Original Articles

# Rainfall redistribution under native shrubland and avocado orchards in central Chile: effects of vegetation cover replacement

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## Abstract

Rainfall interception plays a key role in regulating water inputs in semi-arid Mediterranean ecosystems. This study evaluated rainfall redistribution under *Vachellia caven* (native shrubland) and *Persea americana* (orchard) in central Chile using rainfall simulations at two intensities (8 and 25 mm $h^{-1}$). Throughfall (TF), stemflow (SF), and interception (I) were measured in three individuals per species. Rainfall intensity was the main factor controlling redistribution, with significantly higher TF and net precipitation under high intensity ($P < 0.01$). Interception tended to be higher in *V. caven* (up to 87%) than in *P. americana*, although differences were not statistically significant. Stemflow contributed less than 1% of total precipitation in both species. These results highlight the dominant role of rainfall intensity over species traits in rainfall partitioning, with implications for soil water inputs and hydrological processes in semi-arid environments.

*Keywords:* rainfall redistribution, canopy interception, throughfall, stemflow, *Vachellia caven, Persea americana*.

## Introduction

Rainfall redistribution by vegetation is a key ecohydrological process that determines the proportion of water reaching the soil surface and the fraction intercepted by the canopy (interception), part of which is subsequently evaporated back to the atmosphere (interception loss) (Belmonte-Serrato, 1997; Crockford & Richardson, 2000). This redistribution occurs through three main components: canopy interception, corresponding to water temporarily retained on leaves, branches and stems; throughfall, defined as rainfall that passes through the canopy; and stemflow, which reaches the soil by flowing along trunks or stems (Carlyle-Moses et al., 2018; Levia et al., 2015). The sum of throughfall and stemflow constitutes net precipitation, representing the effective water input to the soil (Carlyle-Moses et al., 2018; Crockford & Richardson, 2000). The relative magnitude of these components depends on vegetation structural traits, including canopy architecture, leaf characteristics, and bark roughness, as well as rainfall properties (Crockford & Richardson, 2000; Levia et al., 2015; Magliano et al., 2019; Skhosana et al., 2023). Therefore, the redistribution of rainfall plays a fundamental ecohydrological role to explain differences in water balance between natural ecosystems and agricultural systems (Huber & Oyarzún, 1990; Iroumé & Huber, 2002).

Vegetation cover replacement, defined as the total or partial substitution of one vegetation type by another (Turner et al., 1994), represents one of the main drivers of change in rainfall redistribution processes. Such replacement modifies canopy architecture, leaf density, crown continuity, and surface roughness, thereby affecting water storage and redistribution within the canopy (Aboal et al., 1999; Crockford & Richardson, 2000; Healey & Rover, 2022). Changes in vegetation cover may also alter stemflow dynamics, which depend on bark roughness, stem diameter, and branch inclination (Aboal et al., 1999, Levia et al., 2015). Consequently, the spatial redistribution of rainfall varies among vegetation types, as canopy attributes differ among distinct vegetation covers, and may change substantially when natural ecosystems are replaced by agricultural or forest plantations (Foley et al., 2005; Nosetto et al., 2005).

In the Mediterranean zone of central Chile, extensive areas of native shrubland dominated by *Vachellia caven* have been progressively replaced by avocado (*Persea americana*) orchards (Del Pozo et al., 2024). These two species differ markedly in their ecological context and structural attributes. *V. caven,* a dominant species in semi-arid environments, typically exhibits a multi-stemmed, densely branched architecture with thick bark, small compound leaves, and high structural complexity (INFOR, 2012; Ovalle et al., 2016). In contrast, *P. americana*, a perennial crop characterized by a more open canopy structure compared to native scrubland and more intensive management, has larger leaves and thin, smooth bark (Chanderbali et al., 2024; Ramírez-Gil et al., 2024). These differences suggest possible contrasts in water storage and redistribution processes within the canopy. This vegetation replacement may modify rainfall interception, throughfall, and stemflow proportions, thereby influencing surface water balance and the microenvironment beneath the canopy (Healey & Rover, 2022; Huber & Oyarzún, 1990). However, the effects of this vegetation replacement on rainfall interception, throughfall, and stemflow remain poorly understood.

