Pérdidas por intercepción de lluvia en el Matorral Espinoso Tamaulipeco bajo diferentes intensidades de raleo

Rainfall interception loss in the Tamaulipan thorn scrub under different thinning intensities

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Resumen

La cantidad de precipitación que llega a la superficie terrestre depende en gran medida de la cobertura vegetal. Está cubierta intercepta gran parte de la precipitación y la almacena temporalmente, donde es devuelta a la atmósfera por medio de la evapotranspiración. El objetivo del presente trabajo fue cuantificar y analizar las pérdidas por intercepción de lluvia bajo diferentes intensidades de raleo en un área de Matorral Espinoso Tamaulipeco (MET) en el noreste de México. En la Facultad de Ciencias Forestales dentro del municipio Linares, Nuevo León, se establecieron cuatro parcelas para la precipitación directa bajo cuatro intensidades de raleo; 75, 50, 25 y 0 %, y una parcela para la precipitación incidente. Se registraron 79 eventos de lluvia (907.6 mm) para 2016 y 2017. Los porcentajes de intercepción de lluvia fueron de 16, 29, 34 y 41 % para las intensidades de raleo de 75, 50, 25 y 0 %, respectivamente. Los análisis de regresión lineal simple señalan que la precipitación directa representa 83, 70, 65 y 58 % del total de precipitación para las intensidades de 75, 50, 25 y 0 %, respectivamente. Los coeficientes de determinación para precipitación directa e incidente fueron de r^2=0.8651 y r^2=0.8017 para los raleos al 25 y 0 %; esto indica que a medida que se incrementó el raleo, aumentó la precipitación directa. Las características del dosel y el follaje de las distintas especies del MET pudieron influir en el porcentaje de intercepción de lluvia.

Palabras clave: Hidrología forestal, intensidad de raleo, Matorral Espinoso Tamaulipeco, pérdidas por intercepción, precipitación directa, saturación del dosel.

Abstract

The amount of precipitation that reaches the earth's surface depends to a large extent on the vegetation cover. This cover intercepts much of the precipitation and stores it temporarily, where it is returned to the atmosphere by means of evapotranspiration. The objective of this study was to quantify and analyses the rainfall interception loss under different thinning intensities in an area of the Tamaulipan thorn scrub (MET) in northeastern Mexico. At the School of Forest Sciences in *Linares*, *Nuevo León*, Mexico, four plots were established for throughfall under four thinning intensities; 75, 50, 25 and 0 %, and a plot for gross rainfall measurement. 79 rainfall events were recorded (907.6 mm) for the years 2016-2017. The percentages of rainfall interception were 16, 29, 34 and 41 % for the thinning intensities of 75, 50, 25 and 0 %, respectively. Simple linear regression analyses indicate that throughfall represents 83, 70, 65 and 58 % of total precipitation for intensities of 75, 50, 25 and 0 %, respectively. The coefficients of determination for throughfall and gross rainfall were of r^2 = 0.8651 and r^2 = 0.8017 for the intensities to 25 and 0 %. This indicates that as the intensities is increased, throughfall is increased. The characteristics of the canopy and foliage of the different species of the MET could influence the percentage of rainfall interception.

Key words: Forest hydrology, thinning intensities, Tamaulipan thorn scrub, interception loss, throughfall, canopy saturation.

Introduction

The amount of precipitation that reaches the soil surface depends, to a large extent, on the percentage of vegetation cover (Pérez *et al.,* 2016). This cover intercepts part of the precipitation and stores it temporarily on the surface of the leaves and branches, where it is returned to the atmosphere by evaporation. The interception is that part of the precipitation stored temporarily on the surface of the leaves and branches, while the interception losses correspond to the evaporation of the water stored in the trees canopy (López *et al.,* 2017).

The main components of the process of redistribution of the gross precipitations in a plant thinning area are: 1) loss by interception, or the amount of water retained by the canopy and that is then evaporated or absorbed by the plants; 2) direct precipitation, also known as infiltration through foliage or rain under the canopy, which is that part of the precipitation that reaches the ground (Besteiro and Rodríguez, 2012; Sun *et al*., 2015).

