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Research article

Intercepción de lluvia en bosques del ejido Adolfo Ruiz Cortines, Pueblo Nuevo, Durango

Rainfall interception in forests of the *Adolfo Ruiz Cortines ejido, Pueblo Nuevo, Durango*

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Abstract

The redistribution of rainfall was studied in two species of the *Pinus* genus in the *Adolfo Ruiz Cortines ejido*, *Pueblo Nuevo*, state of *Durango*, with the aim of evaluating incident rainfall, direct rainfall, stemflow, interception losses, pH values, and electrical conductivity for *Pinus teocote* and *Pinus engelmannii*. Twenty-six rainfall events were assessed in a 2 500 m^2 plot, where hydrological properties were measured from June to December 2019. Results indicated an incident rainfall of 812.28 mm. Direct rainfall in *P. engelmannii* and *P. teocote* amounted to 84.93 and 83.15 %, respectively, with an average of 84 % of total rainfall. Stemflow amounted to 0.29 % for *P. engelmannii* and 0.33 % for *P. teocote*. Meanwhile, canopy interception losses were 16.52 % for *P. teocote* and 15 % for *P. engelmannii*. In the rainfall pH, the highest value compared to the incident rainfall was 7.0, for the stemflow of *P. teocote* it was 4.7 and for *P. engelmannii* it was 5.5; direct rainfall recorded 5.4 pH for both species. The electrical conductivity exhibited an increasing trend as it traveled through the tree crowns and stems; a value of 29.5 μS cm^{-1} was obtained for the incident rainfall, 44.4 μS cm^{-1} for the direct rainfall, and the stemflow registered higher values, with an average of 90.2 μS cm^{-1}.

Key words: Stemflow, interception, rainfall throughfall, incident rainfall, direct rainfall, hydrological properties.

Resumen

Se estudió la redistribución de la precipitación en dos especies del género *Pinus* en el ejido Adolfo Ruiz Cortines, Pueblo Nuevo, Durango, con el objetivo de evaluar la precipitación incidente, precipitación directa, escurrimiento fustal, pérdidas por intercepción, valores de pH y conductividad eléctrica para las especies *Pinus teocote* y *Pinus engelmannii*. Se evaluaron 26 eventos de lluvia, en una parcela de 2 500 m^2, donde se midieron las propiedades hidrológicas durante el periodo de junio a diciembre de 2019. Los resultados indicaron una precipitación incidente de 812.28 mm. La precipitación directa en *P. engelmannii* y en *P. teocote* representó 84.93 y 83.15 %, respectivamente, con un promedio de 84 % de la precipitación total. El escurrimiento fustal representó 0.29 % para *P. engelmannii* y 0.33 % en *P. teocote*; mientras que las pérdidas por intercepción del dosel vegetal fueron de 16.52 % para *P. teocote* y 15 % para *P. engelmannii*. En el pH del pluviolavado, el valor más alto respecto a la precipitación incidente fue 7.0, para el escurrimiento fustal de *P. teocote* de 4.7 y para *P. engelmannii* de 5.5; la precipitación directa registró un pH de 5.4 para las dos especies. La conductividad eléctrica mostró una tendencia de aumento conforme recorría las copas y fustes de los árboles; se obtuvo un valor de 29.5 μS cm^{-1} en la precipitación incidente, 44.4 μS cm^{-1} en la precipitación directa y el escurrimiento fustal registró valores superiores, con un promedio de 90.2 μS cm^{-1}.

Palabras claves: Escurrimiento fustal, intercepción, pluviolavado, precipitación incidente, precipitación directa, propiedades hidrológicas.

Introduction

The hydrological cycle is a general circulation process involving a complex display of water movements and transformations (Echeverría *et al.*, 2007). Within a hydrological system, intercepted water can be a loss or gain of the resource, depending on the scenario. When the water retained in the vegetation cover evaporates due to wind and temperature, it is a loss; if it comes from air humidity or condensation, interception constitutes an increase or gain of the resource (Tamez *et al.*, 2018).

The amount of rainfall reaching the ground surface depends, to a large extent, on the type and density of the vegetation cover (Iroume and Huber, 2000). Several research studies have contributed to the understanding of the importance of forest canopies as a filter that significantly modifies the spatial distribution of rainfall and spatial variations in humidity, as well as the physical and chemical properties of soils (Yáñez-Díaz *et al.*, 2014).

