DOI: 10.29298/rmcf.v15i83.1443

Research article

Pérdidas de agua por intercepción de lluvia en un fragmento de bosque mixto en Durango

Water losses from rainfall interception in a fragment of a mixed forest in the state of *Durango*

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Fecha de recepción/Reception date: 20 de septiembre de 2023.
Fecha de aceptación/Acceptance date: 16 de febrero de 2024.

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Abstract
In order to understand the hydrological properties of a fragment of mixed forest in the state of *Durango*, Mexico, an experiment was carried out during the 2017-2020 period. The distribution and flow of rainwater incident rainfall, direct rainfall and stemflow, were quantified in order to assess the interception losses and the physical and chemical properties of the water. 77 events with an accumulation of 2 236.1 mm of rainfall were evaluated. Direct rainfall in *Pinus durangensis*, *P. engelmannii*, and *P. teocote* amounted to 72.4, 71.9, and 70.4 %, respectively. The rainfall that trickled down through the canopy showed an acceptable relationship with respect to incident rainfall, with average values of 0.83 of the Coefficient of Determination (R^2); the stemflow was 0.41 for *P. durangensis*, 0.40 for *P. engelmannii*, and 0.46 % for *P. teocote*, with an average R^2 of 0.47 and a greater variation. The interception losses were 27, 28, and 29 %, respectively, with an R^2 ranging between 0.35, for *P. teocote*, and 0.44 for *P. engelmannii*. The pH of throughfall was 5.9 for incident rainfall, 5.0 for the direct rainfall, and 4.1 for stemflow. Electrical conductivity evidenced a chemical change in the water composition, with 32.4 μS cm^{-1} values for incident rainfall, 39.0 μS cm^{-1} for direct rainfall and 75.0 μS cm^{-1} for stemflow. The hydrological properties of the three species of conifers do not exhibit variation in terms of the various pathways of redistribution of rainfall.
Key words: Stemflow, interception, throughfall, rainfall, physiochemical properties, hydrological properties.

Resumen
Para conocer las propiedades hidrológicas de un fragmento de bosque mixto en Durango, se desarrolló un experimento durante el periodo 2017-2020. Se cuantificó la distribución y el flujo de agua de las precipitaciones incidente, directa y escurrimiento fustal para cuantificar las pérdidas por intercepción y las propiedades físicas y químicas del agua. Se evaluaron 77 eventos, con una acumulación de 2 236.1 mm de precipitación. La precipitación directa para *Pinus durangensis*, *P. engelmannii* y *P. teocote* representó 72.4, 71.9 y 70.4 %, respectivamente. La lluvia que atravesó el dosel mostró una relación aceptable en referencia a la precipitación incidente, con valores promedio de 0.83 del Coeficiente de Determinación (R^2); el escurrimiento fustal fue de

0.41 para *P. durangensis*, 0.40 en *P. engelmannii* y 0.46 % en *P. teocote*, con un R^2 promedio de 0.47, y una mayor variación. Las pérdidas por intercepción fueron de 27, 28 y 29 %, respectivamente, con un R^2 entre 0.35 para *P. teocote* y 0.44 para *P. engelmannii*. El pH del pluviolavado fue de 5.9 para la precipitación incidente, que decreció a 5.0 en relación con la precipitación directa y 4.1 al escurrimiento fustal. La conductividad eléctrica evidenció un cambio químico en la composición del agua, con valores de 32.4 μS cm^{-1} para la precipitación incidente, 39.0 μS cm^{-1} en la precipitación directa y 75.0 μS cm^{-1} en el escurrimiento fustal. Las propiedades hidrológicas de las tres especies de coníferas no presentan variación en función de las diversas vías de redistribución de la lluvia.

Palabras clave: Escurrimiento fustal, intercepción, pluviolavado, precipitación, propiedades fisicoquímicas, propiedades hidrológicas.

Introduction

Rainfall interception in forest ecosystems plays an important role in the return of water to the atmosphere and in the amount that reaches the ground. The process of rainfall interception usually depends on the characteristics of rainfall (amount, intensity, duration, size and number of drops), as well as on the micrometeorological conditions, species composition and distribution, canopy structure (leaf area, crown density, stem surface area), and climate (Sheng and Cai, 2019).

The characteristics of the interception processes within the hydrological cycle in natural forests are the result of interactions between ecosystem components and, therefore, they project the dynamics of the water cycle (Fathizadeh *et al.*, 2017); therefore, its study is an important prerequisite for the development of water conservation strategies.

According to Návar (2020), rainfall interception in coniferous forests, which are among the plant associations with the highest water retention capacity, reaches values of up to 25 % of total precipitation; however, the evaluation of interception in the canopy and its subsequent evaporation, which directly affects the water yield of watersheds, has been neglected, mainly due to the difficulties involved in making direct measurements in the field.

One way to estimate the interception of the rainwater is to divide its redistribution into three portions: incident rainfall, direct rainfall, and stemflow. The rainwater retained in the canopy is called direct rainfall, while the rainfall that falls directly to the ground without touching the vegetation is known as incident rainfall, and the stemflow is all the rainwater that runs down the trunk and reaches the base of the tree, which, when added to the direct rainfall, results in the total rainfall that reaches the ground, known as net rainfall (Cantú and González, 2005).

Therefore, rainwater interception is estimated based on the difference between the incident rainfall and the net rainfall (Zabret *et al.*, 2018). However, rainwater losses induced by climatic variables and forest structure are an issue for the studies on the interception in forest ecosystems (Yann *et al.*, 2015), which imply considering the role of forests in water cycling within the various regional, state and continental climates (Sheil and Murdiyarso, 2009).