These differences are due to the fact that the amount of intercepted water does not depend only on the species under thinning, but also on the rainfall regime and the demand for the evapotranspiration existing in each specific area. Interception of rainfall is indirectly estimated as the difference between gross precipitation (above the canopy) and direct precipitation (below the canopy). The amount of water flowing by the canopy through clearings, or drip from leaves and branches known as direct precipitation (Xiao *et al.,* 2000; Huber, 2003), is considered the main source of water supply to the soil; in general, their contributions constitute between 74 and 80 % of the gross precipitation (Yáñez *et al.,* 2014). The level that exists between the canopy and the soil, as well as the clearings between the canopy and the wind conditions, are characteristics that influence the amount of direct precipitation (Crockford and Richardson, 2000).

The precipitation and the recharge pattern of the aquifers are crucial to understand the effect that a forest plantation exerts on the water resource and its management. Interception and vegetation cover are related; the more densely it is

covered with vegetation, the greater the volume of rain will be intercepted and the runoff will be smaller (Prado *et al*., 2007).

Any change in the cover can cause the difference in the recharge of the basin and affect the local hydrology in terms of volumes and times of runoff (Calvo *et al.,* 2012).

The scrub is the most abundant and historically used resource in the arid and semiarid zones of Mexico. The Tamaulipan thorn scrub (MET) extends over 200 000 km^2 of northeastern Mexico and south Texas. It is a shrubby community formed by the dominance of thorny, deciduous species a large part of the year. Interception in arid and semi-arid ecosystems is important mainly from the irregularity and scarcity of rain, which affects the space-time variability of soil moisture (Yáñez *et al.,* 2013).

The aim of this study was to determine the amounts of rain intercepted at different intensities of thinning within the Tamaulipan thorn scrub, by means of measurements of the gross precipitation and direct precipitation, based on the hypothesis that states that different intensities of thinning differ the amount of interception of rain and modify the amount of water that enters this type of ecosystem governed by irregular rainfall.

Materials and Methods

Study area

The study was carried out in the *Campus de la Facultad de Ciencias Forestales de la Universidad Autónoma de Nuevo León* (Campus of the School of Forest Sciences of the Autonomous University of Nuevo León) (24°47' N; 99°32' W) (Figure 1), at 350 masl, which is located 8 km away towards the south of *Linares* municipality, approximately. The type of climate according to Köppen modified by García (1981) is described as semi-warm sub-humid with rainfall mainly in summer. The average annual air temperature ranges between 14.7 °C in January and 22.3 °C in August, although temperatures of 45 °C are common in summer. The average annual rainfall is 805 mm with bimodal distribution in April and September (González and Cantú, 2001).
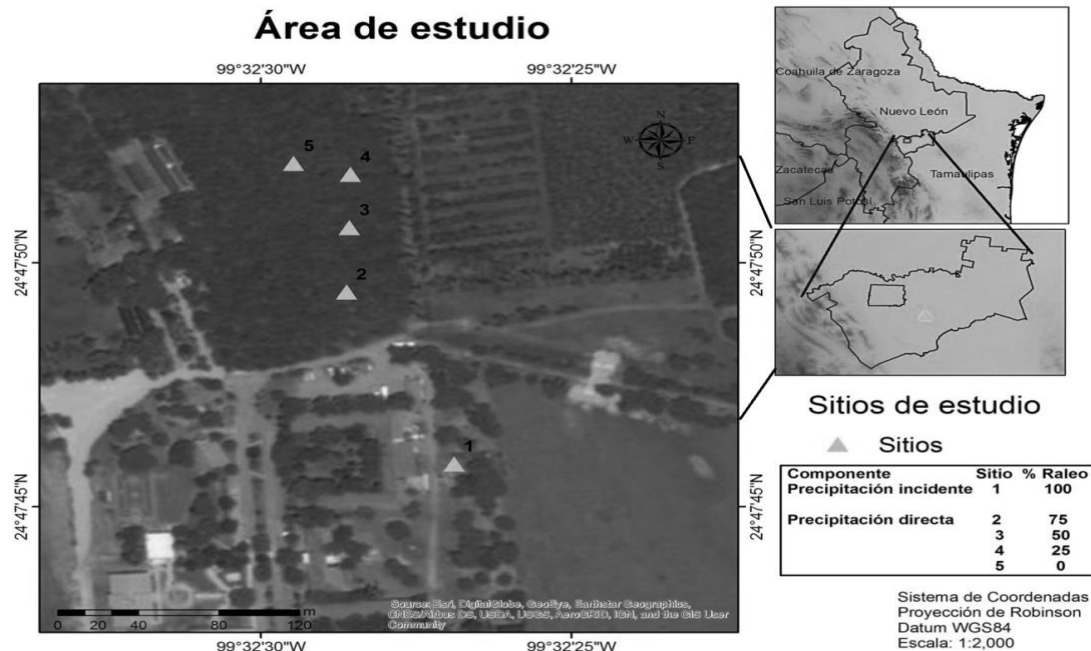
Área de studio = Study area; *Sitios de studio* = Sampling sites; *Componente* = Component; *Precipitación incidente* = Gross rainfall; *Precipitación directa* = Throughfall; *Raleo* = Thinning

Figure 1. Location of the study area and sampling sites, School of Forest Sciences, UANL.