Based on the above, the objective of this study was to evaluate changes in canopy interception, throughfall, and stemflow associated with the replacement of native *V. caven* shrubland by *P. americana* orchards using controlled rainfall simulations. We hypothesize that differences in canopy structure and morphological traits between species lead to distinct rainfall redistribution patterns, with *V. caven* exhibiting higher interception due to its denser and more complex canopy, while *P. americana* promotes greater throughfall and stemflow associated with its larger leaves and smoother bark.

## Materials and Methods

***Study area.*** The study was conducted in the district of La Cruz (commercial *Persea americana* Mill. orchard) and Villa Alemana (*Vachellia caven* (Mol.) native shrubland), located in the Valparaíso Region of central Chile. Both sites present a warm temperate suprathermal climate with semi-arid moisture regime (Csb2Sa), characterized by warm, dry summers and cool, rainy winters. Mean monthly temperature ranges from 10.2 °C in July to 18.9 °C in January. Mean monthly maximum temperatures reach 27.5 °C, while mean monthly minimum temperatures decrease to 5.4 °C. Mean annual precipitation reaches approximately 429 mm, with nearly 80 % (347 mm) occurring between May and August, resulting in a dry season lasting approximately eight months (Santibáñez, 2017).

***Rainfall simulation.*** Due to the scarcity of natural rainfall during the study period, precipitation events were simulated using a rainfall simulator modified from the design described by Sangüesa et al., (2010).

Two rainfall intensities representative of local storm events with different return periods were applied: low intensity (8 mm $h^{-1}$, < 5-year return period) and high intensity (22.6 mm $h^{-1}$, 100-year return period), based on historical records from the Quillota meteorological station (Pizarro et al., 2007). Due to operational characteristics of the rainfall simulator, the high-intensity treatment was applied at 25 mm $h^{-1}$, which represents an approximation of the target intensity.

To reproduce these conditions, two sprinkler systems were constructed: a simple system consisting of four micro-sprinklers (Figure 1) and a complex system composed of eight micro-sprinklers, both Gyronet LR type (Netafim™, 120 L $h^{-1}$). The simple system operated at 1.5 bar, whereas the complex system operated at 3 bar. Rainfall uniformity was evaluated using Christiansen's Uniformity Coefficient (CU) and Distribution Uniformity (DU), calculated from rainfall depths collected in a grid of collectors placed beneath each system. CU reached 100%, while DU ranged between 82–85% for low intensity and 86–93% for high intensity, classified as good to excellent according to Merriam & Keller (1978) and Keller & Bliesner (1990). Additional system characteristics are summarized in Table 1.

Rainfall simulations were conducted using a fixed duration of 30 minutes. This duration was selected to ensure the development of key rainfall redistribution processes, including throughfall and stemflow. Previous studies have shown that rainfall redistribution processes can stabilize within the first minutes of an event depending on canopy structure (Nanko et al., 2008), and that a minimum duration of approximately 10 minutes is recommended to ensure adequate rainfall distribution (Rodrígues Junior et al., 2017). Therefore, the

**Table 1.** Characteristics of rain simulators.

| System | Sprinkler type (flow rate) | Number of emitters | Pressure (bar) | Rainfall intensity (mm $h^{-1}$) | CU (%) | DU (%) |
|---|---|---|---|---|---|---|
| Simple | Gyronet LR (120 L $h^{-1}$) | 4 | 1.5 | 8 | 100 | 82–85 |
| Complex | Gyronet LR (120 L $h^{-1}$) | 8 | 3.0 | 25 | 100 | 86–93 |

CU: Christiansen's uniformity coefficient; DU: distribution uniformity.