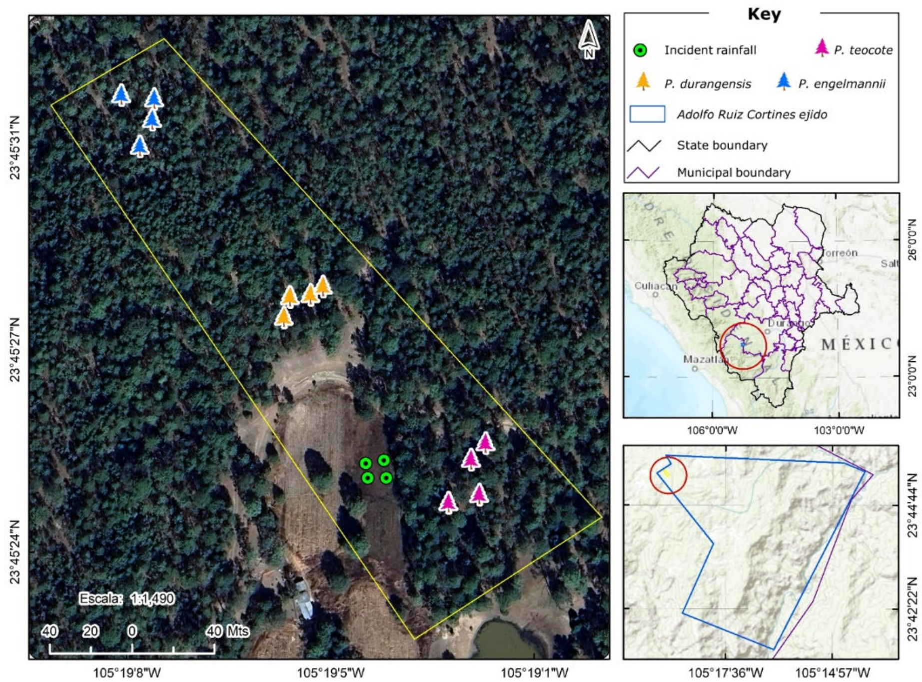
The water that touches and flows through the vegetation cover until it reaches the soil is enriched on its way with mineral elements and organic matter from the leaf and tree stem exudates, creating conditions conducive to optimal plant development (Béjar *et al.*, 2018). In addition, the physical, chemical and biological properties of water in soils under the forest canopy play a crucial role, as they provide quality water to the streams, and, by generating ideal conditions for the development of edaphic fauna, contributing to maintain a highly diverse micro fauna (Neary *et al.*, 2009).

Given the considerations described above and the fact that few studies have been conducted to evaluate the balance of the rainwater intercepted by forest species in the region of *El Salto*, *Durango*, the objective of this study was to estimate the amount of incident rainfall, direct rainfall, stemflow, and water loss in three species of the genus *Pinus* L. (*P. durangensis* Martínez, *P. engelmannii* Carrière and *P. teocote* Schltdl. & Cham.) in the *Adolfo Ruiz Cortines ejido*, for the aim of generating statistical equations by which to predict rainfall interceptions in a fragment of mixed forest. This study also includes the characterization of throughfall in the different rainwater redistribution routes.

Materials and Methods

Study area

The study was conducted in the *Adolfo Ruiz Cortines ejido*, located in the Great Plateau of the Western *Sierra Madre*, in the sub province known as *Cañones Duranguenses*, within *Pueblo Nuevo* municipality, in the state of *Durango*, Mexico. Geographically, it is located between 23°41' and 23°45' N, and between 105°14' and 105°19' W (Figure 1). Its climate is Semi-cold Sub-humid with summer rains and rainfall intervals of 5 to 10.2 mm (García, 2004). Rainfall in the region is generally low, being heaviest from June to September, with an annual average of 850 mm (Domínguez-Gómez *et al.*, 2022). Temperatures at the site fluctuate from -0.9 °C in January, to 22.5 °C in August, with an average annual evaporation of 97.7 mm. These data were obtained from an automated HOBO type sensor (H8 Family, Forestry Suppliers, Inc.®) located next to the site.



Escala = Scale; *México* = Mexico.

Figure 1. Location of the study area within the state context.

According to the cartography published by INEGI (2010) in the Hydrographic Network 2.0, the study area is located within Hydrological Region 11 (*Presidio-San Pedro*); this includes the *Presidio* River basin, which contains the sub-basin of the *El Jaral* Creek. As for the vegetation, most of the property is dominated by pine-oak forests with different productivity conditions and where the following pine and oak species prevail: *Pinus ayacahuite* C. Ehrenb. *ex* Schltdl. var*. veitchi* (Roezl) Shaw, *P. cooperi* C. E. Blanco var. *ornelasii* (Martínez) C. E. Blanco, *P. durangensis*, *P. leiophylla* Schiede *ex* Schltdl. & Cham., *P. teocote*, *Quercus durifolia* Seemen, *Q. rugosa* Née, and *Q. sideroxyla* Bonpl. (Domínguez *et al.*, 2018).

Measurement of rainfall components

Within an experimental area of 2 500 m^2, three 20×20 m plots were delimited, one for each *Pinus* species. Direct rainfall and stemflow collectors were placed in them, considered as replications within each homogeneous plot; also, a representativeness of the canopy was assumed. The most relevant mensuration characteristics considered in the individuals of the three species in each plot were as follows: normal diameter (*Nd*, cm) (model Mantax Blue 500 mm, Haglöf® caliper), total height (*H*, m) (model 360PC/360R DG, Suunto Tandem® clinometer) and crown area (model TP50ME, Truper® tape) with north-south and east-west orientation (Silva-González *et al.*, 2021); the data of this last variable served as a basis for estimating the representativeness of the canopy by species. The coverage data were compared with those of Domínguez-Gómez *et al.* (2022), who established study plots in the area and determined that the average coverage of the taxa studied was 8 m^2; therefore, the estimated coverages were regarded as representative of the species.

After each rainfall event, the rainwater volume was measured and a sample was taken for chemical analysis. These measurements were carried out from June 2017 to December 2020.