The soils of the place are of the deep Vertisol type with a dark gray color; clay-silt with high montmorillonite, which expands and contracts in relation to changes in soil moisture content.

The predominant vegetation is the Tamaulipan thorn scrub. It is composed of a great diversity of shrubs, grasslands and dense and thorny trees, with different growth patterns and dynamics, as well as phenological developments and foliar longevity (Alanís, 2006).

The MET is made -up by the dominance of thorny species, deciduous for a large part of the year or aphids (without leaves). In this regard, Yáñez (2013) recorded in this type of vegetation a total of 11 families distributed in 18 species with a total of 285 individuals, whose average height is 4.17 m; the highest dominance for coverage corresponds to *Diospyros texana* Scheele and *Condalia hookeri* M. C. Johnst. (Brazil). The most outstanding ones in terms of abundance, dominance and

frequency were the first mentioned and *Havardia pallens* (Benth.) Britton & Rose, of 48.25 and 36.2 % of Importance Value Index (IVI), respectively. The species with the lowest IVI were *Caesalpinia mexicana* A. Gray with 2.15 %; *Helietta parvifolia* (A. Gray) Benth. with 2.92 % and *Parkinsonia aculeata* L. with 2.99 %.

Measurement of precipitation components

Plots of 100 m^2 (10 × 10 m) were established in which the percentage of coverage for each plot was measured and the required thinning was performed to obtain 100, 75, 50 and 25 % of vegetation cover and there the collectors were placed for direct precipitation.

The experiment lasted about 18 months (April 2016 to September 2017); 79 rain events were collected, which met the established parameters of at least six repetitions of eight gutters established for each plot. The rain event is a concept that refers to the period of precipitation consisting of rain, drizzle or shower, continuous or separated from the previous and subsequent, for a dry period for a minimum period of eight hours (Yáñez *et al.,* 2014).

Rain-volume measurements were recorded after each event and a portion was taken for analysis with a Corning brand model 542 pH conductivity meter. For the incidental and direct precipitation, pvc gutters of 0.1 m^2 (10 cm wide × 100 cm long) were used in U-shape, connected by means of hoses to 20 L containers. These 8 gutters were covered with a mesh to prevent obstruction of leaf litter and insects and fulfilled the function of rain gauges; they were installed in each of the plots for each intensity of thinning (direct precipitation) and in an open area without trees (gross precipitation), adjacent to the experimental plots.

Data analysis

To determine the amount of rainfall obtained from these two components, the water collected (mL) was divided by the area of the gutter (m^2) and multiplied by 10 to transform the rainfall mm collected.

Interception losses

With the above-described measurements of gross precipitation and direct precipitation the interception losses were estimated with the expression:

$$I = Pi - Pd \qquad\qquad (1)$$

Where:

I = Interception losses (mm)

Pi = Gross precipitation (mm)

Pd = Direct precipitation (mm)

The data obtained were subjected to an adjusted linear regression to determine the final percentage of interception for the applied model.

Canopy storage capacity

The relevant characteristic of a vegetation cover is the amount of water stored in the canopy in a single rainfall that is sufficient to exceed the capacity of the vegetation and thus retain water on its surface. This condition is known as interception storage capacity or saturation capacity of the canopy, which on this occasion was determined by relating the gross precipitation against direct precipitation for individual and continuous rain events up to a maximum value of

2.5 mm, knowing the value of the intercept of the adjusted linear model of the data (Leyton *et al.*, 1967).

The pH and electrical conductivity data did not show a normal distribution by the Kolmogorov-Smirnov test; they were statistically analyzed with the non-parametric Kruskal-Wallis test, using the statistical package SPSS (2005).