Interception losses reach significant values at the river basin level as well as in some tree cover types. In coniferous forests, losses between 21 and 48 % of the average annual rainfall have been determined (López-Lambraño *et al.*, 2017). The measurement and prediction of rainfall interception losses by the forest is an essential requirement in forecasting the effects of the vegetation cover on the water yield of a watershed (Cantú and González, 2005).

In the case of Mexico, this area of research has been little explored, particularly in the state of *Durango*; most research has focused on the vegetation of semi-arid environments in the north of the country. Given that in temperate forests the most abundant and most important tree genus for timber is *Pinus* L., the objective of the present study was to assess precipitation losses by interception through incident rainfall, direct rainfall, stemflow, and the physical and chemical properties of the water in the hydrological cycle within the interception subsystem in two species of the *Pinus* genus in the *Adolfo Ruiz Cortines ejido*, *Pueblo Nuevo* municipality, *Durango*.

Materials and Methods

Study area

The research was carried out in the *Adolfo Ruiz Cortines ejido*, in *Pueblo Nuevo* municipality of the state of *Durango*, Mexico. It is located in the southwestern region of the state, in the Western *Sierra Madre*, as part of the sub province called *Cañones Duranguenses*, 20 km southeast of the city of *El Salto*, *Durango*, at a medium altitude of 2 480 m (INEGI, 2014). Access to this *ejido* is through the

Durango-Mazatlán highway, and geographically it is located at coordinates UTM Zone 13N 0467600, 2627410 (Figure 1).

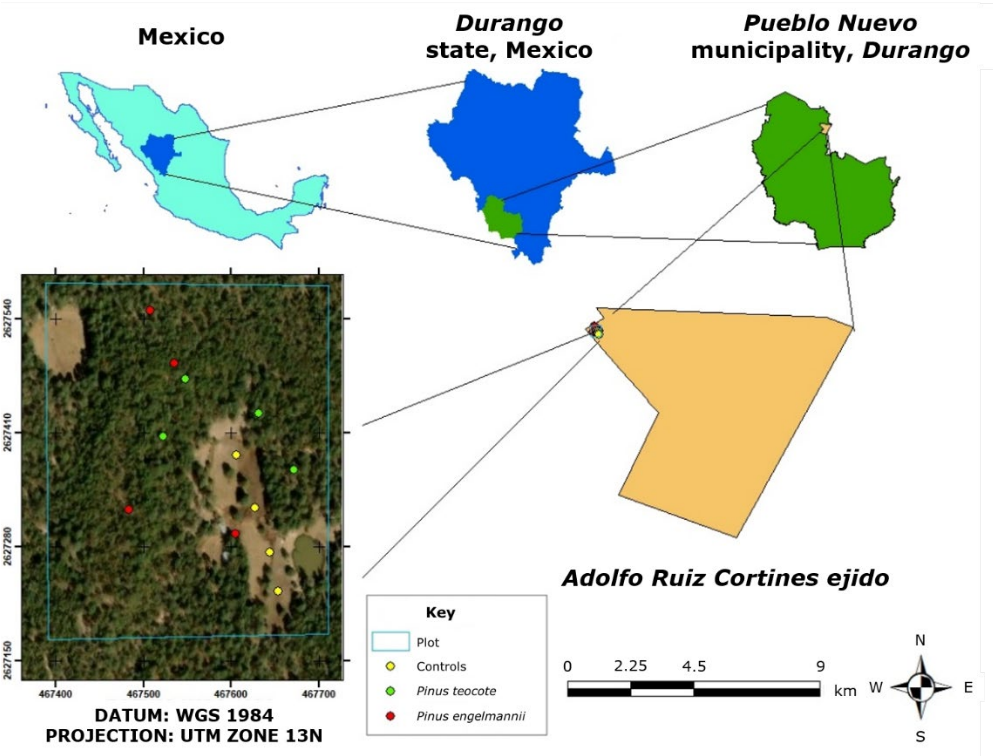


Figure 1. Location of the study area.

The types of climate present are temperate sub-humid and semi-cold sub-humid, with summer rains (García, 2004). The rainfall is scarce, although at certain times of the year precipitation can reach important intensities in the range of 5 to 50 mm, with an average annual precipitation of 800-1 200 mm, while March, April, and May are the least rainy months of the year (INEGI, 2014).

According to the soil chart of INEGI (2014), the soils of the study area are of the Lithosol, Regosol and Cambisol types, with an average depth of 10 cm, an average texture, and 18 % stoniness.