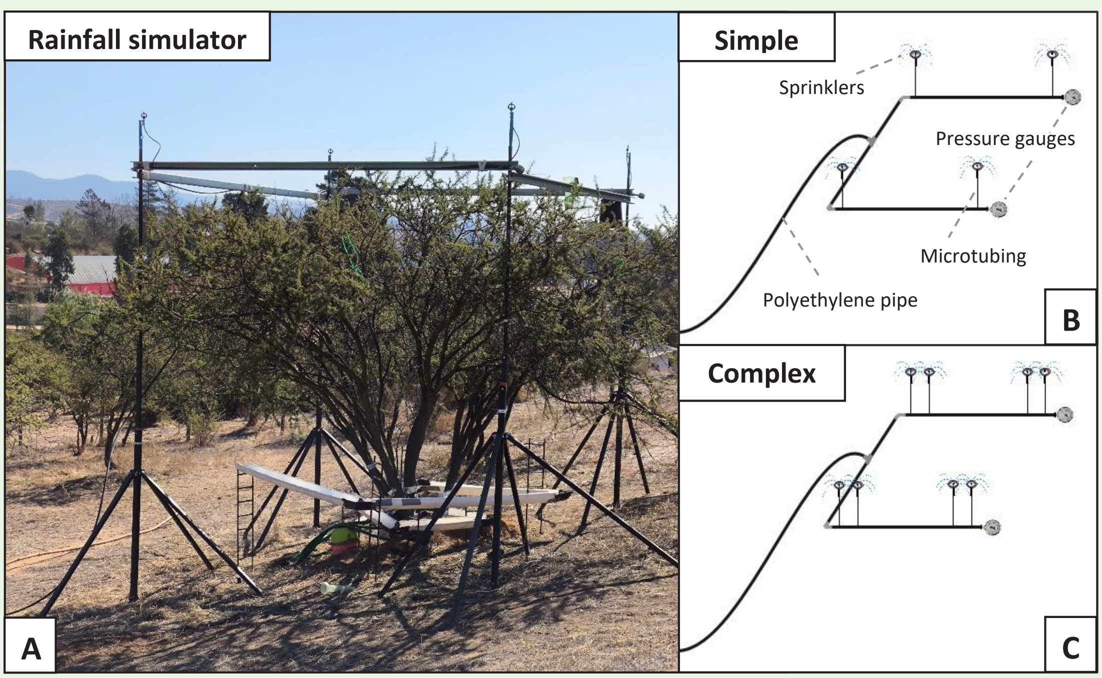


**Figure 1.** Rainfall simulator A) simulator assembled on a *V. caven* tree on a slope with an 18% gradient, B) simulator with a single system and C) simulator with a double system.

selected duration was considered appropriate for capturing the processes evaluated in this study.

Simulations were conducted during the spring–summer period (September to February). Due to logistical constraints and the need to relocate the rainfall simulator across multiple trees at two geographically separate sites (one per species), experiments were conducted on different days throughout the study period. All simulations were carried out under stable weather conditions, avoiding natural rainfall events and strong wind in order to minimize external interference.

*Evaluated vegetation covers.* Rainfall simulations were conducted under two tree cover types: *Vachellia caven* (Mol.) and *Persea americana* (Mill.). Three representative individuals per species were selected. For each tree, canopy area, total height, number of stems, diameter at breast height (DBH), and bark roughness were determined.

Canopy area was estimated assuming an elliptical projection calculated from major and minor crown radii measured using a measuring tape. Effective canopy cover was quantified through orthophotographic analysis of UAV-acquired imagery. To enhance the contrast between canopy and background, a white sheet was placed on the ground beneath each plant prior to image acquisition. The percentage of ground area covered by canopy projection was then determined using CobCal software (Ferrari et al., 2009).

Diameter at breast height was measured at 1.3 m above ground level or, in cases of early branching, at 1 m above stem division, with each stem treated as an independent measurement unit (Saket et al., 2004).

Bark roughness index was determined as the ratio between the contour length of the external bark surface and that of the internal contour, obtained from ink impressions of bark samples measuring 5 × 1 cm, following Aboal et al. (1999). The external contour follows bark irregularities, whereas the internal contour represents a smoothed reference line. Values ≥ 1 indicate increasing bark roughness. A schematic representation of this procedure is provided in Figure 2.

Mean morphological characteristics of both species are presented in Table 2.

*Measurement of rainfall redistribution components.* Total precipitation (PP) was recorded using a tipping-bucket rain gauge equipped with a datalogger installed above the canopy under the rainfall simulator and complemented with three manual rain gauges. Rainfall was continuously monitored using a HOBO data logger connected to a tipping-bucket rain gauge with a resolution of 0.2 mm.