Incident rainfall. The rainwater that reached the ground directly, without touching the plant canopy was collected using U-shaped gutters made of 0.1 m^2 (100 cm long×10 cm wide) PVC connected with hoses to 20 L containers; the gutters were covered with a mesh to prevent clogging with debris (Figure 2A). Four gutters total were installed at 1.30 m from the ground in a site devoid of vegetation (Yáñez-Díaz *et al.*, 2014).

A = Direct and incident rainfall; B = Stemflow.

Figure 2. Design of the gutters utilized for rainfall collection.

Direct rainfall. The same gutter design described above was followed. Four gutters were installed per plot of each species (one per individual), fixed in the lower part of the canopy of the selected trees, where they remained during the entire experimental period. The total number of gutters located within the study site was 12.

Stemflow. Stemflow was measured with steel plastic hoses with perforations of 1.5×2.5 cm, at every 4 cm. The hoses were placed over the tree trunks stripped of bark, in a spiral shape, in two and a half turns, until reaching a maximum height of 2 m. The hoses were sealed with silicone at the top and bottom (Figure 2B) and placed on the same individuals selected for direct rainfall measurement, in order to avoid rainfall loss (Béjar *et al.*, 2018).

Throughfall. In order to determine the values of electrical conductivity (*EC*) and pH of the samples collected in each of the components (direct rainfall, incident rainfall, and stemflow), a direct measurement was made using a model C3010 Consort Multiparameter Analyzer® potentiometer/conductivity meter with electrodes.

Interception losses. Interception was estimated as the difference between the incident rainfall and the sum of direct rainfall and the stemflow (Cantú and González, 2005), using Equation 1:

$$I = PI - (PD + SF) \quad (1)$$

Where:

I = Interception losses (mm)

PI = Incident rainfall (mm)

PD = Direct rainfall (mm)

SF = Stemflow (mm)

Statistical analysis and linear regression were used to obtain estimates of the intercept values for each species under study. This made it possible to determine the specific values of the volumes of water intercepted by each.

Statistical analysis

The Kolmogorov and Shapiro-Wilk test (Brown and Forsythe, 1974) was applied in order to demonstrate whether or not the dependent variables pH and electrical conductivity result from a normal distribution and meet the basic assumptions regarding the normality of residuals, homogeneity of variance of residuals, and independence of residuals to fit a regression model and analysis of variance. As the above assumptions were not met, the Kruskal-Wallis nonparametric test (Ott and Longnecker, 2001) was performed with the Statistical Package for Social Sciences (SPSS) version 22.0 for Windows (IBM, 2016), with a significance level of 5 %.

The intercepted rainfall, direct rainfall, and stemflow were predicted as a function of the incident rainfall by means of simple linear regression analysis whose model expression is Equation 2. The parameter estimation was performed using the least squares technique.

$$y_i = \beta_0 + \beta_1 \times x_{i1} + \ldots + \beta_p \times x_{ip} + e_i \qquad (2)$$

Where:

y_i = Dependent variable

x_i =Independent variable

β_0 = Ordered at the origin

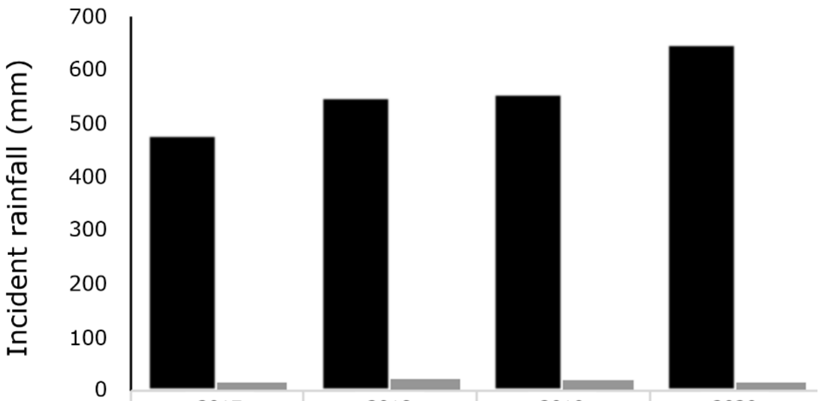
β_1 = Slope parameter

e_i = Random error or disturbance; (i=1,2,…,n) of the i^{th} observation, where n is the number of observations used in the model fit.

Results and Discussion

Incident and direct rainfall, stemflow and interception losses

During the four years of the study (June 2017-December 2020), 2 236.1 mm of rainwater were registered, distributed over 77 rainfall events. The cumulative rainfall over the experimental period indicated a larger number of events (23 events) occurred in 2018; however, the highest rainfall sheet was recorded in 2020 (649.0 mm) (Figure 3), and accounted for 29 % of the total cumulative rainfall.



	2017	2018	2019	2020
Incident rainfall (mm)	480.2	550.4	556.5	649.0
Number of rainfall event	17	23	21	16

Figure 3. Cumulative rainfall during the experimental period.

The percentage of direct rainfall registered was 72.4, 71.9 and 70.4 % for *P. durangensis*, *P. engelmannii* and *P. teocote*, respectively, which, on average, amounted to 73.91 % of the total incident rainfall. Linear regression analysis showed that there is an acceptable relationship between direct rainfall and incident rainfall for each of the species studied. In all three taxa, the R^2 values were above 0.70.

Besteiro and Rodríguez (2012), when studying the temporal distribution of rainfall and its redistribution under a plantation of *Pinus radiata* D. Don., recorded a ratio of direct rainfall to incident rainfall of 69.2 %. The linear regression analyses showed a Correlation coefficient (R^2) value above 0.80; that is, the amount of rainwater passing through the canopy has a close relationship with the rainwater above the canopy, even though they are different pine species, which shows that the vegetation cover given by the pines has an immediate influence on the redistribution of rainfall. In addition, it has been pointed out that the canopy of these taxa forms a damping and redirection system for the droplets, so that they reach the ground in a softer and less impacting way, which prevents a soil particle detachment process and an erosion process from occurring (Tonello *et al.*, 2014).

