was used to explore linear associations between ETr volume and quantitative variables. The coefficient ranges from -1 to $+1$ and describes the direction and intensity of the linear association. The analyses are bivariate and exploratory; no formal tests of comparisons between shell categories, p values, confidence intervals, treatment of dependence between repeated measures, or simultaneous control of precipitation event characteristics were presented.

5 RESULTS AND DISCUSSION

During the sampling period, precipitation and ETr volumes were recorded on a monthly scale. The conversion of these volumes into a percentage of total precipitation is not presented in this version because the calculation depends on the confirmation of the units, the reference area, and the statistical unit adopted (Van Stan II *et al.*, 2011). Synthesis studies indicate that ETr often represents a small fraction of

precipitation in forests, although it can concentrate water at the base of individuals (Levia; Germer, 2015; Carlyle-Moses *et al.*, 2018). The volume observed in this study should be interpreted as a measure of localized water transfer, without inferring subsequent effects on soil or vegetation (Goldstein *et al.*, 1998).

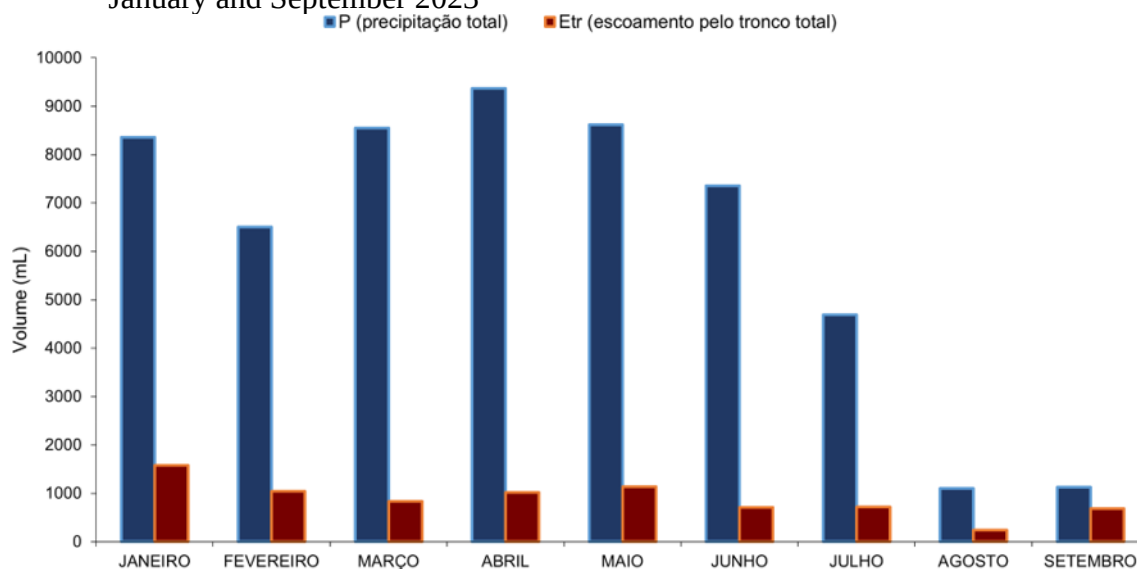
In Amazonian upland forests, the magnitude of ETr can vary with vegetation structure, precipitation characteristics, and local conditions. These sources of variation need to be considered together when interpreting the associations between individual attributes and ETr volume. Quantifying ETr allows us to describe its contribution to precipitation partitioning at the studied site. The relevance to nutrients, infiltration, soil moisture, or other ecological processes remains a hypothesis for studies that directly measure these responses. The results from other environments also show variations in ETr among trees and rainfall events. Comparisons between studies should consider differences in units, temporal scales, contributing areas, vegetation compositions, and collection protocols (Hernández-Ramos *et al.*, 2022).

ETr volumes varied from January to September. Quantitative comparisons between the two components require unit auditing and normalization calculations. ETr

can concentrate water near the base of the trunks, but the data presented do not allow quantification of the spatial distribution of

this water, infiltration, soil moisture, or nutrient flux. These consequences should be evaluated in specific studies.

Figure 5. Monthly variation in total precipitation volume (mL) and stemflow (mL) between January and September 2023



Source: Authors (2025)

The highest monthly precipitation volume was recorded in April 2023, with 9,375 mL, and the lowest was recorded in August, with 1,105 mL, according to the records presented. This variation describes the monitored period and is not sufficient by itself to characterize an annual seasonal cycle. The highest monthly ETr volume was observed in January, at 1,577 mL, while the lowest was recorded in August, at 241 mL. The relationships between these volumes and precipitation should be interpreted as descriptive temporal associations since the intensity, duration, and number of events were not analyzed separately. The monthly

variation is consistent with the possibility that the characteristics of the precipitation events contributed to the observed volumes; however, without data on intensity, duration, and antecedent rainfall, it is not possible to attribute the monthly differences to a single cause.

Table 1 presents the average monthly ETr volumes by bark category. Descriptively, individuals classified as having smooth bark presented the highest values in most months, followed by those classified as having rough bark and scaly bark.

Table 1. Monthly averages of stem flow (mL) between January and September 2023, considering different bark types (smooth, rough, and scaly).

Bark	Jan.	Feb.	sea.	Apr.	May.	June	July.	Aug.	set.
Rough	1,494	1.064	806	907	972	836	685	196	708
Lisa	2.123	1,469	1.149	1,596	1,631	824	1.055	495	577
Scaly	803	309	291	497	547	347	234	40	588

Source: Authors (2025)

Between January and March, the highest volumes were observed in all three categories, with the smooth bark category standing out in January and February. This pattern may reflect a combination of rainfall event characteristics and differences between sampled individuals. From April onward, the monthly volumes decreased in the presented categories, especially in the scaly bark category. As no formal test was performed between categories or between months, the description should not be interpreted as a statistically significant difference. Between June and August, the volumes were lower in all categories. The interpretation of these differences should consider recorded precipitation and the possibility that absolute volume, tree size, and crown area are confounded. In September, an increase was observed compared with that in August. This pattern may be related to the conditions of the period and rainfall events but does not allow us to conclude physiological reactivation, adaptation, or the effect of trunk moisture. In summary, the bark categories presented different average volumes, as shown in Table 1, with higher values for individuals classified as smooth bark. Without taxonomic identification, comparison tests,

and control of event variables, it is not possible to attribute this pattern exclusively to bark texture.