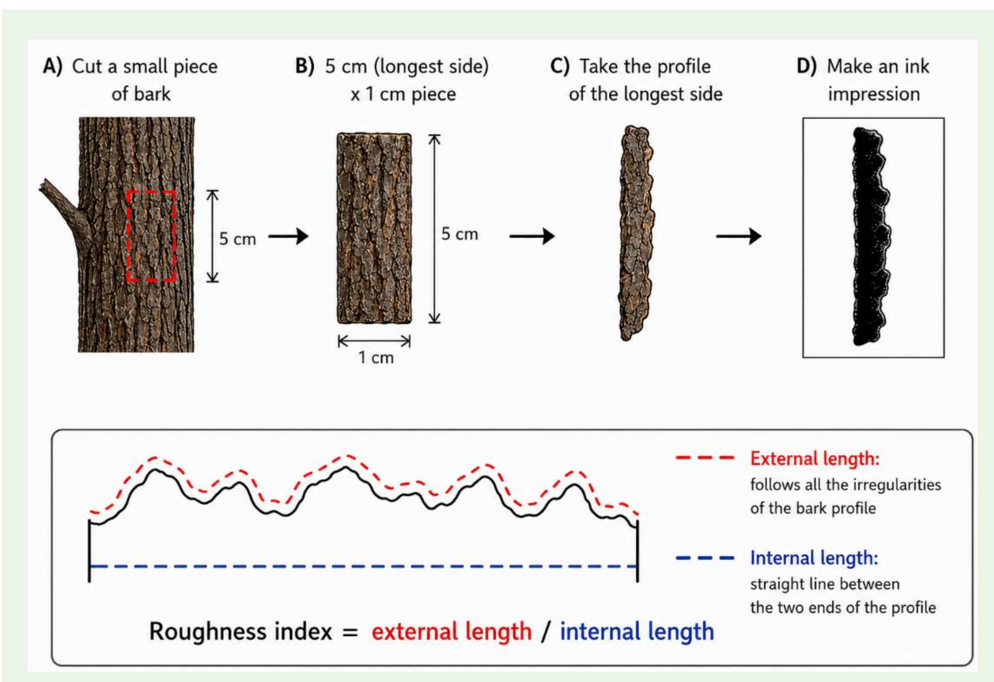


Figure 2. Flowchart for calculating the crust roughness index according to Aboal et al., 1999.

Throughfall (TF) was measured using two PVC gutter systems installed beneath each tree (Figure 3). Two gutters formed an open rectangle (1.3556 $m^2$) surrounding the trunk with a slight slope allowing water drainage. One gutter discharged into a tipping-bucket rain gauge connected to a datalogger, while the second drained into a storage collector. To characterize spatial variability, six additional rain gauges were randomly distributed beneath each canopy (Rodrigo & Ávila, 2001; Zhang et al., 2016).

Stemflow (SF) was quantified using aluminum collars installed around each trunk and sealed with silicone to prevent leakage (Figure 4). Collars were connected via hose to tipping-bucket rain gauges equipped with dataloggers following Aboal et al. (1999).

Canopy interception (I) was estimated as the difference between total precipitation and the sum of water reaching the soil surface according to Brasil et al. (2018); Crockford & Richardson (2000) and Iroumé & Huber (2000).

$$I = PP - Pn \quad [1]$$

$$Pn = TF + SF \quad [2]$$

where PP corresponds to total precipitation, Pn to net precipitation, TF to throughfall, and SF to stemflow.

All variables were analyzed at the event scale using cumulative values of TF, SF, and I for each 30-minute rainfall simulation.

**Table 2.** Morphological parameters of the three sample trees studied from each species.

| Vegetation Characteristics | *Vachellia caven* | | | | *Persea americana* | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | Average | 1 | 2 | 3 | Average |
| Total height (m) | 3.4 | 2.8 | 2.9 | 3.0 | 2.8 | 3 | 3.5 | 3.1 |
| Canopy area ($m^2$) | 20.5 | 21.4 | 19.4 | 20.4 | 12.7 | 9.5 | 10.1 | 10.8 |
| Canopy cover (%) | 64.9 | 72.2 | 67.8 | 68.3 | 100 | 100 | 100 | 100.0 |
| Number of stems | 4 | 4 | 5 | 4.3 | 1 | 1 | 1 | 1.0 |
| DBH (cm) | 10.7 | 13.9 | 8.8 | 11.1 | 20.1 | 16.6 | 15.9 | 17.5 |
| Stem roughness index (dimensionless) | 1.3 | 1.34 | 1.26 | 1.3 | 1.08 | 1.04 | 1.08 | 1.06 |