The ratio of stemflow to incident rainfall was less than one percent for each of the species. In addition, very little variation was observed in this sense, so it can be considered as non-significant; mainly because the mensuration and phenological characteristics of the species under study are very similar. The percentages of stemflow for *P. durangensis*, *P. engelmannii*, and *P. teocote* were 0.41, 0.40, 0.46 %, respectively; the similarities in the percentages are related, mainly, to their bark type, diameter and height. The three species have grooved stems, as well as similar diameters and heights (Table 1).

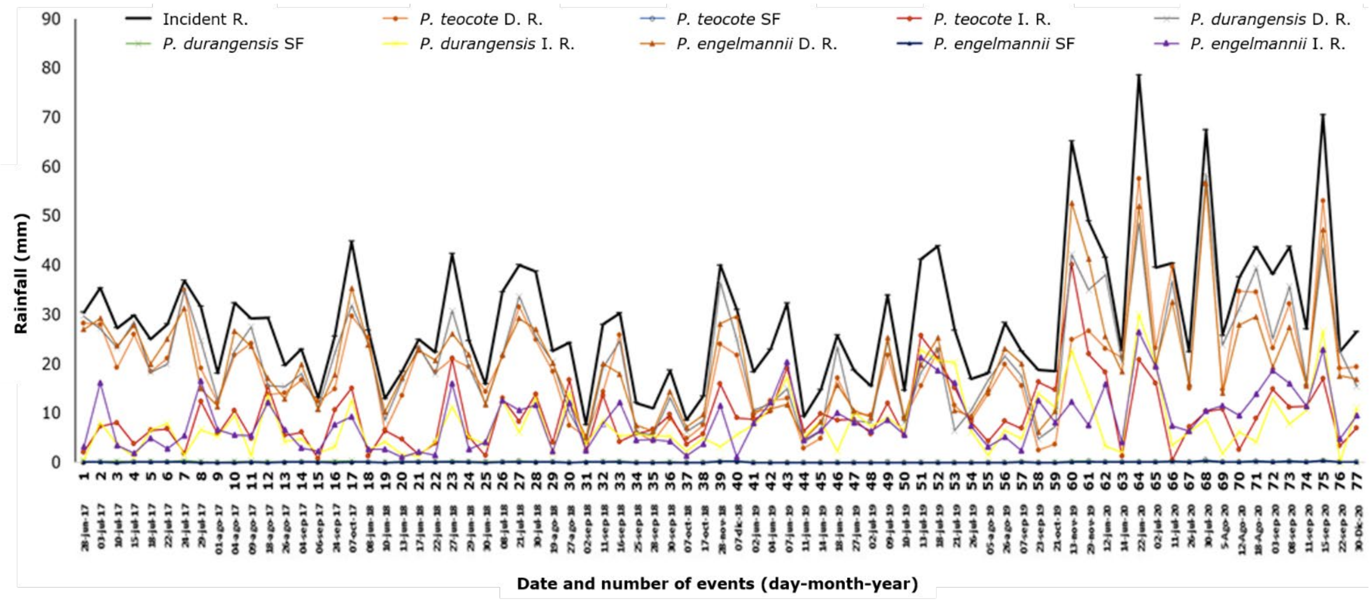
Table 1. Mensuration data of the species under study.

Species	**Normal diameter (cm)**	**Height (m)**	**Crown cover (m²)**
Pinus teocote Schltdl. & Cham.	30	22.7	8.0

Pinus durangensis Martínez	28	22.5	7.5
Pinus engelmannii Carrière	32	21.0	7.0

Although stemflow is considered of little relevance because it usually represents a tiny fraction of total (incident) precipitation, it has important biogeochemical implications in forest ecosystems beyond the abundance or scarcity of water for the soil near the forest canopy (Levia and Germer, 2015; Van Stan and Gordon, 2018). For example, it is a significant source of water supply for plant species that have been suppressed or are developing in the lower strata of forests (Tamez *et al.*, 2018), and provides a greater carryover of both solutes, as well as of particles that incorporate nutrients into the soil (Wang *et al.*, 2011).

The individual analysis of total rainfall, direct rainfall, stemflow, and interception in each event showed little variability (Figure 4). The highest rainfall accumulation occurred during the last period, from event 60 onwards; event 64 had the highest accumulated water for the three species. In contrast, the lowest accumulation occurred in event 31. The events with a greater rainfall show that, as the amount of incident rainfall increases, the values in the other redistribution pathways increase as a result of water runoff in the various components of the forest canopy. Yáñez-Díaz *et al.* (2014) point out that the rain that is deposited on the ground, is not a constant fraction of the total rainfall.



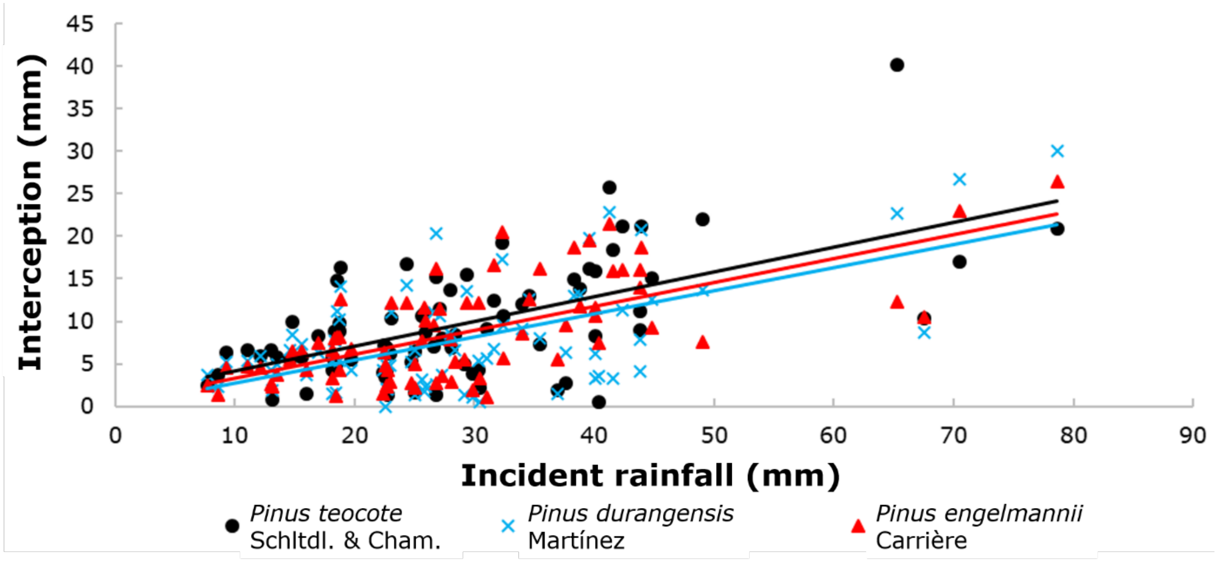
R. = Rainfall; D. R. = Direct rainfall; SF = Stemflow; I. R. = Interception losses.