Tables 2 and 3 show the structural variation of the sample. This variation helps to contextualize the correlations presented in the following tables, which should be interpreted as bivariate associations and not as independent effects of the attributes. The sampled individuals showed variation in their dendrometric and morphological characteristics. The DBH ranged from 19.0 to 116 cm, the height ranged from 3.0 to 24.7 m, and the crown area ranged from 2.92 to 68.21 m², as shown in Tables 2 and 3.

These values describe heterogeneity among the individuals analyzed. The rough bark category was predominant, followed by the scaly and smooth categories. The categories are visual classifications and can group individuals with different physical surface properties and different taxonomic identities (Germer *et al.*, 2012). Most individuals were classified as upright, and a smaller portion were inclined. As inclination was recorded in categories, the table describes the observed conformations without quantifying the angle or testing its independent association with ETr (Ford *et al.*, 2004).

Table 2. Individual dendrometric and morphological characteristics and total trunk flow of 41 sampled individuals.

Individual	CAP (cm)	Height (m)	Basal (m ²)	Cup (m ²)	Type of Bark	Type of Stem	Et (mL)
1	78	8.0	0.05	43.5	Scaly	Erect	112
2	32	7.0	0.01	18.9	Rough	Slanted	637
3	30	6.5	0.01	16.1	Rough	Erect	2,300
4	30	6.5	0.01	6.2	Lisa	Erect	881
5	40	5.0	0.01	2.9	Lisa	Slanted	3,218
6	40	8.5	0.01	23.7	Rough	Erect	1,816
7	22	5.0	0.00	4.8	Rough	Slanted	687
8	19	5.0	0.00	11.1	Lisa	Slanted	3,062
9	42	4.2	0.01	9.0	Lisa	Slanted	968
10	58	7.5	0.03	5.5	Rough	Slanted	534
11	53	7.5	0.02	3.4	Rough	Slanted	362
12	45	7.5	0.02	3.4	Rough	Slanted	2,276
13	34	6.0	0.01	6.6	Rough	Slanted	1,058
14	34	6.5	0.01	9.0	Rough	Slanted	980
15	30	6.0	0.01	7.3	Rough	Erect	1,245
16	39	7.5	0.01	7.5	Rough	Erect	739
17	39	6.0	0.01	14.4	Rough	Erect	666
18	28	3.5	0.01	4.9	Rough	Erect	1,360
19	28	6.0	0.01	8.6	Rough	Erect	140
20	39	7.0	0.01	9.2	Rough	Erect	604
21	32	5.5	0.01	13.8	Rough	Erect	723
22	40	3.0	0.03	12.0	Rough	Erect	226
23	44	5.0	0.02	7.1	Rough	Erect	562
24	21	4.0	0.00	15.1	Lisa	Tilted	587
25	25	4.0	0.00	16.8	Rough	Erect	712
26	41	6.0	0.02	28.2	Rough	Tilted	380
27	49	4.0	0.02	9.3	Rough	Erect	362
28	61	12.3	0.03	11.8	Rough	Erect	1,175
29	63	10.6	0.03	16.8	Scaly	Erect	770
30	42	12.3	0.01	9.2	Rough	Erect	1,499
31	94	14.1	0.07	34.6	Scaly	Erect	246
32	44	12.3	0.02	11.1	Lisa	Tilted	2,558
33	51	12.3	0.02	14.7	Lisa	Erect	1,579
34	47	12.3	0.02	16.7	Lisa	Erect	2,803
35	116	15.9	0.11	18.3	Scaly	Erect	623
36	70	12.3	0.04	27.0	Rough	Tilted	154
37	57	8.8	0.03	10.8	Rough	Erect	352
38	95	15.9	0.07	31.1	Rough	Erect	443
39	40	14.1	0.01	5.7	Rough	Erect	875
40	45	12.3	0.02	5.7	Scaly	Erect	627
41	60	24.7	0.03	17.4	Rough	Erect	2,477

Source: Authors (2025)

Table 3. Characteristics of individual dendrometric and morphological measurements and total trunk flow of 11 sampled individuals

Individual	CAP (cm)	Height (m)	Basal (m ²)	Cup (m ²)	Type of Bark	Type of Stem	Et (mL)
42	66	15.9	0.03	14.5	Rough	Erect	709
43	94	10.6	0.07	68.2	Rough	Tilted	197
44	76	15.9	0.05	21.6	Rough	Tilted	228
45	60	15.9	0.03	12.3	Rough	Erect	1,760
46	47	14.1	0.02	19.7	Lisa	Erect	473
47	60	17.7	0.03	6.9	Rough	Erect	920
48	67	14.1	0.04	28.4	Lisa	Erect	830
49	40	14.1	0.01	37.8	Lisa	Erect	178
50	46	15.9	0.02	9.6	Lisa	Erect	90
51	60	15.9	0.03	15.3	Scaly	Tilted	91
52	65	17.7	0.03	51.0	Scaly	Slanted	220

Source: Authors (2025)

Table 4 presents the Pearson correlation coefficients between total trunk flow and the analyzed dendrometric

variables, including circumference at breast height, basal area, crown area, and trunk moisture.