Results and Discussion

The gross precipitation derived from 79 events during the course of the experiment totaled 907.6 mm. Figure 2 shows the behavior of rainfall during the study period; the interval of individual rains was from 0.39 to 60.15 mm, with values less than 5 mm in 40 % of the total of the analyzed events; between 10 and 20 mm in 22 %, between 5 and 10 mm in 20 %; between 20 and 30 mm in 9 %; between 30 and 40 mm in 5 %, between 40 and 50 mm in 3 %; and in less than 1 % of events > 50 mm.
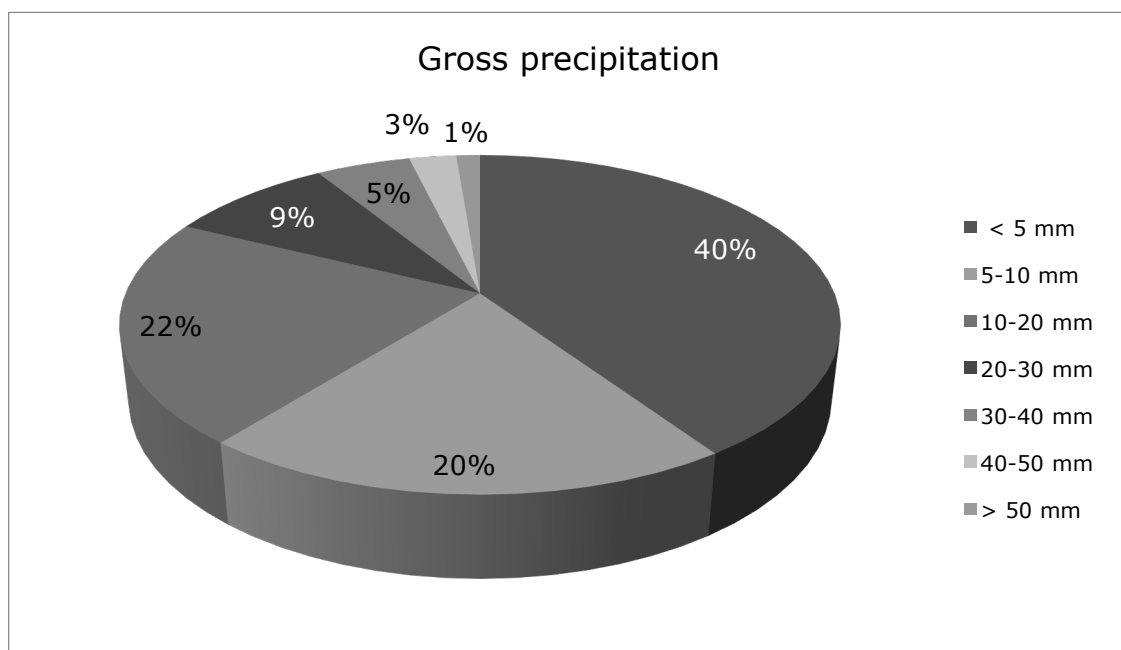
Figure 2. Percentage of rainfall events according to the amount recorded during the experimental period.

The relation between gross precipitation and direct precipitation registered an average coefficient of determination of $r^2 > 0.80$, similar to the results of Besteiro AND Rodríguez (2012), of $r^2 > 0.80$ for a forest plantation of pine and eucalyptus, and of Cantú and González (2005) from 0.78 to 0.85 for *A. berlandieri* Benth., *A. riguidula* Benth. and *Diospyros texana* from MET.