Figure 4. Dynamics of the total rainfall for the three species under study in the various pathways of redistribution of rainfall events during the experimental period.

Canopy interception losses were, on average, 28.13 % for the three species; *P. durangensis* 27.16 %, *P. engelmannii* 28.07 %, and *P. teocote* 29.17 %. The intercept intervals in the present study are within the intercept values cited in the specialized literature for similar forests (Flores *et al.*, 2016; Magliano *et al.*, 2019). This proves that the patterns in the values of canopy interception losses follow a trend.

Understanding the processes of interception by the plant canopy provides the opportunity to have hydrological prediction tools (Deng *et al.*, 2022), as it is an important component of the water and energy balance in forest ecosystems. However, the multiple agents involved in this process and their interactions are quite complex (Su *et al.*, 2022). The canopy is the first part of the vegetation to come into contact with rainfall and to affect its redistribution, which makes its architecture and variation in its structure increase spatial heterogeneity across the various rainfall redistribution pathways (Schumacher and Christiansen, 2015). Consequently, the relationship between canopy and interception has become a central topic in hydrological research (Su *et al.*, 2016).

Some studies (Rotenberg and Yakir, 2010; Wang and Guo, 2023) have shown that interception is an important component that influences the microclimates and the water balance by affecting the amount of rainfall reaching the ground and plays a role in regulating the transpiration rate of trees (Zore *et al.*, 2022). Figure 5 illustrates the dispersion of incident rainfall and rainwater interception data for the three conifer species during the experimental period.



Each value represents the mean of the four replicates per species during the 77 events recorded.

Figure 5. Relationship between incident precipitation (mm) and interception (mm) for the different species.

The results of the linear regression analysis between the incident rainfall and interception losses are shown in Table 2, where the estimated coefficients of determination (R^2) were 0.35, 0.44 and 0.36 for *P. durangensis*, *P. engelmannii* and *P. teocote*, respectively. These values suggest a moderate correlation and indicate that, although incident rainfall influences interception losses, there are multiple factors that affect this process both, passively and actively. The Coefficient of determination for the equations was significant in all three cases, confirming that when the amount of incident rainfall (mm) increases, the absolute values for canopy interception increase.

Table 2. Equations for estimating interception losses of the different species.

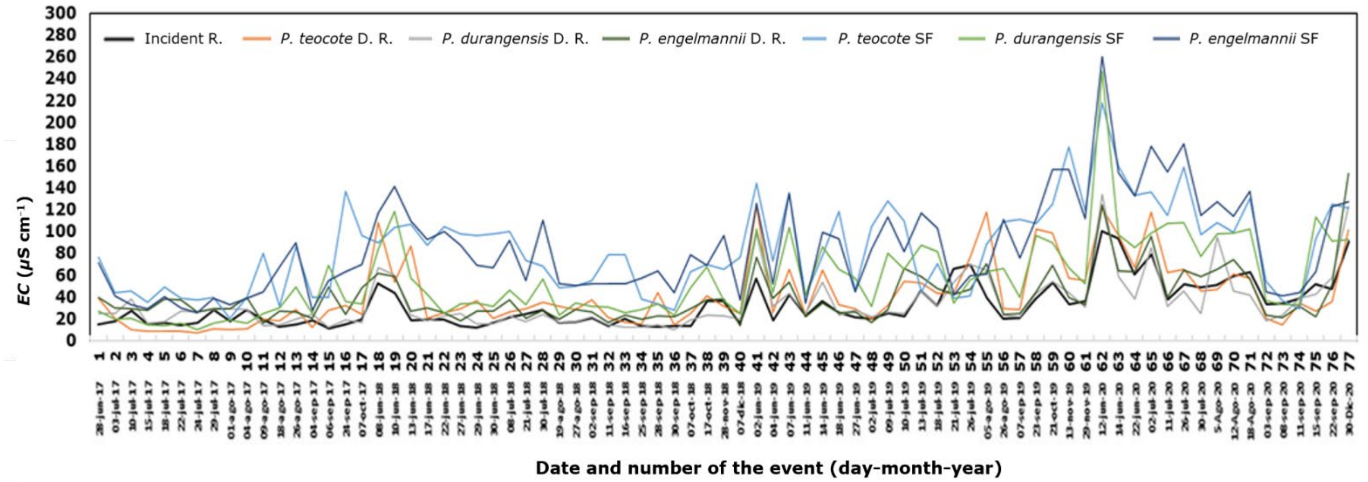
Species	*n*	Equation	R^2	*ESE*	*P*-value
Pinus durangensis Martínez	77	$y = 0.2716x + 0.0405$	0.35	5.28	<0.001
Pinus engelmannii Carrière	77	$y = 0.2807x + 0.4812$	0.44	4.44	<0.001
Pinus teocote Schltdl. & Cham.	77	$y = 0.2914x + 1.2052$	0.36	5.45	<0.001

ESE = Estimated Standard Error.