The most important plant communities in the *ejido* are composed of mixed forests with species of the *Pinus*, *Quercus* L., as well as shrub species (INEGI, 2014).

Studied species

The studied species were *Pinus teocote* Schltdl. & Cham. and *Pinus engelmannii* Carrière, which are important in terms of their representativeness in the *ejido*.

Pinus teocote has a wide natural distribution in Mexico and Guatemala, growing at altitudes of 1 000 to 3 000 m in clay loam soils, in sub-humid and humid climates with annual rainfall in the range of 1 000 to 1 500 mm (López *et al.*, 2017). It is a tree of medium size, with a rounded and irregular crown, reaching heights of 10 to 20 m (Guerra-De la Cruz *et al.*, 2019). Its fascicles are surrounded by a dark brown sheath measuring 5 to 9 mm in length, with three acicular leaves triangular in shape, flexible, 7 to 10 cm long, and with serrated edges. Its cones are symmetrical, ovoid or ovoid-conical, measuring 4 to 7 cm in length, with flattened or slightly elevated scales and uniform apophyses (Pérez *et al.*, 2019). Its fruits ripen and disperse their seeds during the month of January. The seeds are blackish, angular, measuring approximately 4 mm in length and 2 to 3 mm in width. The tree is recognized by its coarse, wrinkled, grayish bark; its wood is hard, heavy, and resinous (Alba, 2006).

Pinus engelmannii, commonly known as royal pine, Apache pine, Arizona longleaf pine, and red pine, grows on dry, moderately moist canyon slopes, ridges, plateaus, lower slopes, valleys, and stream terraces, at altitudes of 1 500 to 2 700 m (5 000-2 000 ft), in semi-arid to temperate-sub-humid climates (Ávila-Flores *et al.*, 2016).

A medium sized tree, it is 15 to 25 m tall and measures 60 to 80 cm in diameter at breast height. It has evergreen leaves; it blooms in winter, and its cones ripen from late October to mid-December. Its natural distribution is restricted to the states of *Chihuahua*, *Sonora*, *Sinaloa*, *Durango* and *Zacatecas (*Santos *et al.*, 2018).

Measurement of rainfall components

Interception losses were estimated with incident rainfall, direct rainfall, and stemflow as variables. Incident rainfall is the total rainfall that descends upon the vegetation cover. Direct precipitation is the fraction of rainfall that passes directly through the foliage, leaves and branches. Stemflow consists of the fraction of rainfall that flows down the canopy and reaches the ground (Cantú and González, 2002). A 2 500 m^2 plot was established for the selection of the two species of interest. The components were measured after each rain event, considered as any rain, drizzle or shower, separated from the previous and subsequent one by a dry period of at least 8 hours (Cantú and González, 2005).

In the selection of the four individuals per species, we considered dominant trees that were free of pests or any other physical damage, with similar dasometric characteristics of normal diameter (cm), height (m), and crown area (m^2); we determined the representativeness of the canopy of each taxon based on the latter variable (Table 1).

Table 1. Mensuration characteristics of the species under study.

Species	Normal diameter (cm)	Height (m)	Crown area (m^2)

Pinus teocote Schltdl. & Cham.	33	17.0	7.1
Pinus engelmannii Carrière	35	15.0	7.0

Incident precipitation was collected through U-shaped, 10 cm wide×100 cm long PVC gutters (model Nmx-e-199/1, TRUPER®) of 0.1 m^2 connected by means of hoses (model MAN-1R, TRUPER®) to 20 L containers (Figure 2A). The gutters were covered with a mesh to prevent leaf litter, insects or any other material from obstructing water flow. Four gutters were installed at 1 m from the ground in an open area without trees, at about 25 m from the tree cover, in order to prevent the trees from influencing the capture of incident rainfall (Yáñez-Díaz *et al.*, 2014).

A = Direct and incident rainfall; B = Stemflow.

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

For the collection of direct rainfall, the same type of gutters described above were utilized. Four gutters per species were placed under the canopy. Each was connected to a 20 L plastic container and covered with a protective mesh to avoid contamination by leaf litter and insects. They were not removed during the entire study period.