The precipitation that crosses the canopies in the thorny *tamaulipeco* scrub presented a greater amount of rain that reached the ground as the percentage of thinning applied increases; thus, for 75, direct precipitation was 83 %; for 50 %, of 70 %; for 25 %, of 65 % and for 0 %, of 58 %, which indicates that the greater the intensity of thinning, the proportion of rain that reaches the ground is greater (Figure 3). Similar results were obtained by San-Juan (2004) who investigated two comparative plots of *Pinus radiata* D. Don., and their results were 65 and 74 % for direct precipitation, confirming the above.
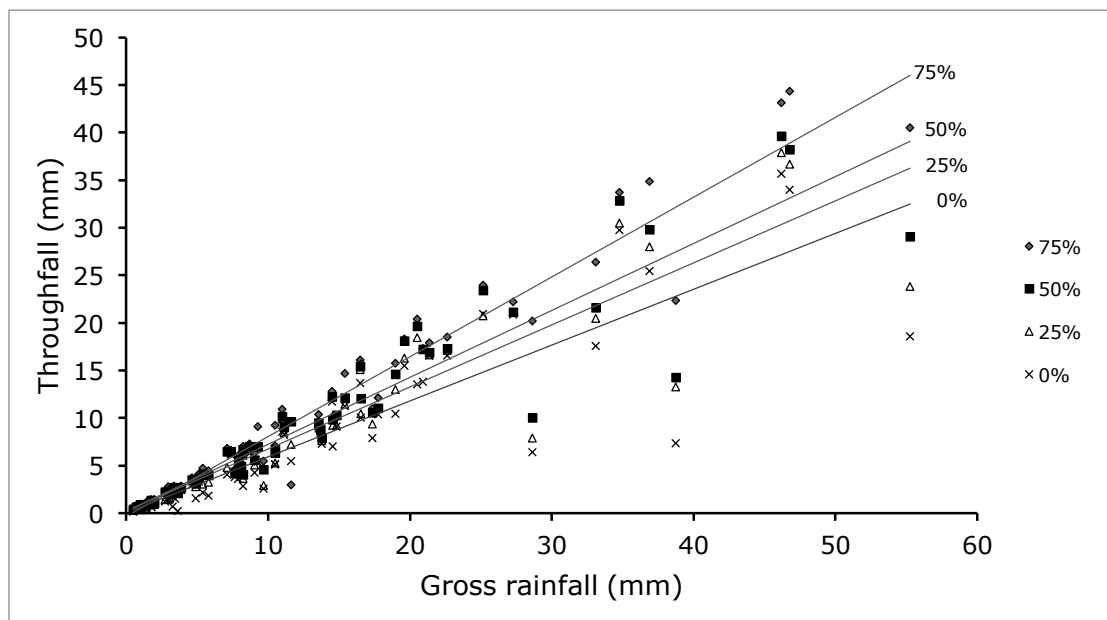

Figure 3. Relation between gross rainfall (mm) and throughfall (mm) for the different thinning intensities.

The results corresponding to the interception losses varied from 16 to 41 %; the plot without thinning had the highest value of interception, followed by those of 25

and 50 %, with losses by interception of 34 and 29 %, while the lowest refer to the plot with 75 % of thinning (Figure 4).
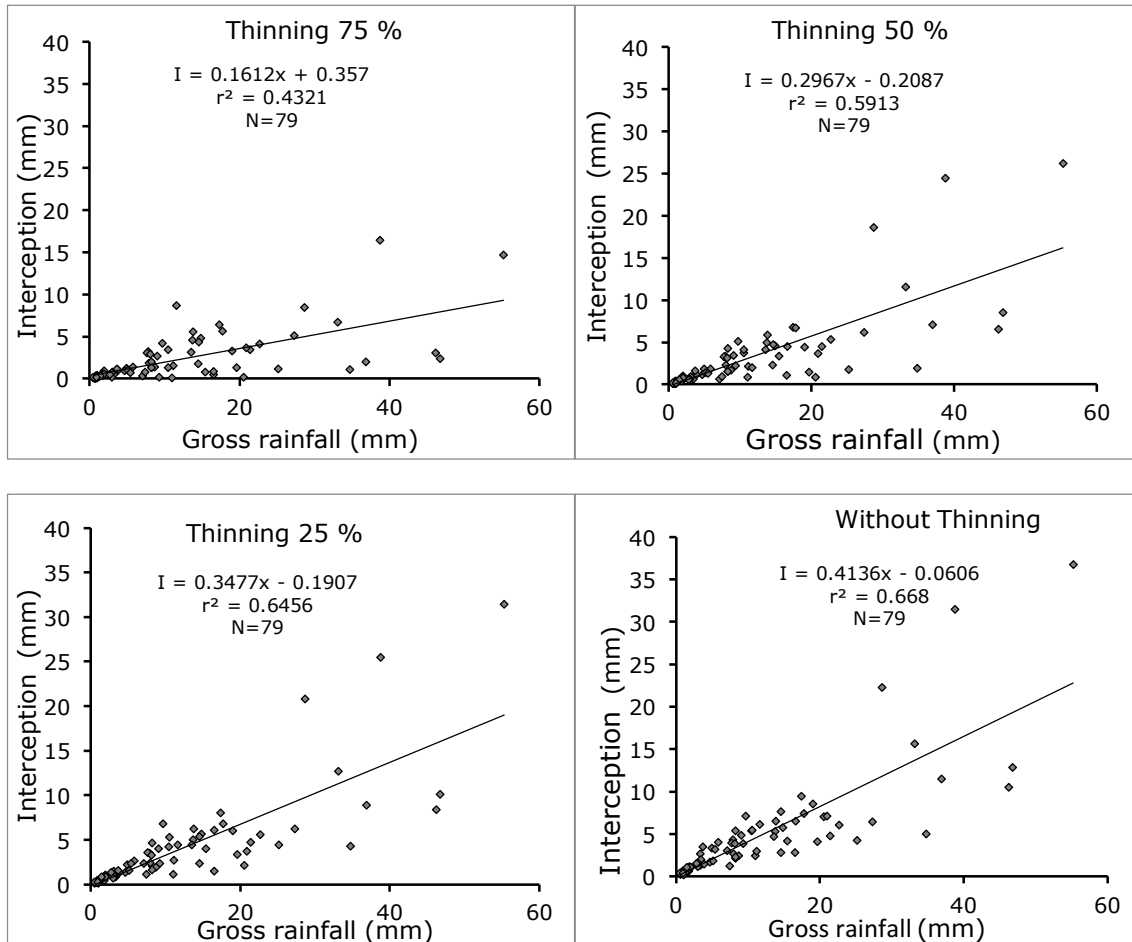
Figure 4. Relationship between interception losses and gross precipitation for for the different thinning intensities.