Table 4. Monthly average stem flow (mL) between January and September 2023, considering different bark types (smooth, rough, and scaly)

	Area from the cup	Area basal	CAP	Humidity of Trunk
Total drainage	0.371	-0.305	-0.297	-0.039

Source: Authors (2025)

The crown area was positively associated with the total ETr volume ($r = 0.371$). This result is consistent with the possibility that a relatively large crown is associated with a relatively large potential interception surface, but the correlation does not allow us to distinguish absolute volume from efficiency or demonstrate a causal mechanism. The basal area ($r = -0.305$) and CBH ($r = -0.297$) were negatively associated with the ETr volume. As CBH and basal area describe related trunk dimensions, their coefficients should not be interpreted as independent evidence of distinct mechanisms (Sousa, 2017). The trunk moisture reading showed a very weak linear association with the ETr volume ($r = -0.039$). These results do not support inferences about internal storage, autoregulation, or physiological water

conduction. The weak association may reflect the nature of the measurement, precipitation, and the time of the reading, among other possibilities that require further investigation. Taken together, the results indicate associations of different magnitudes between structural attributes and the ETr volume. Crown area was positively correlated, DBH and basal area were negatively correlated, and moisture readings were weakly correlated. The absence of p values and confidence intervals limits the assessment of the precision and statistical significance of these coefficients (Carlyle-Moses *et al.*, 2018).

Table 5 presents the Pearson correlation coefficients between stemflow and the dendrometric variables, considering the different morphological characteristics of the bark.

Table 5. Pearson correlation coefficients between the dendrometric variables and stem flow (mL) according to different bark types (smooth, rough and scaly)

Correlation	Bark rough	Bark scaly	Bark Lisa
ETr x CAP	-0.216	0.011	-0.358
ETr x Area basal	-0.514	0.127	0.044
ETr x Area from the cup	-0.424	-0.522	-0.407
ETr x Height	0.441	-0.706	-0.093
ETr x Humidity from the bark	0.409	-0.113	-0.419

Source: Authors (2025)

The correlations by bark category presented in Table 5 were calculated separately and should be interpreted as exploratory associations. The differences between the coefficients do not, by themselves, demonstrate that the categories differ statistically. In the rough bark category, negative correlations were observed with basal area ($r = -0.514$), DBH ($r = -0.216$), and crown area ($r = -0.424$), and positive correlations were observed with height ($r = 0.441$) and moisture content ($r = 0.409$). These coefficients describe the pattern of the subsample and do not allow the ETr volume to be attributed to the bark texture.

The associations observed in the rough category may result from a combination of size, crown, precipitation, and unmeasured characteristics. Moisture readings should also not be interpreted as a direct measure of internal storage or conduction efficiency. In the scaly category, stronger negative associations were observed between ETr and height ($r = -0.706$) and between ETr and crown area ($r = -0.522$). These results may reflect the specific composition of the subsample, the number of individuals, and the combined influence of structural and precipitation variables. DBH ($r = 0.011$), basal area ($r = 0.127$), and moisture reading ($r = -0.113$) showed associations close to zero in this category.

In the smooth category, negative associations were observed between ETr and crown area ($r = -0.407$), DBH ($r = -0.358$), height ($r = -0.093$), and moisture reading ($r = -0.419$). These coefficients describe the subsample and do not demonstrate greater conduction efficiency. The negative association with moisture readings may be compatible with different explanations, including instrument characteristics, measurement time, antecedent precipitation, and nonlinear relationships. The available data do not allow us to select a mechanism among these possibilities.

The magnitude and direction of the correlations varied among the categories. This variation may reflect differences in sample composition, crown structure, size, and rainfall event conditions, as well as the visual classification of the bark itself. Thus, the tables describe patterns of association between morphological categories and ETr volume. Interpreting the bark as a determinant of the process or as responsible for nutrient fluxes requires further analysis and measurements.

The correlation coefficients between stemflow and the dendrometric variables for the different types of trunks are presented in Table 6. The interaction between trunk geometry and bark properties may be relevant to flow, but it was not tested in this study. This possibility should be presented as a hypothesis, without treating it as a demonstrated mechanism.

Table 6. Pearson correlation coefficients between the dendrometric variables and trunk flow (mL) considering different trunk conformations (erect and inclined).

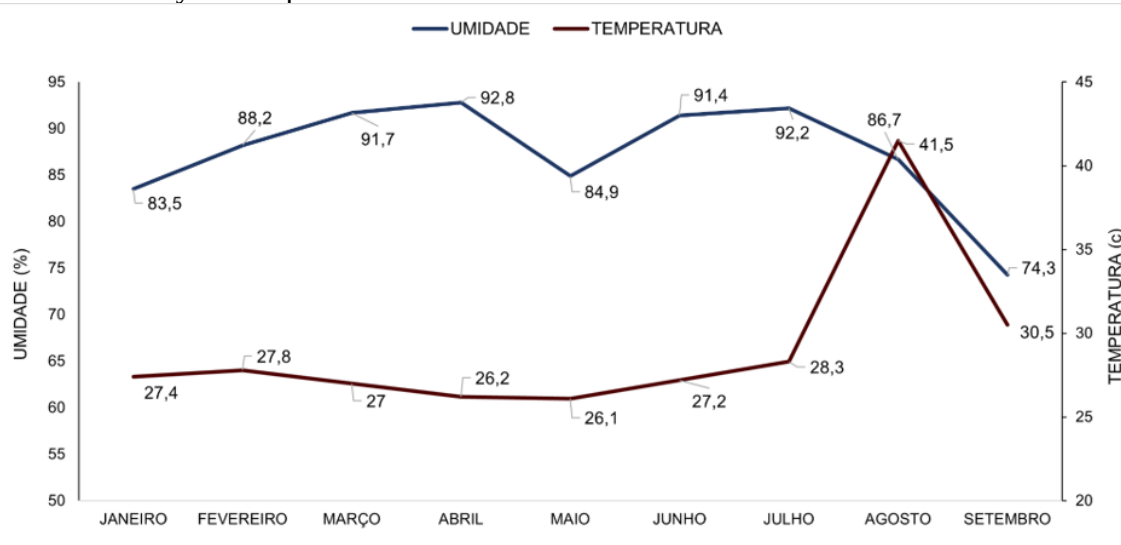
Correlation	Bark rough	Bark scaly
ETr x CAP	-0.170	-0.472
ETr x Basal area	-0.234	-0.529
ETr x Area of the canopy	-0.252	-0.439
ETr x Height	0.325	-0.212
ETr x Shell moisture	0.060	-0.000

Source: Authors (2025)

In Table 6, the coefficients presented for the indicated categories show predominantly weak associations between ETr and the dendrometric variables. Since the correspondence between the table headings and the trunk conformation categories needs to be confirmed, the values should not be interpreted as a validated comparison between erect and inclined trunks. Among the coefficients presented, the association with moisture reading was close to zero (0.060 in one category and -0.000 in another). The values for DBH, basal area, crown area, and height should also be read as associations within the reported categories, without causal conclusion or inference of significance. Inclination may alter the surface trajectory of water, but the

table and the available method do not allow for independent evaluation of this mechanism. This interpretation should remain a hypothesis for studies that measure the angle and control for precipitation, crown, size, and taxonomic identity.