Throughfall

Electrical conductivity

The rainwater passing through the canopy of the species studied showed constant changes in the electrical conductivity values (μS cm^{-1}) in direct rainfall and stemflow relative to incident rainfall. Based on these results, it is reasonable to assume that, as rainwater passes through the vegetation cover, it carries several mineral salts that cause changes in this property. Figure 6 shows the behavior of *EC*.



R. = Rainfall; D. R. = Direct rainfall; SF = Stemflow. Each plotted value represents the mean (*n*=4).

Figure 6. Temporal variation of Electrical Conductivity in the components of rainfall redistribution.

Table 3 summarizes the *EC* values. The incident rainfall amounted to 32.4 *µ*S cm^{-1}, showing an increase in relation to the values for direct rainfall in the three studied species. According to the analysis of the data on the electrical conductivity (*µ*S cm^{-1}) of the collected water, the behavior of stemflow was more varied than that of direct rainfall, with values above those of the incident rainfall, due mainly to the greater incorporation of particles and sediments during the movement of water through the stem and leaves. Based on these arguments, differences may be assumed between the chemical compositions of some of the components, which are associated with the presence of mineral salts and with particulate incorporation (Luna-Robles *et al.*, 2019). Another factor that alters the behavior of the electrical conductivity is the quantity and entrainment of cortical anions, when the occurrence and quantity of rainfall events decrease, there is a greater accumulation of ions in the atmosphere, which will be entrained by the subsequent rains (Pérez-Suárez *et al.*, 2006).

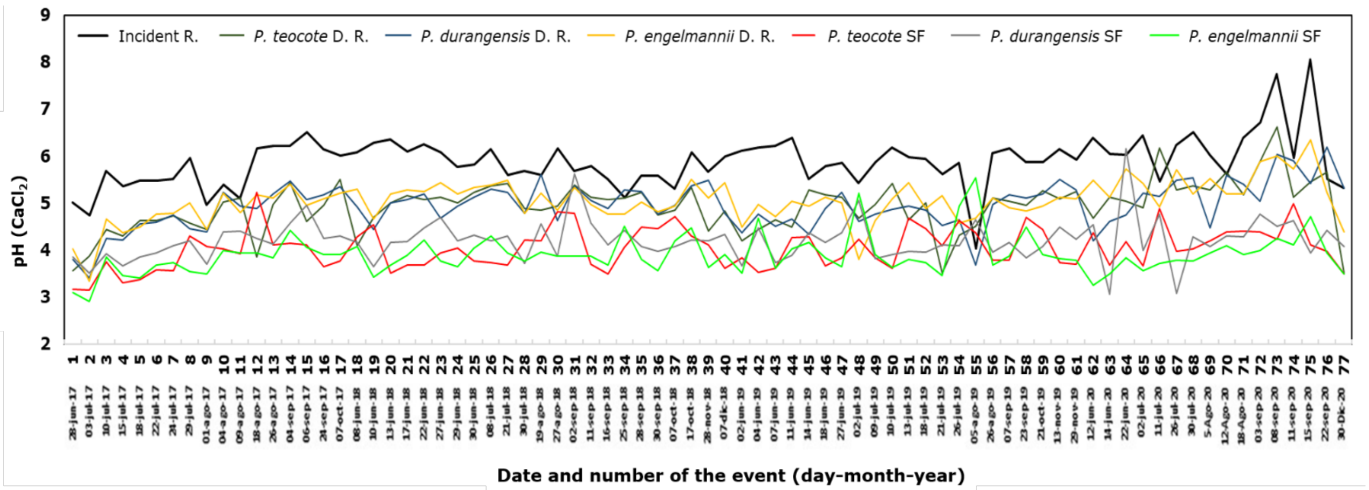
Table 3. Average electrical conductivity and pH values of direct rainfall (DR), incident rainfall (IR), and stemflow (SF).

Species	*n*	pH		*EC* (μS cm^{-1})		IR	
		DR	SF	DR	SF	pH	*EC*
Pinus teocote Schltdl. & Cham.	77	4.9±0.06	4.0±0.05	42.2±3.60	84.1±4.80	5.9±0.07	32.4±2.45
Pinus durangensis Martínez	77	5.0±0.06	4.2±0.05	34.5±2.90	56.4±4.45		
Pinus engelmannii Carrière	77	5.0±0.05	3.9±0.05	40.2±2.83	84.6±5.30		

Values represent the mean±standard error of the mean (*n*=77).

pH

When analyzing the behavior of pH both in direct rainfall and in the stemflow of the three species under study, it was observed that their values corresponded mostly to moderately acid, while for incident rainfall they were slightly acid (Figure 7).



R. = Rainfall; D. R. = Direct rainfall; SF = Stemflow. Each plotted value represents the mean (*n*=4).

Figure 7. Behavior of pH on the various components of rainfall redistribution.

Table 3 shows that the average pH for incident rainfall was 5.9, for direct rainfall in the three species, it dropped to 5.0, while for the stemflow the value reached 4.1. Studies like the one by Béjar *et al.* (2018), who estimated the redistribution of precipitation and nutrient input in *Pinus cooperi* C. E. Blanco, documented results with the same trend; its pH records for incident rainfall ranged between 4.42 and 6.12; however, once the water flowed through the canopy, it decreased slightly to 4.21, and once the water came into contact with and flowed down the stem, it tended to acidify and reach figures of 3.85.

The analyses of variance of the Kruskal-Wallis test revealed significant differences ($P<0.05$) in the *EC* and pH variables of the three rainfall redistribution pathways of the 77 events analyzed for the three species, especially in the pH (56 of the 77 events), while the *EC* exhibited such differences only in 18 of the 77 events. The results of the statistical analysis showed that the differences between the events are influenced by the particularity of each rainfall event, which has a bearing on the intensity of the storm and the wind direction, causing various particles to be deposited and thereby modifying the values of the stemflow in the various redistribution pathways (Yáñez-Díaz *et al.*, 2014).