The results of the regression analysis of the intercept (Table 1), ranged from $r^2 = 0.42$ for thinning 75 % to values of $r^2 = 0.66$ in which there is no thinning, which had a higher percentage of interception losses. This suggests that other factors, such as fog, dew, rain intensity, continuity of the rain event, wind speed, among others, should be taken into account in order to predict the interception more accurately.

Table 1. Summary of the regression analysis to describe interception loss for the different thinning intensities.

Thinning percentage	n	Y-value of the intercept (β_0)			Slope (β_1)			$R^2_{ajusted}$
		(β_0)	(EEE)	(*P*-value)	(β_1)	(EEE)	(*P*-value)	
75 %	79	0.3570	0.3488	0.3093	0.1612	0.0210	<0.001	0.4247
50 %	79	0.2087	0.4657	0.6553	0.2967	0.0281	<0.001	0.5859
25 %	79	0.1907	0.4863	0.6984	0.3477	0.0293	<0.001	0.6409
0 %	79	0.0606	0.5506	0.9126	0.4136	0.0332	<0.001	0.6637

* The Estimated Standard Error (EEE) for the regression coefficients is included.

In the semi-desert zone of northern Mexico, Carlyle (2004) recorded values for interception loss from 15 to 27 % in isolated trees without thinning (2004). In Japan, Sun *et al.* (2015) obtained between 85 and 89 % interception, for 100 % coverage. Also, Calvo *et al.* (2012) concluded that interception losses admit that the percentage of intercepted rain is directly proportional to the cover percentage. In that sense, Donoso (1983, quoted by Valenzuela (2003) mentions that the interception losses reach their maximum values in intermediate ages, when the closing of the canopy takes place.

Cantú and González (2005) reached similar results for *Acacia berlanderi*, *A. rigidula* and *Diospyros texana*, with 18 %, 15 % and 22 %, respectively. In that same sense, Yáñez *et al.* (2014) determined 25% for *Prosopis laevigata* (Humb. & Bonpl.ex Willd.) M. C. Johnst., 33 % for *Helietta parvifolia* (Gray ex Hemsl.) Benth. and 34 % for *Ebenopsis ebano* (Berl.) Barneby & J. W. Grimes.

González *et al.* (2009) quoted by Guevara *et al.* (2010) calculated from 21 % to 27 % in the interception of rain by the canopy of *Prosopis laevigata*. On the other hand, Mastachi *et al.* (2010) reported an average interception from 20.6 to 22 % for *P. laevigata* and *A. farnesiana* (L.) Willd. in the semi-arid region of central Mexico.

When comparing the interception of events in the field and under simulation, Prado *et al.* (2007) identified differences of 15.6 % in the field and 34.6 % in the laboratory, in which the

conditions of wind speed, evapotranspiration and the inclination of rainfalls were some of the factors that most influenced the interception process.

The values obtained for the storage capacity were 0.15 mm for thinning to 75 %; with 0.12 mm for thinning to 25 %; 0.18 mm for thinning to 50 % which was the highest saturation in the canopy, and 0.0063 mm where there was no thinning (Table 2). The saturation value is similar to the data of Cantú and González (2005), with values between 0.14 and 0.24 mm.