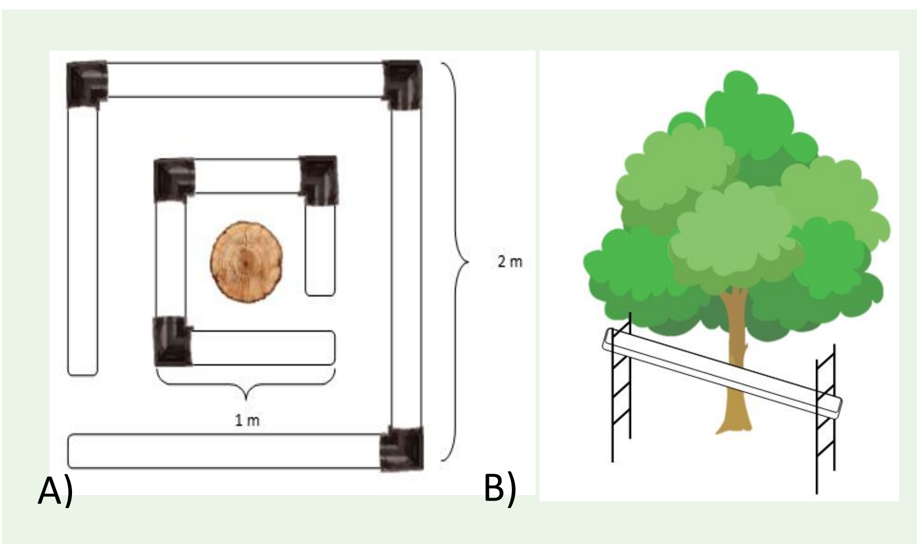


Figure 3. Diagram of gutters for throughfall collection. A) Top view of the gutter installation beneath the tree canopy. B) Side view of the gutter setup beneath the trees.

Figure 4. Detail of collars for collecting stemflow installed in *V. caven*.

Each tree was subjected to three rainfall repetitions per intensity level (low intensity: 8 mm $h^{-1}$ using the simple system; high intensity: 25 mm $h^{-1}$ using the complex system), totaling 36 simulations. Rainfall application uniformity and flow stability were verified during all experiments.

A minimum drying period of 2 hours was allowed between rainfall simulations to ensure comparable initial canopy conditions. Each simulation was conducted only after the canopy reached a visually dry state, defined as approximately 90% of the foliage appearing dry, following Moratiel et al. (2016). This criterion is consistent with previous studies reporting canopy drying times ranging from a few hours to more than 8 hours depending on environmental conditions and vegetation structure (Domingo et al., 1998; Llorens et al., 2014; Moreno-Pérez et al., 2018; Pérez-Arellano et al., 2016).

*Data analysis.* Data were analyzed using a parametric statistical approach. Prior to analysis, assumptions of normality and homoscedasticity were evaluated using the Anderson–Darling and Levene's tests, respectively.

A two-way analysis of variance (ANOVA) was performed to assess the effects of species (*Vachellia caven* and *Persea americana*) and rainfall intensity (low and high) on rainfall redistribution components. The experimental unit was the individual tree ($n$ = 3 per species). For each tree, response variables were calculated as the mean of three repeated rainfall simulations per intensity level, thereby reducing within-tree variability.

Response variables included canopy interception (I), throughfall (TF), stemflow (SF), and net precipitation (Pn). When significant effects were detected, Tukey's honestly significant difference (HSD) test was applied for multiple comparisons among factor levels. Pearson correlation coefficients were calculated to evaluate relationships among total precipitation (PP) and rainfall redistribution components (TF, SF, Pn and I). All statistical analyses were performed using Minitab 22 (Minitab LLC, State College, PA, USA), with a significance level of $P < 0.05$.

## Results

Two-way ANOVA indicated that rainfall intensity had a significant effect on canopy interception (I), throughfall (TF), and net precipitation (NP), whereas no significant effects of species or species × intensity interaction were detected (Table 3). Stemflow (SF) was not significantly affected by either factor.