The monthly variations in relative air humidity (%) and temperature (°C) in a terra firme forest area from January to September 2023 are shown in Figure 6. In general, the results indicate distinct associations between ETr volume and structural attributes in the analyzed categories. The magnitude of these associations is variable, and the absence of formal tests, p values, confidence intervals, and repeated measures limits the strength of the conclusions.

Figure 6. Monthly variations in relative air humidity (%) and air temperature (°C) between January and September 2023

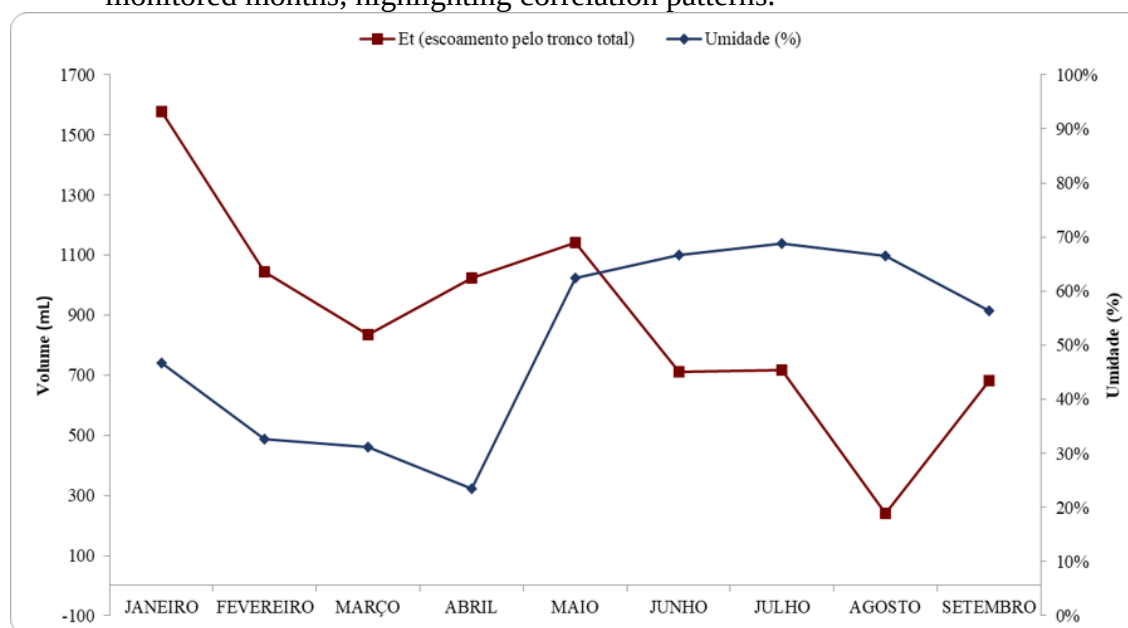
Source: Authors (2025)

The relative air humidity was high during part of the monitored period, while the temperature varied between months. These observations describe the recorded atmospheric conditions and do not, in isolation, allow the establishment of a causal relationship with ETr. The temperature remained relatively stable between January and July, with a maximum recorded temperature of 41.5 °C in August. This value differs from the range observed in other months and should be verified regarding the sensor, shelter, time of day, and number of observations before receiving an ecological interpretation. The inverse relationship between temperature and relative humidity observed throughout the months is a

description of the presented series. Characterizing seasonality would require a complete annual period and an appropriate temporal analysis. Atmospheric conditions may follow the variation in precipitation and ETr, but the available data do not allow for separation of their effects. Physiological processes such as sap flow, water potential, or internal storage were not evaluated.

The monthly variations in stem moisture and ETr volume are shown in Figure 7. The relationship between the series should be described as a temporal pattern, not as an inversely proportional relationship, until the coefficients per period are presented.

Figure 7. Relationships between trunk moisture (%) and trunk flow volume (mL) during the monitored months, highlighting correlation patterns.



Source: Authors (2025)

The monthly ETr and moisture readings varied throughout the monitored period. The overall correlation between moisture readings and ETr was very weak ($r = -0.039$), although associations during specific periods could be investigated in future analyses. From February onward, the monthly volume of ETr decreased, whereas the moisture readings varied throughout the

months. This pattern may reflect precipitation and the timing of measurements and does not allow for inferences about internal storage or physiological response. From May onward, the moisture readings increased, whereas the ETr remained lower in some months. The divergence between the series reinforces the need to distinguish instrumental stem cell

readings from physiological variables and to consider intensity, duration, and antecedent precipitation. The literature describes ETr as a component of precipitation partitioning and as a potential pathway for localized water transfer. In the present study, this interpretation should remain limited to the

6 CONCLUSIONS

Under the environmental, sampling, and temporal conditions of this study, the volume of ETr varied between individuals and the months monitored. The percentage of ETr in relation to total precipitation is not maintained in this version because it depends on the confirmation of the units, the reference area, and the corresponding calculation.

Individuals belonging to different bark texture categories presented different average observed volumes, with higher values for the smooth category. This description does not demonstrate that bark texture is a determining factor, especially since taxonomic identity was not recorded and no formal comparison tests were presented.