The same four trees per species that were used to measure direct rainfall were used to record stemflow, using plastic hoses (TRUPER®, model MAN-1R) of 3 cm diameter —one hose per tree—, with perforations measuring 1.5×2.5 cm, separated from each other at distances of 4 cm. The hoses were attached to the trunks at a height of 1 m and placed in a spiral fashion, in such a way that they went around the trunk two and a half times, and they were fixed with 1" nails and sealed with silicone where the water was transported to the collection cans (Figure 2B) (Cantú and González, 2002). They were kept fixed on the selected trees during the entire experimental period. Figure 1 of the location of the study area shows the location and distribution of the trees within the study plot.

The analysis of interception losses for each species was estimated as the difference between incident rainfall and the sum of direct rainfall and stemflow, by applying descriptive statistics and linear regression analysis with the following formula (Cantú and González, 2005):

$$I = PI - (PD + SF)$$

Where:

I = Interception losses (mm)

PI = Incident rainfall (mm)

PD = Direct rainfall (mm)

SF = Stemflow (mm)

In the case of the rainfall washing or throughfall, the electrical conductivity (*EC*) and pH were determined as physical and chemical properties of the water in the samples collected in each component (direct rainfall, incident precipitation, and stemflow) by direct measurement of an electrode of a potentiometer/conductivity meter (model C6010, Consort Multi-Parameter Analyser®). It is important to know the relationship between the rainfall and the *EC* and pH content, as these concentrate nutrients that are indispensable for plant development (Béjar *et al.*, 2018).

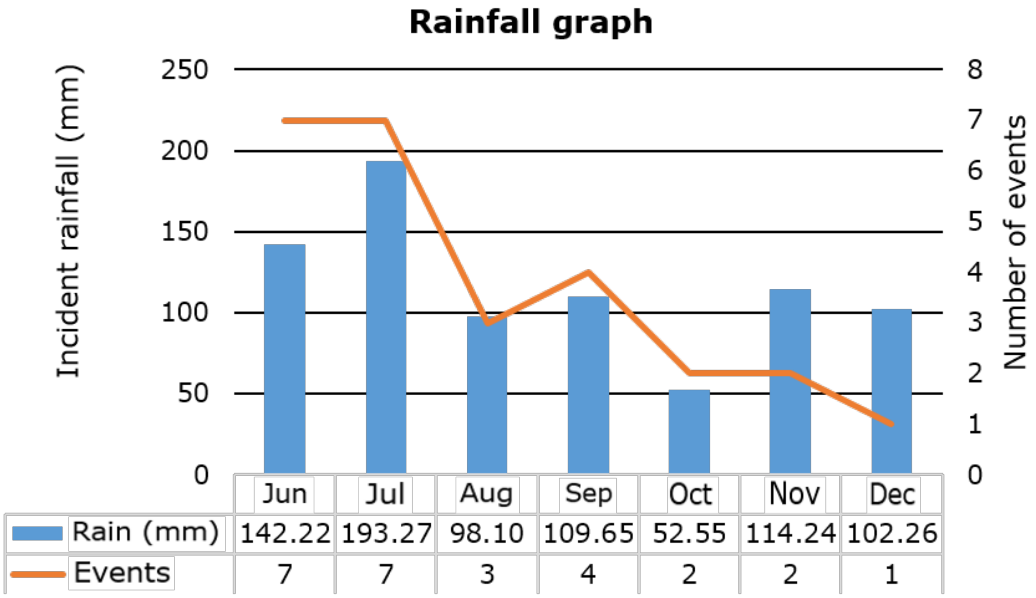
The pH and electrical conductivity (μS cm^{-1}) values estimated for the various rainfall components were subjected to a Kolmogorov-Smirnov normality test with the SPSS version 22.0 statistical package (Méndez and Cuevas, 2013). The distribution of the data did not meet the assumption of normality; therefore, a statistical analysis was performed using the nonparametric Kruskal-Wallis test with the SPSS Statistical Package version 22.0 (Méndez and Cuevas, 2013).

Results and Discussion

Incident rainfall

26 rainfall events were recorded during the period from June 2 to December 31, 2019, with a cumulative total of 812.28 mm (Figure 3). These values coincide with those cited by Domínguez-Gómez *et al.* (2022), who during eight months of study

recorded 30 rainfall events and a cumulative rainfall of 856.25 mm in the same *ejido*. Higher values were recorded by Rodríguez *et al.* (2010) in a 9-year-old *Pinus pinaster* Aiton plantation, where they studied the characteristics of net rainfall and estimated a total rainfall of 938.2 mm during 2007. The differences between the studies are due to the fact that the climatic conditions (altitude, temperature, annual precipitation) are different for each area; also, the number of events and the characteristics of rainfall exert great influence: the duration of the rainfall event can vary between a few minutes, hours, or even several days. On the other hand, the frequency with which rainfall occurs in each study area is different from the average time that elapses between two rainfall events.