Tukey's post hoc test revealed significant differences between rainfall intensities for TF, NP, and I, with higher values observed under high rainfall intensity (Table 4).

Consistent with these results, canopy interception tended to be higher in *Vachellia caven* than in *Persea americana* across both rainfall intensities, although these differences were not statistically significant. Under low rainfall intensity (8 mm $h^{-1}$), interception ranged from 2.6 to 3.2 mm (54–87%; 51–69 L $tree^{-1}$) in *V. caven* and from 1.5 to 2.4 mm (38–63%; 16–23 L $tree^{-1}$) in *P. americana* (Table 5). Under high rainfall intensity (25 mm $h^{-1}$), interception ranged from 5.1 to 6.3 mm (38–63%; 99–135 L $tree^{-1}$) in *V. caven* and from 1.5 to 5.9 mm (18–47%; 15–75 L $tree^{-1}$) in *P. americana* (Table 6). Throughfall increased with rainfall intensity in both species. Mean values derived from tree-level averages (Table 5 and Table 6) ranged from 1.23 to 5.29 mm in *V. caven* and from 1.83 to 6.28 mm in *P. americana*.

*Vachellia caven* exhibited greater canopy area and a higher number of stems, whereas *Persea americana* tended to have lower bark roughness (Table 2). Nevertheless, stemflow remained low across treatments, representing less than 1% of total precipitation (generally < 1 L $tree^{-1}$). Notably, two of the three *V. caven* individuals showed no measurable stemflow under low rainfall intensity, whereas all *P. americana* trees produced detectable stemflow.

Significant positive relationships were observed among rainfall redistribution components (Figure 5). Throughfall and net precipitation were strongly associated with total precipitation ($r = 0.900$; $P < 0.001$). Stemflow also showed a positive association with net precipitation ($r = 0.801$; $P = 0.002$) and total precipitation ($r = 0.721$; $P = 0.008$).

Canopy interception was positively associated with total precipitation ($r = 0.779$; $P = 0.003$), but showed weaker relationships with throughfall, net precipitation, and stemflow ($r = 0.342–0.428$).

The strong association between throughfall and net precipitation ($r = 1.00$) reflects the minimal contribution of stemflow to net precipitation.

**Table 3.** Results of two-way ANOVA evaluating the effects of species, rainfall intensity, and their interaction on rainfall redistribution components.

| Variable | Factor | DF | F | P-value |
|---|---|---|---|---|
| TF | Species | 1 | 0.97 | 0.355 |
| | Rainfall intensity | 1 | 27.85 | 0.001 |
| | Species x Intensity | 1 | 0.06 | 0.818 |
| SF | Species | 1 | 0.02 | 0.891 |
| | Rainfall intensity | 1 | 3.76 | 0.088 |
| | Species x Intensity | 1 | 0.03 | 0.858 |
| NP | Species | 1 | 0.90 | 0.371 |
| | Rainfall intensity | 1 | 26.91 | 0.001 |
| | Species x Intensity | 1 | 0.05 | 0.829 |
| I | Species | 1 | 2.75 | 0.136 |
| | Rainfall intensity | 1 | 11.85 | 0.009 |
| | Species x Intensity | 1 | 0.27 | 0.616 |

## Discussion

Stemflow represented a minor fraction of total precipitation in both species, particularly in *Vachellia caven*, which is consistent with previous studies reporting negligible stemflow contributions largely controlled by bark roughness and stem morphology (Khan, 1999; Levia & Germer, 2015; Magliano et al., 2019). The slightly higher stemflow observed in *Persea americana* may be associated with its smoother bark surface, which could facilitate water channeling along the trunk.

Intraspecific variability was observed among sampled individuals. The lower interception recorded in tree n°3 of *P. americana* may be related to its position within the interior of the orchard, where reduced lateral light availability likely resulted in lower foliar density and fewer leaf layers in the lower and lateral portions of the canopy, potentially limiting rainfall retention.

Despite presenting lower canopy cover (≈ 68%), *V. caven* exhibited greater canopy area (≈ 20 $m^2$) and higher bark roughness, which may have contributed to increased water retention within the canopy. In

**Table 4.** Tukey's HSD test (95% confidence) for the effect of rainfall intensity on rainfall redistribution components.

| Variable | Rainfall intensity | N | Mean | Group |
|---|---|---|---|---|
| TF | High | 6 | 5.78 | A |
| | Low | 6 | 1.53 | B |
| NP | High | 6 | 5.86 | A |
| | Low | 6 | 1.55 | B |
| I | High | 6 | 5.01 | A |
| | Low | 6 | 2.53 | B |

Different letters indicate significant differences between rainfall intensities ($P < 0.05$).