Crown area was positively associated with ETr ($r = 0.371$), whereas DBH ($r = -0.297$) and basal area ($r = -0.305$) were negatively correlated. Trunk moisture reading showed a weak linear association with ETr ($r = -0.039$), not providing sufficient evidence to support a direct relationship between these variables under the evaluated conditions.

The observed associations should be interpreted in conjunction with the characteristics of the precipitation events. This study has several limitations, including the absence of individual taxonomic identification, the predominant use of simple correlations, the possible dependence between repeated observations on the same individual, the absence of formal tests

measured volume, without extrapolation to infiltration, nutrients, or the ecosystem's water balance. The increase in ETr in September should be interpreted in conjunction with the precipitation conditions of the period.

between groups, and the measurement of precipitation at a single point.

Future research should expand sampling; identify individuals taxonomically; record intensity, duration, and antecedent precipitation; quantify bark and crown properties; evaluate rainfall-normalized measures; and utilize multivariate or mixed-effects models. It can also be used to investigate soil moisture, sap flow, and nutrients associated with ETr.

7 REFERENCES

- ALMEIDA, Á. S.; FERREIRA, JN; COUDEL, ES. Perception of ecosystem services by family farmers in the municipality of Irituia/PA, Eastern Amazon: subsidies for forest restoration. **Development and Environment**, Curitiba, v. 62, p. 1423-1438, 2023. DOI: <https://doi.org/10.5380/dma.v62i0.84539>. Available at: <https://revistas.ufpr.br/made/article/view/84539>. Accessed on: August 24, 2025.
- BALIEIRO, RMF; TONELLO, KC; DA COSTA NETO, SV; BRAMORSKI, J. Influence of dendrometric and morphological characteristics on stemflow in a forest-savanna transition area in the Brazilian Amazon. **Journal of Tropical Forest Science**, Kuala Lumpur, vol. 33, no. 3, p. 368-377, 2021. DOI: <https://doi.org/10.26525/jtfs2021.33.3.368>. Available at: <https://jtfs.frim.gov.my/jtfs/article/view/63>. Accessed on: 24 Aug. 2025.

BORGES, EBM; PINA, NVM; NASCIMENTO, CF; LATUF, MO. **Construction and calibration of an alternative rain gauge as a subsidy to precipitation measurement.** 2011.

Undergraduate Thesis (Geography) – Federal University of Bahia, Barreiras, 2011. Available at: https://d1wqtxts1xzle7.cloudfront.net/74221524/Confeco_e_calibrao_de_pluviometro_alterna20211105-11984-wed7hm.pdf. Accessed on: August 10, 2025.

BREDIN, Y.K.; HAWES, J.E.; PERES, CA; HAUGAASEN, T. Structure and composition of terra firma and seasonally flooded floodplain forests in the Western Brazilian Amazon. **Forests**, Basel, vol. 11, no. 12, art. 1361, 2020. DOI: <https://doi.org/10.3390/f11121361>. Available at: <https://www.mdpi.com/1999-4907/11/12/1361>. Accessed Published on: August 24, 2025.

CARLYLE-MOSES, DE; IIDA, SI; GERMER, S.; LLORENS, P.; MICHALZIK, B.; NANKO, K.; TISCHER, A.; LEVIA, DF. Expressing stemflow commensurate with its ecohydrological importance. **Advances in Water Resources**, Amsterdam, v. 121, p. 472-479, 2018. DOI: <https://doi.org/10.1016/j.advwatres.2018.08.015>. Available at: <https://www.sciencedirect.com/science/article/pii/S030917081830602X>. Accessed Published on: August 24, 2025.

COLLET, C.; FOURNIER, M.; NINGRE, F.; HOUNZANDJI, API; CONSTANT, T. Growth and posture control strategies in *Fagus sylvatica* and *Acer pseudoplatanus* saplings in response to canopy disturbance. **Annals of Botany**, Oxford, vol. 107, no. 8, p. 1345-1353, 2011. DOI: <https://doi.org/10.1093/aob/mcr058>. Available at: <https://academic.oup.com/aob/article/107/8/1345/210083>. Accessed on: 24 Aug. 2025.

COSTA, JDM da; BARNI, PE; SOTTA, ED; CARIM, M. de JV; CUNHA, AC da; GUEDES, MC; APARICIO, P. da S.; OLIVEIRA, LL de; BARBOSA, RI; FEARNside, PM; NASCIMENTO, HEM; TOLEDO, JJ de. Dense forests in the Brazilian State of Amapá store the highest biomass in the Amazon Basin. **Sustainability**, Basel, v. 17, n. 12, art. 5310, 2025. DOI: <https://doi.org/10.3390/su17125310>. Available at: <https://www.mdpi.com/2071-1050/17/12/5310>. Accessed on: August 24, 2025.

EPAL. **Water cycle**. [S. l.]: Grupo Águas de Portugal, 2023. Available at: <https://www.epal.pt/EPAL/menu/epal/comunicacao%20C3%A7%C3%A3o-ambiental/ciclod-da-%20C3%A1gua>. Accessed Published: September 20, 2025.

FORD, CR; GORANSON, CE; MITCHELL, RJ; WILL, RE; TESKEY, RO. Diurnal and seasonal variability in the radial distribution of sap flow: predicting total stem flow in *Pinus taeda* trees. **Tree Physiology**, Victoria, vol. 24, no. 9, p. 951-960, 2004. DOI: <https://doi.org/10.1093/treephys/24.9.951>. Available at: <https://academic.oup.com/treephys/article/24/9/951/1644080>. Accessed on: 24 Aug. 2025.