	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rain (mm)	142.22	193.27	98.10	109.65	52.55	114.24	102.26
Events	7	7	3	4	2	2	1

Figure 3. Number of rainfall events and monthly rainfall during the study period.

Direct rainfall

The average direct rainfall for *P. teocote* and *P. engelmannii* amounted to 84 % of the incident precipitation. The linear regression analyses yielded values of the Coefficient of Determination (R^2) of 0.829 (*P. teocote*) and 0.857 (*P. engelmannii*) (figures 4 and 5), which evidenced that the increase in direct rainfall given the incident rainfall is the same; that is, for each unit increase in incident rainfall, direct rainfall increases by 0.84 units. The same effect was observed in both species, although the ordinate at the origin was different. Rodríguez *et al.* (2010) cite values of 72.7 % of direct rainfall in a *Pinus pinaster* plantation. In a tropical montane pine-oak forest in central Mexico, Gómez-Tagle *et al.* (2015) report 80.6 % of direct rainfall, with a Coefficient of Determination of R^2=0.976, indicating that the water that falls through the tree canopy is highly correlated with total rainfall. Tamez *et al.* (2018) estimated values of 77 % for *Acacia farnesiana* (L.) Willd., 76 % for *Condalia hookeri* M. C. Johnst., 86 % for *Leucaena leucocephala* (Lam.) de Wit, and 83 % for *Casimiroa greggii* (S. Watson) F. Chiang. Direct rainfall in particular is affected by leaf density, canopy shape, tree leaf arrangement and branch position.

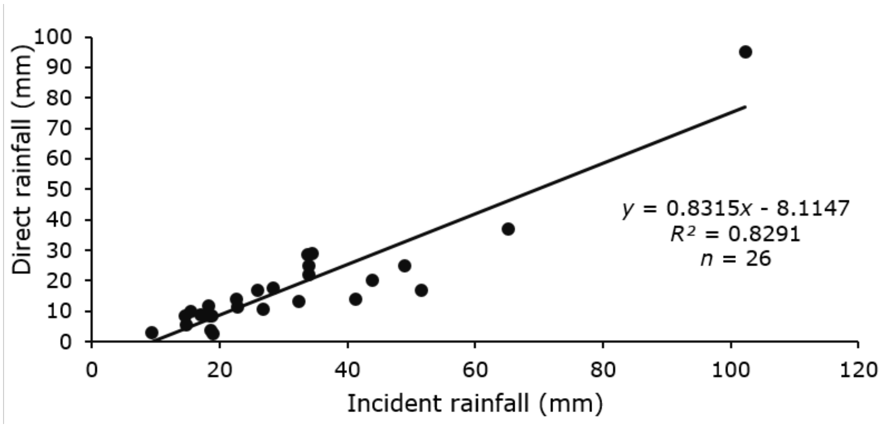


Figure 4. Relationship between incident rainfall and direct rainfall in *Pinus teocote* Schltdl. & Cham.

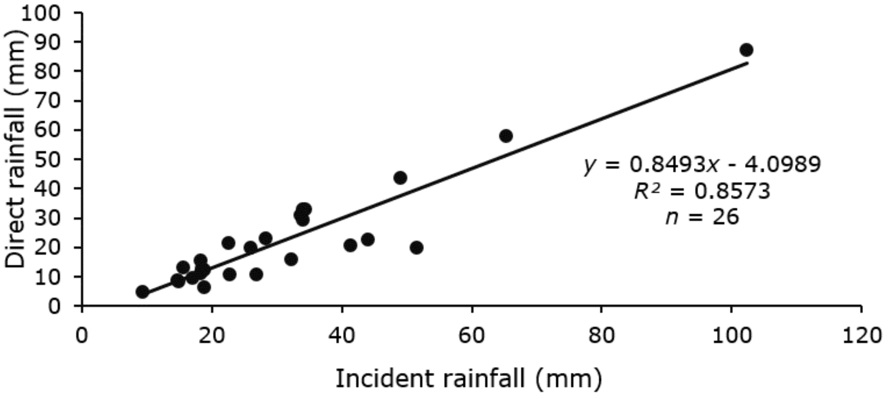


Figure 5. Relationship between incident rainfall and direct rainfall in *Pinus engelmannii* Carrière.