Table 2. Canopy saturation values for the thinning treatment studied, determined in 19 individual rain events less than 2.5 mm.

Thinning	Storage capacity	
	Saturation value (mm)	Coefficient of determination r^2
75 %	0.1501	0.8214
50 %	0.1878	0.7920
25 %	0.1251	0.7282
Without thinning	0.0063	0.6534

The results corresponding to the analysis of pH and electrical conductivity indicate in an indirect way the behavior of the nutrients through the washing of the canopy by the precipitation that occurred in the thinning studied. It is generally observed that the pH value shows a similar tendency between incident and thinning precipitation, with neutral numbers (6.7) for the gross precipitation.

Yáñez (2013) established a pH relation around 6.61 for species of the Tamaulipan thorn scrub. In this regard, Calvo and Gómez (2002) defined that the amount of deposition is altered by the canopies of the forest, which also modifies the pH of throughfall and stem runoff; their average values were 6.2 and 5.4 for a pine-oak forest, 6.3 and 6.0 for oak forest and 6.2 and 3.7 for the pine forest. They concluded that the canopies of conifers show a tendency to lower the pH with respect to other species that are important in the hydraulic context for northeastern Mexico.

Jiménez *et al.* (2006) reveal an increase in the values of pH and electrical conductivity, which increases in its passage through the leaves and branches of trees of a secondary forest and forest plantations, which they attribute to the increase of bases. The data of Cantú and González (2002) in this context showed a pattern of increase in electrical conductivity for direct precipitation and fusional runoff from pine, oak and pine-oak canopies. In the present study, the average electrical conductivity was 110.3 µS cm^{-1} for the gross precipitation, which increased in the following order for throughfall: thinning 75 %> thinning 50 %> thinning 25 %> without thinning.

Table 3 lists the results from the comparison analysis of the pH and electrical conductivity values of the gross precipitation and the throughfall between the thinnings studied for the 15 analyzed events. For pH, six occasions show significant differences (P <0.05) and 12 electrical conductivity, which implies greater variability between them. This could be explained as the rain of the rainwash that flows through the canopy is chemically different from the rainfall of the gross precipitation in most of the events that occurred.

Table 3. Analysis of the Kruskal-Wallis test to detect significant differences, in pH and electrical conductivity in the 15 events analyzed of the gross precipitation and throughfall.

Event	Date of the event	pH		Electric conductivity	
		x^2	P value	x^2	P value
1	19/03/2016	14.638	**0.006**	6.755	0.149
2	20/03/2016	16.227	**0.003**	9.486	**0.050**
3	28/03/2016	8.802	0.066	9.029	0.060
4	16/04/2016	13.166	**0.010**	16.755	**0.002**
5	18/04/2016	8.483	0.075	11.519	**0.021**
6	19/04/2016	11.752	**0.019**	10.136	**0.038**
7	24/04/2016	7.095	0.131	14.329	**0.006**
8	13/05/2016	8.520	0.074	13.986	**0.007**
9	15/05/2016	11.080	**0.026**	14.529	**0.006**
10	22/07/2016	9.166	0.057	15.867	**0.003**
11	15/08/2016	7.945	0.094	14.771	**0.005**
12	31/08/2016	6.803	0.147	8.357	0.079
13	03/09/2016	4.696	0.320	11.621	**0.020**
14	06/09/2016	10.190	**0.037**	10.308	**0.036**
15	26/08/2016	9.186	0.057	10.536	**0.032**

P values in bold (P <0.05) indicate differences in the 15 events analyzed.

Conclusions

Based on the results described, it is concluded that according to the hypothesis proposed, the higher the intensity of thinning, the lower losses due to rain interception.

The estimated values of the storage capacity of the canopy influenced the percentages of interception losses. Rainwater evaporates and returns to the atmosphere, having an impact on its performance, which is particularly important in semi-arid ecosystems where this element constitutes one of the main limitations.

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Conflict of interests

The authors declare no conflict of interests.

Contribution by author

Yahaira Wegelmy García Ledezma: realization of the research study, structure, interpretation of results and design of the manuscript; Israel Cantú Silva: design of the research study and interpretation of results; Humberto González Rodríguez: review and structure of the manuscript; María Inés Yáñez Díaz: review and interpretation of results.

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