Conclusions

The hydrological properties under the different canopies of the studied species do not differ or vary according to rainfall redistribution pathways. Rainwater interception by the vegetation cover amounts to 28.1 %, a value that furthers knowledge of this component at a local scale. The value of rainwater interception in the watersheds depends on the type of vegetation cover and its distribution, which made it possible to recognize that, for the purposes of forest management, the existence and distribution of species is of utmost importance for water management within the ecosystem, as it contributes to maintain active biogeochemical processes.

The pH and electrical conductivity exhibit changes as the rainwater flows through the canopy and its different components, with variations between the different rainfall redistribution pathways, as well as significant differences during most months of the experimental period for the three conifer species under analysis.

Acknowledgments

The authors are grateful to the *Instituto Tecnológico de El Salto* ("*El Salto*" Technological Institute) for the technical support provided for this research; to the Project TECNM. 5746.16-P "*Ciclos Biogeoquímicos en Bosques de la Sierra Madre*

Occidental de la Región de El Salto, *Durango*, *México*" ("Biochemical Cycles in Forests of the Western *Sierra Madre* in the *El Salto* Region of *Durango*, Mexico)". To Conahcyt, for the postgraduate scholarship granted for the accomplishment of this research and the postdoctoral fellowship awarded to the corresponding author.

Conflict of interest

The authors declare that they have no conflict of interest.

Contribution by author

César Gerardo Ramos Hernández: research development, data analysis, and drafting of the manuscript; Israel Cantú Silva: experimental design and review of the manuscript; Sacramento Corral Rivas: data analysis and review of the manuscript; Francisco Javier Hernández: review of the manuscript; Tilo Gustavo Domínguez Gómez: planning, research development and data collection in the field.

References

Béjar P., S. J., I. Cantú S., T. G. Domínguez G., H. González R., … y E. O. Luna R. 2018. Redistribución de la precipitación y aporte de nutrimentos en *Pinus cooperi* C. E. Blanco. Revista Mexicana de Ciencias Forestales 9(50):94-120. Doi: 10.29298/rmcf.v9i50.237.

Besteiro, S. I. y A. M. Rodríguez V. 2012. Redistribución de las precipitaciones sobre plantaciones forestales en un predio del partido de La Plata, Buenos Aires. Revista de la Facultad de Agronomía, La Plata 111(2):75-82. https://ri.conicet.gov.ar/handle/11336/101680. (11 de abril de 2023).

Brown, M. B. and A. B. Forsythe. 1974. Robust tests for the equality of variances. Journal of the American Statistical Association 69(346):364-367. Doi: 10.1080/01621459.1974.10482955.

Cantú S., I. y H. González R. 2005. Pérdidas por intercepción de la lluvia en tres especies de matorral submontano. Ciencia UANL 8(1):80-85. http://eprints.uanl.mx/1629/1/perdidas_intercepcion_lluvia.pdf. (11 de abril de 2023).

Deng, J., Y. Yu, J. Shao, S. Lu, … and X. Shi. 2022. Rainfall interception using the revised Gash analytical model for *Pinus sylvestris* var. *mongolica* in a semi-humid region of NE China. Ecological Indicators 143:109399. Doi: 10.1016/j.ecolind.2022.109399.

Domínguez G., T. G., B. N. Hernández G., H. González R., I. Cantú S., E. Alanís R. y M. del S. Alvarado. 2018. Estructura y composición de la vegetación en cuatro sitios de la Sierra Madre Occidental. Revista Mexicana de Ciencias Forestales 9(50):9-34. Doi: 10.29298/rmcf.v9i50.227.

Domínguez-Gómez, T. G., S. Vicente-Juan, E. G. Velásquez-Ortíz, E. S. Córdova-Delgado, … y J. G. Colín. 2022. Intercepción de la precipitación en *Pinus engelmannii* Carr. y *Quercus rugosa* Née en el Ejido Adolfo Ruiz Cortines, Pueblo Nuevo, Durango. e-CUCBA 9(17):173-181. Doi: 10.32870/ecucba.vi17.225.

Fathizadeh, O., S. M. Hosseini, A. Zimmermann, R. F. Keim and A. D. Boloorani. 2017. Estimating linkages between forest structural variables and rainfall interception parameters in semi-arid deciduous oak forest stands. The Science of the Total Environment (601-602):1824-1837. Doi: 10.1016/j.scitotenv.2017.05.233.

Flores A., E., V. Guerra De la C., G. H. Terrazas G., F. Carrillo A., … y E. Buendía R. 2016. Intercepción de lluvia en bosques de montaña en la cuenca del río Texcoco, México. Revista Mexicana de Ciencias Forestales 7(37):65-76. Doi: 10.29298/rmcf.v7i37.52.

García, E. 2004. Modificaciones al sistema de clasificación climática de Köppen. Instituto de Geografía de la Universidad Nacional Autónoma de México. Coyoacán, D. F., México. 90 p.

Instituto Nacional de Estadística, Geografía e Informática (INEGI). 2010. Red hidrográfica edición 2.0. Cuenca R. Baluarte. Región H. Presidio-San Pedro. Escala 1:50 000. Carta: RH11C. INEGI. https://www.inegi.org.mx/app/biblioteca/ficha.html?upc=702825006855. (12 de abril de 2023).

International Business Machines (IBM). 2016. Statistical Package for the Social Sciences (SPSS) V22.0. Chicago, IL, United States of America. IBM Inc.

Levia, D. F. and S. Germer. 2015. A review of stemflow generation dynamics and stemflow-environment interactions in forests and shrublands. Reviews of Geophysics 53(3):673-714. Doi: 10.1002/2015RG000479.