- GERMER, S.; WERTHER, L.; ELSENBEER, H. Have we underestimated stemflow? Lessons from an open tropical rainforest. **Journal of Hydrology**, Amsterdam, v. 395, n. 3-4, p. 169-179, 2010. DOI: <https://doi.org/10.1016/j.jhydrol.2010.10.022>. Available at: <https://www.sciencedirect.com/science/article/pii/S0022169410006384>. Access Published on: August 24, 2025.
- GERMER, S.; ZIMMERMANN, A.; NEILL, C.; KRUSCHE, AV; ELSENBEER, H. Disproportionate single-species contribution to canopy-soil nutrient flux in an Amazonian rainforest. **Forest Ecology and Management**, Amsterdam, v. 267, p. 40-49, 2012. DOI: <https://doi.org/10.1016/j.foreco.2011.11.041>. Available at: <https://www.sciencedirect.com/science/article/pii/S0378112711007262>. Access Published on: August 24, 2025.
- GOLDSTEIN, G.; ANDRADE, JL; MEINZER, FC; HOLBROOK, N.M.; CAVELIER, J.; JACKSON, P.; CELIS, A. Stem water storage and diurnal patterns of water use in tropical forest canopy trees. **Plant, Cell & Environment**, Oxford, vol. 21, no. 4, p. 397-406, 1998. DOI: <https://doi.org/10.1046/j.1365-3040.1998.00273.x>. Available at: <https://onlinelibrary.wiley.com/doi/10.1046/j.1365-3040.1998.00273.x>. Accessed on: 24 Aug. 2025.
- HERNÁNDEZ-RAMOS, J.; REYES-HERNÁNDEZ, VJ; BELTRÁN-RODRÍGUEZ, L. The canopy as a relevant photosynthetic indicator in el forestry management of temperate forests. **Mexican Science Magazine Forestales**, Mexico City, v. 13, n. 74, p. 4-33, 2022. DOI: <https://doi.org/10.29298/rmcf.v13i74.1267>. Available at: <https://cienciasforestales.inifap.gob.mx/index.php/forestales/article/view/1267>. Accessed Published on: August 24, 2025.
- HUSCH, B.; BEERS, TW; KERSHAW JUNIOR., JA **Forest measurement**. 4th ed. Hoboken: John Wiley & Sons, 2002.
- JANA, P.; DASGUPTA, S.; TODARIA, NP Throughfall and stemflow nutrient flux in deodar and oak forests, Garhwal Himalaya, India. **Water Supply**, London, vol. 21, no. 4, p. 1649-1656, 2021. DOI: <https://doi.org/10.2166/ws.2021.009>. Available at: <https://iwaponline.com/ws/article/21/4/1649/78693/Throughfall-and-stemflow-nutrient-flux-in-deodar>. Access Published on: August 24, 2025.
- KEIM, RF; TROMP-VAN MEERVELD, HJ; MCDONNELL, JJ A virtual experiment on the effects of evaporation and intensity smoothing by canopy interception on subsurface stormflow generation. **Journal of Hydrology**, Amsterdam, v. 327, no. 3-4, p. 352-364, 2006. DOI: <https://doi.org/10.1016/j.jhydrol.2005.11.024>. Available at: <https://www.sciencedirect.com/science/article/pii/S0022169405006207>. Access Published on: August 24, 2025.

- KUNERT, N.; APARECIDO, LMT; WOLFF, S.; HIGUCHI, N.; SANTOS, J. dos; ARAUJO, AC de; TRUMBORE, S. A revised hydrological model for the Central Amazon: the importance of emergent canopy trees in the forest water budget. **Agricultural and Forest Meteorology**, Amsterdam, v. 239, p. 47-57, 2017. DOI: <https://doi.org/10.1016/j.agrformet.2017.03.002>. Available at: <https://www.sciencedirect.com/science/article/pii/S0168192317300825>. Accessed Published on: August 24, 2025.
- LEVIA, DF; FROST, EE A review and evaluation of stemflow literature in the hydrologic and biogeochemical cycles of forested and agricultural ecosystems. **Journal of Hydrology**, Amsterdam, v. 274, no. 1-4, p. 1-29, 2003. DOI: [https://doi.org/10.1016/S0022-1694\(02\)00399-2](https://doi.org/10.1016/S0022-1694(02)00399-2). Available at: <https://www.sciencedirect.com/science/article/pii/S0022169402003992>. Access Published on: August 24, 2025.
- LEVIA, DF; GERMER, S. A review of stemflow generation dynamics and stemflow-environment interactions in forests and shrublands. **Reviews of Geophysics**, Washington, DC, vol. 53, no. 3, p. 673-714, 2015. DOI: <https://doi.org/10.1002/2015RG000479>. Available at: <https://agupubs.onlinelibrary.wiley.com/doi/10.1002/2015RG000479>. Accessed on: 24 Aug. 2025.
- LEVIA, DF; VAN STAN II, JT; MAGE, SM; KELLEY-HAUSKE, PW Temporal variability of stemflow volume in a beech-yellow poplar forest in relation to tree species and size. **Journal of Hydrology**, Amsterdam, v. 380, no. 1-2, p. 112-120, 2010. DOI: <https://doi.org/10.1016/j.jhydrol.2009.10.028>. Available at: <https://www.sciencedirect.com/science/article/pii/S0022169409006878>. Access Published on: August 24, 2025.
- LI, X.-Y.; YANG, Z.-P.; LI, Y.-T.; LIN, H. Connecting ecohydrology and hydrogeology in desert shrubs: stemflow as a source of preferential flow in soils. **Hydrology and Earth System Sciences**, Göttingen, vol. 13, no. 7, p. 1133-1144, 2009. DOI: <https://doi.org/10.5194/hess-13-1133-2009>. Available at: <https://hess.copernicus.org/articles/13/1133/2009/>. Accessed on: 24 Aug. 2025.
- LIANG, W.-L.; KOSUGI, K.; MIZUYAMA, T. Characteristics of stemflow for tall stewartia (*Stewartia monadelphica*) growing on a hillslope. **Journal of Hydrology**, Amsterdam, v. 378, no. 1-2, p. 168-178, 2009. DOI: <https://doi.org/10.1016/j.jhydrol.2009.09.027>. Available at: <https://www.sciencedirect.com/science/article/pii/S0022169409005903>. Access Published on: August 24, 2025.
- LIMA, JA de; TONELLO, KC Rainfall partitioning in Amazon Forest: implications of reduced impact logging for hydrological processes. **Agricultural and Forest Meteorology**, Amsterdam, v. 337, art. 109505, 2023. DOI: <https://doi.org/10.1016/j.agrformet.2023.109505>. Available at: <https://www.sciencedirect.com/science/article/pii/S016819232300196X>. Accessed on: 24 Aug. 2025.