Stemflow

For the two species, the average stemflow was 0.31 % of the total incident rainfall; no differences are observed between the two species because they have similar mensuration and phenotypic characteristics. The values of the Coefficient of Determination were R^2=0.766 (*P. teocote*) and 0.605 (*P. engelmannii*) (figures 6 and 7). Figures 6 and 7 also show that the incident rainfall of 20 to 40 mm has a better fit; therefore, they explain the stemflow more clearly. Domínguez-Gómez *et al.* (2022) recorded similar values for total rainfall of 0.46 % in *P. engelmannii* and 0.11 % in *Quercus rugosa* Née.

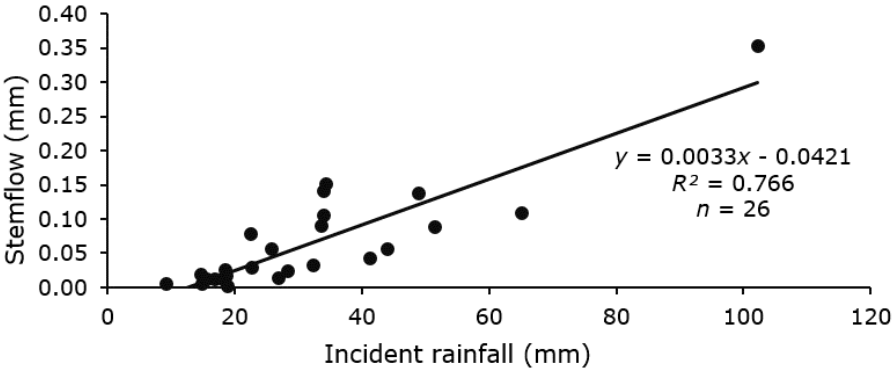


Figure 6. Relationship of incident precipitation and stemflow for *Pinus teocote* Schltdl. & Cham.

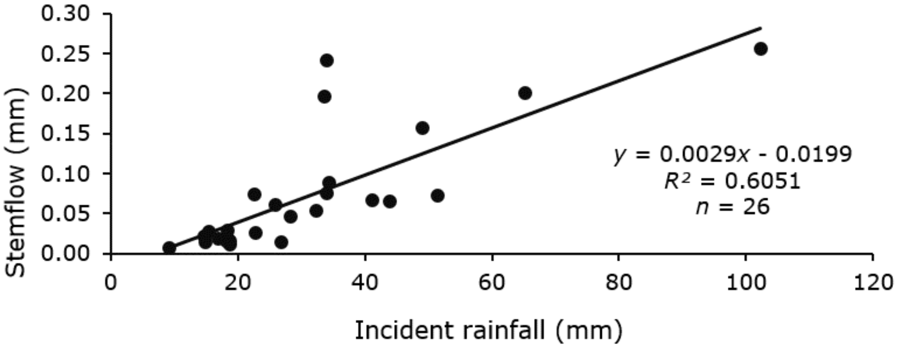


Figure 7. Relationship of incident precipitation and stemflow in *Pinus engelmannii* Carrière.

Conversely, Huber and Oyarzún (1983) document higher figures in an adult forest of *Pinus radiata* D. Don, with a 13 % stemflow; the different percentages of this contribution are explained mainly by the characteristics of rainfall and meteorological conditions. According to Rodríguez *et al.* (2010), the stemflow in a

Pinus pinaster plantation was 4.0 % of the total precipitation; Tamez *et al.* (2018) point out that this component is an important source of water supply for plant species that have been suppressed or that develop in the lower strata of forests.

In general, the water that reaches the ground can be associated with species, age, dasometric variables (height and normal diameter), crown area (Table 1) and the direction of branches towards the stem. Certain taxa have a cleaner shaft, this helps the branches not to obstruct the path of the water that arrives directly to the stem if the bark is rough or has striations.