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**Table 5.** Average values ($\bar{x}$), standard deviation (σ) and respective percentage to the total precipitation (PP) of the precipitation redistribution components: Stemflow (SF), Throughfall (TF), Net precipitation (Pn) and Interception (I) for each tree with an intensity of 8 mm $h^{-1}$.

| Block | Species | Intensity | SF | $\bar{x}$ | σ | % | TF | $\bar{x}$ | σ | % | Pn | $\bar{x}$ | σ | % | I | $\bar{x}$ | σ | % | PP | $\bar{x}$ | σ | % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 0.00 | | | | 0.67 | | | | 0.67 | | | | 3.23 | | | | 3.90 | | | |
| 1 | *V. caven* | Low | 0.00 | 0.00 | 0.00 | 0.00 | 0.73 | 1.03 | 0.58 | 25.67 | 0.73 | 1.03 | 0.58 | 25.67 | 3.09 | 3.00 | 0.29 | 74.33 | 3.81 | 4.03 | 0.30 | 100 |
| | | | 0.00 | | | | 1.71 | | | | 1.71 | | | | 2.67 | | | | 4.38 | | | |
| | | | 0.00 | | | | 1.08 | | | | 1.08 | | | | 3.55 | | | | 4.64 | | | |
| 2 | *V. caven* | Low | 0.00 | 0.00 | 0.00 | 0.00 | 0.31 | 0.49 | 0.53 | 13.31 | 0.32 | 0.49 | 0.53 | 13.31 | 3.07 | 3.20 | 0.31 | 86.69 | 3.39 | 3.70 | 0.83 | 100 |
| | | | 0.00 | | | | 0.08 | | | | 0.08 | | | | 2.98 | | | | 3.06 | | | |
| | | | 0.04 | | | | 2.38 | | | | 2.42 | | | | 2.46 | | | | 4.88 | | | |
| 3 | *V. caven* | Low | 0.05 | 0.05 | 0.02 | 1.09 | 2.15 | 2.17 | 0.19 | 44.87 | 2.19 | 2.22 | 0.18 | 45.96 | 2.62 | 2.61 | 0.15 | 54.04 | 4.81 | 4.84 | 0.03 | 100 |
| | | | 0.07 | | | | 1.99 | | | | 2.06 | | | | 2.76 | | | | 4.83 | | | |
| | | | 0.02 | | | | 2.03 | | | | 2.05 | | | | 1.87 | | | | 3.92 | | | |
| 1 | *P. americana* | Low | 0.02 | 0.01 | 0.00 | 0.36 | 1.53 | 1.62 | 0.38 | 40.47 | 1.55 | 1.63 | 0.38 | 40.83 | 2.07 | 2.36 | 0.69 | 59.17 | 3.63 | 3.99 | 0.41 | 100 |
| | | | 0.01 | | | | 1.28 | | | | 1.29 | | | | 3.15 | | | | 4.44 | | | |
| | | | 0.01 | | | | 0.97 | | | | 0.98 | | | | 2.76 | | | | 3.74 | | | |
| 2 | *P. americana* | Low | 0.03 | 0.02 | 0.01 | 0.55 | 2.14 | 1.43 | 0.63 | 36.66 | 2.17 | 1.45 | 0.63 | 37.21 | 2.02 | 2.44 | 0.38 | 62.79 | 4.19 | 3.89 | 0.26 | 100 |
| | | | 0.02 | | | | 1.17 | | | | 1.19 | | | | 2.56 | | | | 3.75 | | | |
| | | | 0.02 | | | | 2.70 | | | | 2.71 | | | | 1.49 | | | | 4.20 | | | |
| 3 | *P. americana* | Low | 0.02 | 0.02 | 0.00 | 0.52 | 2.48 | 2.45 | 0.25 | 61.05 | 2.50 | 2.48 | 0.25 | 61.57 | 1.24 | 1.55 | 0.34 | 38.43 | 3.74 | 4.02 | 0.25 | 100 |
| | | | 0.02 | | | | 2.19 | | | | 2.21 | | | | 1.91 | | | | 4.13 | | | |