LORENZON, AS. **Hydrological processes in a fragment of Semideciduous Seasonal Forest in the municipality of Viçosa, MG**. 2011. Dissertation (Master's in Forest Science) - Federal University of Viçosa, Viçosa, MG, 2011. Available at: <https://poscienciaflorestal.ufv.br/wp-content/uploads/2023/05/Alexandre-Simoes-Lorenzon1.pdf>. Accessed on: October 26, 2025.

LORENZON, AS; DIAS, HCT; TONELLO, KC. Trunk runoff in a semideciduous seasonal forest. **Revista Árvore**, Viçosa, v. 39, n. 3, p. 423-430, 2015. DOI: <https://doi.org/10.1590/0100-67622015000300002>. Available at: <https://www.scielo.br/j/rarv/>. Accessed on: August 24, 2025.

METZGER, JC; SCHUMACHER, J.; LANGE, M.; HILDEBRANDT, A. Neighborhood and stand structure affect stemflow generation in a heterogeneous deciduous temperate forest. **Hydrology and Earth System Sciences**, Göttingen, vol. 23, no. 11, p. 4433-4452, 2019. DOI: <https://doi.org/10.5194/hess-23-4433-2019>. Available at: <https://hess.copernicus.org/articles/23/4433/2019/>. Accessed on: 24 Aug. 2025.

MORAIS, YYGA; FREIRE, FJ; LIMA, RB de A.; ASSUNÇÃO, EA de A.; LEÃO, SLM; RALPH, LN Stemflow Nutrient input in trees in a tropical forest in Pernambuco, Brazil. **Floresta**, Curitiba, v. 51, n. 3, p. 604-613, 2021. DOI: <https://doi.org/10.5380/rf.v51i3.71464>. Available at: <https://revistas.ufpr.br/floresta/article/view/71464>. Accessed on: August 24, 2025.

OLIVEIRA, LL de; COSTA, RF da ; SOUSA, F. de AS de; COSTA, ACL da ; BRAGA, AP. Effective precipitation and interception in Caxiuanã , in Eastern Amazonia. **Acta Amazonica**, Manaus, v. 38, n. 4, p. 723-732, 2008. DOI: <https://doi.org/10.1590/S0044-59672008000400016>. Available at: <https://www.scielo.br/j/aa/a/FwK3KGGJX45CW8VY9KzdMbr/>. Accessed on: August 24, 2025.

OLIVEIRA, LL; CUNHA, AC; COSTA, ACL; COSTA, RF. Seasonality and rainfall interception in the Caxiuanã National Forest - Eastern Amazon. **Scientia Plena**, Aracaju, v. 7, n. 10, p. 1-14, 2011. Available at: <https://scientiaplenu.emnuvens.com.br/sp/article/download/283/208/0>. Accessed on: August 24, 2025.

PINHEIRO, MS; FERREIRA, LV. Effect of topography on floristics in a terra firme forest in Eastern Amazonia. **Nature and Conservation**, Aracaju, v. 15, n. 3, p. 17-28, 2022. DOI: <https://doi.org/10.6008/CBPC2318-2881.2022.003.0002>. Available at: <https://natureandconservation.com/index.php/nature/article/view/7484>. Accessed on: August 24, 2025.

PINOS, J.; FLURY, M.; LATRON, J.; LLORENS, P. Routing stemflow water through the soil via preferential flow: a dual-labeling approach with artificial tracers. **Hydrology and Earth System Sciences**, Göttingen, vol. 27, no. 15, p. 2865-2881, 2023. DOI: <https://doi.org/10.5194/hess-27-2865-2023>. Available at: <https://hess.copernicus.org/articles/27/2865/2023/>. Accessed on: 24 Aug. 2025.

POUDYAL, K.; JHA, PK; ZOBEL, DB; THAPA, CB Patterns of leaf conductance and water potential of five Himalayan tree species. **Tree Physiology**, Victoria, vol. 24, no. 6, p. 689-699, 2004. DOI: <https://doi.org/10.1093/treephys/24.6.689>. Available at: <https://academic.oup.com/treephys/article/24/6/689/1660465>. Accessed on: 24 Aug. 2025.

REID, L.M.; LEWIS, J. Rates, timing, and mechanisms of rainfall interception loss in a coastal redwood forest. **Journal of Hydrology**, Amsterdam, v. 375, no. 3/4, p. 459-470, 2009. DOI: <https://doi.org/10.1016/j.jhydrol.2009.06.048>. Available at: <https://www.sciencedirect.com/science/article/pii/S0022169409003850>. Accessed on: 24 Aug. 2025.

SANTOS, RO dos; LIMA, RB de; SOARES, RN; DANTAS, BS; BRITO, AC de; CORDEIRO, MV; ABREU, JC de; SILVA, BM da S. e. Influence of the soil on the spatial structure of forest species: preliminary results in a terra firma secondary forest Plot, Amapá, Brazil. **Southern Forests: a Journal of Forest Science**, Grahamstown, v. 82, n. 2, p. 179-195, 2020. DOI: <https://doi.org/10.2989/20702620.2020.1759294>. Available at: <https://www.tandfonline.com/doi/abs/10.2989/20702620.2020.1759294>. Accessed Published on: August 24, 2025.

SCHOBER, P.; BOER, C.; SCHWARTE, LA. Correlation coefficients: appropriate use and interpretation. **Anesthesia & Analgesia**, Baltimore, v. 126, n. 5, p. 1763-1768, 2018. DOI: <https://doi.org/10.1213/ANE.0000000000002864>. Available at: https://journals.lww.com/anesthesia-analgesia/fulltext/2018/05000/correlation_coefficients_appropriate_use_and.50.aspx. Accessed on: August 24, 2025.