Interception losses

Canopy interception losses amount, on average, to 15.76 % for the two species, with a relatively low mean Coefficient of Determination for both species (R^2=0.155). The above indicates that the ratio of incident rainfall to interception loss is determined by other factors such as wind and rainfall intensity and time span, or whether the rainfall occurred during the day or at night (figures 8 and 9). Reportedly, the higher the incident rainfall, the lower the interception losses; minor rains tend to be better intercepted by the tree canopy. According to Echeverría *et al.* (2007), a forest lost 33 %, and a meadow 13 % due to evapotranspiration. Cantú and González (2005) calculated interception losses of 18, 15, and 22 % for *Acacia berlandieri* Benth., *Acacia rigidula* Benth. and *Diospyros texana* Scheele, respectively. Yáñez-Díaz *et al.* (2014) cited interception losses of 25, 15, 34, and 33 % for *Prosopis laevigata* (Humb. & Bonpl. *ex* Willd.) M. C. Johnst., *Eucalyptus* *camaldulensis* Dehnh., *Ebenopsis ebano* (Berland.) Barneby & J. W. Grimes and *Helietta parvifolia* (A. Gray *ex* Hemsl.) Benth., respectively.

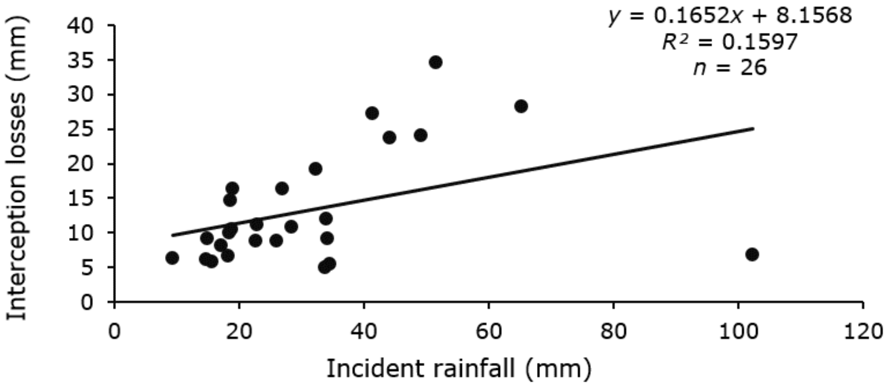


Figure 8. Relationship between incident rainfall and interception losses of *Pinus teocote* Schltdl. & Cham.

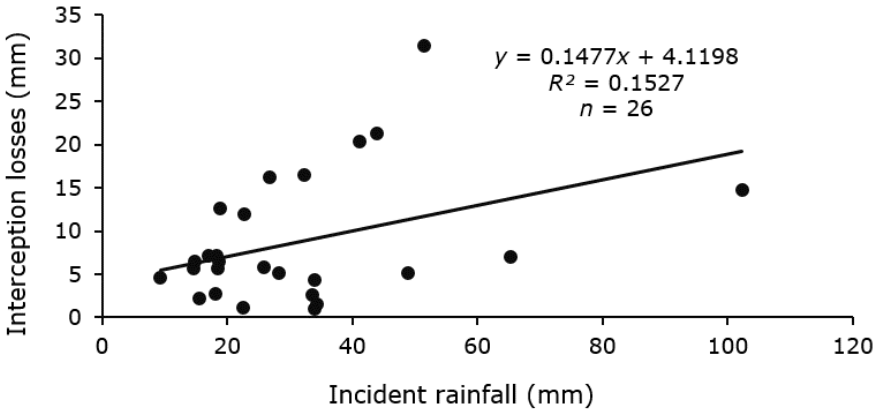


Figura 9. Relationship between incident precipitation and interception losses of *Pinus engelmannii* Carrière.

León *et al.* (2010) describe interception losses in a pine forest with 19 %, an oak forest with 14.5 % and a cypress forest with 10.2 %. Gómez-Tagle *et al.* (2015) indicate that the highest percentage of interception occurs in small events (<5 mm), but tends to stabilize at about 20 % for gross precipitation >20 mm. Huber and Oyarzún (1983) state that rainfall with less than 20 mm, discontinuous, or of low intensity allows higher interceptions, because the rain is retained almost entirely by the canopy or is exposed to a longer time to evaporate. Likewise, according to Iroume and Huber (2000), the percentage of intercepted water decreases as rainfall totals increase, but after 30 mm of rainfall, the relative amounts of interception tend to remain constant at 20 and 30 %. Rainfall interception for each ecosystem can be influenced primarily by the density and canopy cover of each species, average temperatures, wind speed, and raindrop size. Interception has been shown to be an important component affecting microclimates and water balance, as it affects the amount of rainfall reaching the ground.