Luna-Robles, E. O., I. Cantú-Silva, H. González-Rodríguez, J. G. Marmolejo-Monsiváis, M. I. Yáñez-Díaz and S. J. Béjar-Pulido. 2019. Nutrient input via gross rainfall, throughfall and stemflow in scrubland species in northeastern Mexico. Revista Chapingo Serie Ciencias Forestales y del Ambiente 25(2):235-251. Doi: 10.5154/r.rchscfa.2018.12.096.

Magliano, P. N., J. I. Witworth-Hulse and G. Baldi. 2019. Interception, throughfall and stemflow partition in drylands: Global synthesis and meta-analysis. Journal of Hydrology 568:638-645. Doi: 10.1016/j.jhydrol.2018.10.042.

Návar, J. 2020. Modeling rainfall interception loss components of forests. Journal of Hydrology 584:124449. Doi: 10.1016/j.jhydrol.2019.124449.

Neary, D. G., G. G. Ice and C. R. Jackson. 2009. Linkages between forest soils and water quality and quantity. Forest Ecology and Management 258(10):2269-2281. Doi: 10.1016/j.foreco.2009.05.027.

Ott, R. L. and M. Longnecker. 2001. An introduction to statistical methods and data analysis. Duxbury. Pacific Grove, CA, United States of America. 1152 p.

Pérez-Suárez, M., V. M. Cetina-Alcalá, A. Aldrete, M. E. Fenn y L. L. Landois-Palencia. 2006. Química de la precipitación pluvial en dos bosques de la cuenca de la Ciudad de México. Agrociencia 40(2):239-248. https://www.scielo.org.mx/scielo.php?pid=S1405-31952006000200239&script=sci_arttext. (2 de enero de 2023).

Rotenberg, E. and D. Yakir. 2010. Contribution of semi-arid forests to the climate system. Science 327(5964):451-454. Doi: 10.1126/science.1179998.

Schumacher, J. and J. R. Christiansen. 2015. Forest canopy water fluxes can be estimated using canopy structure metrics derived from airborne light detection and ranging (LiDAR). Agricultural and Forest Meteorology 203:131-141. Doi: 10.1016/j.agrformet.2014.12.007.

Sheil, D. and D. Murdiyarso. 2009. How forest attract rain: An examination of a new hypothesis. BioScience 59(4):341-347. Doi: 10.1525/bio.2009.59.4.12.

Sheng, H. and T. Cai. 2019. Influence of rainfall on canopy interception in mixed broad-leaved—Korean pine forest in Xiaoxing’an Mountains, Northeastern China. Forest 10(3):248. Doi: 10.3390/f10030248.

Silva-González, E., O. A. Aguirre-Calderón, E. J. Treviño-Garza, E. Alanís-Rodríguez y J. J. Corral-Rivas. 2021. Efecto de tratamientos silvícolas en la diversidad y estructura forestal en bosques templados bajo manejo en Durango, México. Madera y Bosques 27(2):e2722082. Doi: 10.21829/myb.2021.2722082.

Su, L., C. Zhao, W. Xu and Z. Xie. 2016. Modelling interception loss using the revised Gash model: A case study in a mixed evergreen and deciduous broadleaved forest in China. Ecohydrology 9(8):1580-1589. Doi: 10.1002/eco.1749.

Su, L., J. Yang, X. Zhao and Y. Miao. 2022. Effects of fire on interception loss in a coniferous and broadleaved mixed forest. Journal of Hydrology 613:128425. Doi: 10.1016/j.jhydrol.2022.128425.

Tamez P., C., I. Cantú S., H. González R., M. I. Yáñez D. y J. I. Uvalle S. 2018. Pérdidas por intercepción en cuatro especies de matorral en el noreste de México.

Revista Mexicana de Ciencias Forestales 9(49):126-147. Doi: 10.29298/rmcf.v9i49.177.

Tonello, K. C., E. A. Goes G., E. T. Shinzato, R. de O. Averna V. e H. C. Teixeira D. 2014. Precipitação efetiva em diferentes formações florestais na Floresta Nacional de Ipanema. Revista Árvore 38(2):383-390. Doi: 10.1590/S0100-67622014000200020.

Van Stan, J. T. and D. A. Gordon. 2018. Mini-review: Stemflow as a resource limitation to near-stem soils. Frontiers Plant Science 9:1-7. Doi: 10.3389/fpls.2018.00248.

Wang, Q. and J. Guo. 2023. Rainfall interception loss as a function of leaf area index and rainfall by soybean. Theoretical and Applied Climatology 155(1):289-297. Doi: 10.1007/s00704-023-04633-8.

Wang, X. P., Z. N. Wang, R. Berndtsson, Y. F. Zhang and Y. X. Pan. 2011. Desert shrub stemflow and its significance in soil moisture replenishment. Hydrology and Earth System Science 15(2):561-567. Doi: 10.5194/hess-15-561-2011.

Yann, W., X. Deng, X. Chen, D. Tian, W. Xiang and Y. Peng. 2015. Long-term variations of rainfall interception in different growth stages of Chinese fir plantations. Hydrological Sciences Journal 60(12):2178-2188. Doi: 10.1080/02626667.2014.964243.

Yáñez-Díaz, M. I., I. Cantú-Silva, H. González-Rodríguez y J. I. Uvalle-Sauceda. 2014. Redistribución de la precipitación en tres especies arbustivas nativas y una plantación de Eucalipto del noreste de México. Tecnología y Ciencias del Agua 5(2):71-84. https://www.scielo.org.mx/pdf/tca/v5n2/v5n2a5.pdf. (15 de marzo de 2023).

Zabret, K., J. Rakovec and M. Šraj. 2018. Influence of meteorological variables on rainfall partitioning for deciduous and coniferous tree species in urban area. Journal of Hydrology 558:29-41. Doi: 10.1016/j.jhydrol.2018.01.025.

Zore, A., N. Bezak and M. Šraj. 2022. The influence of rainfall interception on the erosive power of raindrops under the birch tree. Journal of Hydrology 613:128478. Doi: 10.1016/j.jhydrol.2022.128478.