SOUSA, RR de. Low-cost rain gauge and rainfall variation in the municipality of Barra do Garças-MT (October 2015 to April 2016). **InterEspaço: Journal of Geography and Interdisciplinarity**, São Luís, v. 3, n. 8, p. 107-125, 2017. DOI: <https://doi.org/10.18764/2446-6549.v3n8p107-125>. Available at: <https://periodicoseletronicos.ufma.br/index.php/interespaco/article/download/6379/4558/22329>. Accessed Published on: August 24, 2025.

TONELLO, KC; CAMPOS, SD; MENEZES, AJ; BRAMORSKI, J.; MATHIAS, SL; LIMA, MT How is bark absorbability and wettability related to stemflow yield? Observations from isolated trees in the Brazilian Cerrado. **Frontiers in Forests and Global Change**, Lausanne, v. 4, art. 650665, 2021a. DOI: <https://doi.org/10.3389/ffgc.2021.650665>. Available at: <https://www.frontiersin.org/journals/forests-and-global-change/articles/10.3389/ffgc.2021.650665/full>. Access Published on: August 24, 2025.

- TONELLO, KC; VAN STAN II, JT; ROSA, AG; BALBINOT, L.; PEREIRA, LC; BRAMORSKI, J. Stemflow variability across tree stem and canopy traits in the Brazilian Cerrado. **Agricultural and Forest Meteorology**, Amsterdam, v. 308-309, art. 108551, 2021b. DOI: <https://doi.org/10.1016/j.agrformet.2021.108551>. Available at: <https://www.sciencedirect.com/science/article/pii/S0168192321002355>. Access Published on: August 24, 2025.
- VAN STAN II, JT; SIEGERT, CM; LEVIA JUNIOR., DF; SCHEICK, CE Effects of wind-driven rainfall on stemflow generation between codominant tree species with differing crown characteristics. **Agricultural and Forest Meteorology**, Amsterdam, v. 151, no. 9, p. 1277-1286, 2011. DOI: <https://doi.org/10.1016/j.agrformet.2011.05.008>. Available at: <https://www.sciencedirect.com/science/article/pii/S0168192311001523>. Access Published on: August 24, 2025.
- WANG, X.-P.; WANG, Z.-N.; BERNDTSSON, R.; ZHANG, Y.-F.; PAN, Y.-X. Desert shrub stemflow and its significance in soil moisture replenishment. **Hydrology and Earth System Sciences**, Göttingen, vol. 15, no. 2, p. 561-567, 2011. DOI: <https://doi.org/10.5194/hess-15-561-2011>. Available at: <https://hess.copernicus.org/articles/15/561/2011/>. Accessed on: 24 Aug. 2025.
- WANG, Z.-P.; LI, X.-Y.; LIU, L.-Y.; WU, J.-J.; HASI, E.; SUN, Y.-L. Characteristics of stemflow for sand-fixed shrubs in Mu Us sandy land, Northwest China. **Chinese Science Bulletin**, Beijing, vol. 53, no. 14, p. 2214-2221, 2008. DOI: <https://doi.org/10.1007/s11434-008-0165-0>. Available at: <https://link.springer.com/article/10.1007/s11434-008-0165-0>. Accessed on: 24 Aug. 2025.
- XIA, C.; LIU, G.; LUO, J. Stable isotopes reveal the effect of canopy and litter layer interception on water recharge in a subtropical manmade forest of Southwest China. **Forests**, Basel, vol. 14, no. 1, art. 129, 2023. DOI: <https://doi.org/10.3390/f14010129>. Available at: <https://www.mdpi.com/1999-4907/14/1/129>. Accessed Published on: August 24, 2025.
- YANG, T.-R.; HSU, Y.-H.; KERSHAW, JA; MCGARRIGLE, E.; KILHAM, D. Big BAF sampling in mixed species forest structures of northeastern North America: influence of count and measure BAF under cost constraints. **Forestry: An International Journal of Forest Research**, Oxford, vol. 90, no. 5, p. 649-660, 2017. DOI: <https://doi.org/10.1093/forestry/cpx020>. Available at: <https://academic.oup.com/forestry/article/90/5/649/3749606>. Access Published on: August 24, 2025.
- YANG, X.; SHAO, M.; WEI, X. Stemflow production differs significantly among tree and shrub species on the Chinese Loess Plateau. **Journal of Hydrology**, Amsterdam, v. 568, p. 427-436, 2019. DOI: <https://doi.org/10.1016/j.jhydrol.2018.11.008>. Available at: <https://www.sciencedirect.com/science/article/pii/S0022169418308631>. Access Published on: August 24, 2025.

YIN, D.; RODERICK, ML. Interannual variability of the global terrestrial water cycle. **Hydrology and Earth System Sciences**, Göttingen, v. 24, n. 1, p. 381-396, 2020. DOI: <https://doi.org/10.5194/hess-24-381-2020>. Available at: <https://hess.copernicus.org/articles/24/381/2020/>. Accessed on: August 24, 2025.

ZHANG, Y.; WANG, X.; PAN, Y.; HU, R.; CHEN, N. Global quantitative synthesis of effects of biotic and abiotic factors on stemflow production in woody ecosystems. **Global Ecology and Biogeography**, Oxford, vol. 30, no. 8, p. 1713-1723, 2021. DOI: <https://doi.org/10.1111/geb.13322>. Available at: <https://onlinelibrary.wiley.com/doi/10.1111/geb.13322>. Accessed on: 24 Aug. 2025.

ZHONG, F.; JIANG, S.; VAN DIJK, AIJM; REN, L.; SCHELLEKENS, J.; MIRALLES, DG Revisiting large-scale interception patterns constrained by a synthesis of global experimental data. **Hydrology and Earth System Sciences**, Göttingen, vol. 26, no. 21, p. 5647-5667, 2022. DOI: <https://doi.org/10.5194/hess-26-5647-2022>. Available at: <https://hess.copernicus.org/articles/26/5647/2022/>. Accessed on: 24 Aug. 2025.