Rainfall washing

An average pH value in the incident precipitation of 5.7 was obtained; for direct precipitation in *P. teocote* and *P. engelmannii* it was 4.7 on average; this means that the water that passed through the tree crowns slightly decreased the pH in relation to the incident precipitation; and for stemflow, when rain runs through the stem of the tree it acidifies a little, reaching an average value of 3.8. Domínguez-Gómez *et al.* (2022) recorded minimum and maximum pH values of 4.46 and 5.78 for direct rainfall at sites with *P. engelmannii*, while the values for *Q. rugosa* were 5.16 and

6.78, respectively. The stemflow indicates that the highest pH is 6.08 for *P. engelmannii*, and 7.51 for *Q. rugosa*. The differences in pH between each studied species are ascribed to the accumulation of particles in the leaves, branches and stems, as the retained and accumulated atmospheric particles are carried by the water until they reach the soil (Béjar *et al.*, 2018). The wind exerts an influence, as it carries volatile ions that are found in the atmosphere and causes them to adhere to the tree. Furthermore, each of the species have different characteristics that increase or reduce the chemistry of water flowing from the leaves and stem to the ground. High pH values can alter the functioning of forest ecosystems, mainly due to the nutrient imbalance caused by soil acidification, which hinders the growth processes (generative and vegetative) of plants (Pérez-Suárez *et al.*, 2006).

The mean value of the electrical conductivity in incident rainfall was 29.5 μS cm^{-1}, while in direct rainfall it was 48.9 μS cm^{-1} for *P. teocote* and 39.9 μS cm^{-1} for *P. engelmannii*; in the case of the stemflow, it was 87.9 μS cm^{-1} for *P. engelmannii* and 92.5 μS cm^{-1} for *P. teocote*. Pérez-Suárez *et al.* (2006) obtained much lower values than those of the present study: the value of *EC* at *Desierto de los Leones*, Mexico City, was 8 μS cm^{-1}, and 7 μS cm^{-1} in *Zoquiapan*, State of Mexico, where reportedly, there was an increase in *EC* at the end of the rainy season, this is probably due to a dilution effect, for as the amount and frequency of rainfall decreases, there is a greater accumulation of ions in the atmosphere, which are washed away by the subsequent rain.

EC refers to the conditions that affect the soil-plant ratio, the quality and availability of water, the nourishments for plants, and the microorganisms. The accumulation of salts in the soil can render water absorption difficult for plants, as well as generate toxicity of specific ions and interference of salts in physiological processes (indirect effects), reducing the growth and development of plants (Terrazas, 2019).

Kruskal-Wallis Test

The Kruskal-Wallis analysis of variance test for significant differences in pH and *EC* of incident rainfall, direct rainfall and stemflow for the two species in 26 rainfall events revealed significant differences ($P<0.05$) in most of the events for the two variables. These results indicate that rainfall deposited on the canopy (direct precipitation) and running from the tree trunk (stemflow) is enriched in terms of organic matter and mineral elements as a product of leaf and tree trunk exudates, which makes it chemically different from rainfall from incident precipitation.

Conclusions

Pinus species not only offer ecological and economic benefits for the northern part of the country, due to their timber exploitation, but they are also very important in the hydrological cycle*.* The data obtained are useful for making better decisions for watershed recovery and afforestation, and drought and flood reduction through reforestation programs in which the selection of species to be planted relies on criteria based on the results of this study. The information generated in this research shows that *Pinus teocote* has the capacity to retain more water and for this reason can be used to reforest areas at risk of flooding; conversely, *Pinus* *engelmannii* incorporates more water to the soil and is therefore recommended for programs of the recovery and maintenance of hydrological basins.

Direct rainfall is affected by leaf density, crown shape, tree leaf arrangement, and branch position. The study of pH and electrical conductivity of rainfall shows chemical variations in its composition, according to the behavior of rainfall through the canopy, and is also closely related to the number of millimeters of rainfall during the event: the more rainfall, the lower the pH. Electrical conductivity tends to augment as it passes through the canopy and increases even further with the stemflow.

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Conflict of interest

The authors declare that they have no conflict of interest.

Contribution by author

Cristiam Hernández Manzanarez: field data collection, interpretation of results, statistical analysis, structure and drafting of the manuscript; Tilo Gustavo Domínguez Gómez: research design, interpretation, revision and editing of the manuscript; Ernesto Rodríguez García: field data collection, analysis of field data, structure and drafting of the manuscript; Israel Cantú Silva: revision, design and interpretation of the results; José Javier Corral Rivas: editing of the manuscript; José Guadalupe Colín: editing and revision of the document; Humberto González Rodríguez: revision and structuring of the manuscript.

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