Table 6. Average values ($\overline{x}$), standard deviation (σ) and respective percentage to the total precipitation (PP) of the precipitation redistribution components: Stemflow (SF), Throughfall (TF), Net precipitation (Pn) and Interception (I) for each tree with an intensity of 25 mm $h^{-1}$.

| Block | Species | Intensity | SF | $\overline{x}$ | σ | % | TF | $\overline{x}$ | σ | % | Pn | $\overline{x}$ | σ | % | I | $\overline{x}$ | σ | % | PP | $\overline{x}$ | σ | % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 0.00 | | | | 4.18 | | | | 4.18 | | | | 5.73 | | | | 9.92 | | | |
| 1 | *V. caven* | High | 0.01 | 0.01 | 0.00 | 0.07 | 4.55 | 4.15 | 0.41 | 40.72 | 4.56 | 4.16 | 0.41 | 40.79 | 6.63 | 6.04 | 0.51 | 59.21 | 11.19 | 10.20 | 0.88 | 100 |
| | | | 0.01 | | | | 3.73 | | | | 3.74 | | | | 5.76 | | | | 9.50 | | | |
| | | | 0.01 | | | | 2.10 | | | | 2.10 | | | | 8.27 | | | | 10.38 | | | |
| 2 | *V. caven* | High | 0.08 | 0.04 | 0.04 | 0.44 | 4.86 | 3.68 | 1.42 | 36.68 | 4.95 | 3.72 | 1.46 | 37.12 | 5.43 | 6.30 | 1.71 | 62.88 | 10.38 | 10.02 | 0.61 | 100 |
| | | | 0.04 | | | | 4.07 | | | | 4.11 | | | | 5.20 | | | | 9.31 | | | |
| | | | 0.18 | | | | 8.50 | | | | 8.68 | | | | 4.07 | | | | 12.75 | | | |
| 3 | *V. caven* | High | 0.17 | 0.20 | 0.04 | 1.50 | 6.55 | 8.05 | 1.33 | 60.46 | 6.73 | 8.25 | 1.36 | 61.97 | 6.15 | 5.06 | 1.04 | 38.03 | 12.88 | 13.31 | 0.87 | 100 |
| | | | 0.25 | | | | 9.09 | | | | 9.34 | | | | 4.97 | | | | 14.31 | | | |
| | | | 0.07 | | | | 6.18 | | | | 6.25 | | | | 6.44 | | | | 12.69 | | | |
| 1 | *P. americana* | High | 0.09 | 0.07 | 0.02 | 0.56 | 7.02 | 6.59 | 0.42 | 52.53 | 7.10 | 6.66 | 0.43 | 53.09 | 5.46 | 5.88 | 0.50 | 46.91 | 12.56 | 12.54 | 0.16 | 100 |
| | | | 0.06 | | | | 6.56 | | | | 6.62 | | | | 5.76 | | | | 12.38 | | | |
| | | | 0.09 | | | | 5.08 | | | | 5.17 | | | | 4.70 | | | | 9.88 | | | |
| 2 | *P. americana* | High | 0.07 | 0.09 | 0.02 | 0.87 | 4.38 | 5.16 | 0.82 | 49.11 | 4.45 | 5.25 | 0.84 | 49.98 | 5.42 | 5.25 | 0.49 | 50.02 | 9.88 | 10.50 | 1.08 | 100 |
| | | | 0.11 | | | | 6.01 | | | | 6.12 | | | | 5.63 | | | | 11.75 | | | |
| | | | 0.07 | | | | 6.51 | | | | 6.58 | | | | 1.80 | | | | 8.38 | | | |
| 3 | *P. americana* | High | 0.03 | 0.06 | 0.03 | 0.69 | 7.27 | 7.08 | 0.51 | 81.55 | 7.30 | 7.14 | 0.51 | 82.24 | 1.64 | 1.54 | 0.32 | 17.76 | 8.94 | 8.69 | 0.29 | 100 |
| | | | 0.08 | | | | 7.48 | | | | 7.56 | | | | 1.19 | | | | 8.75 | | | |

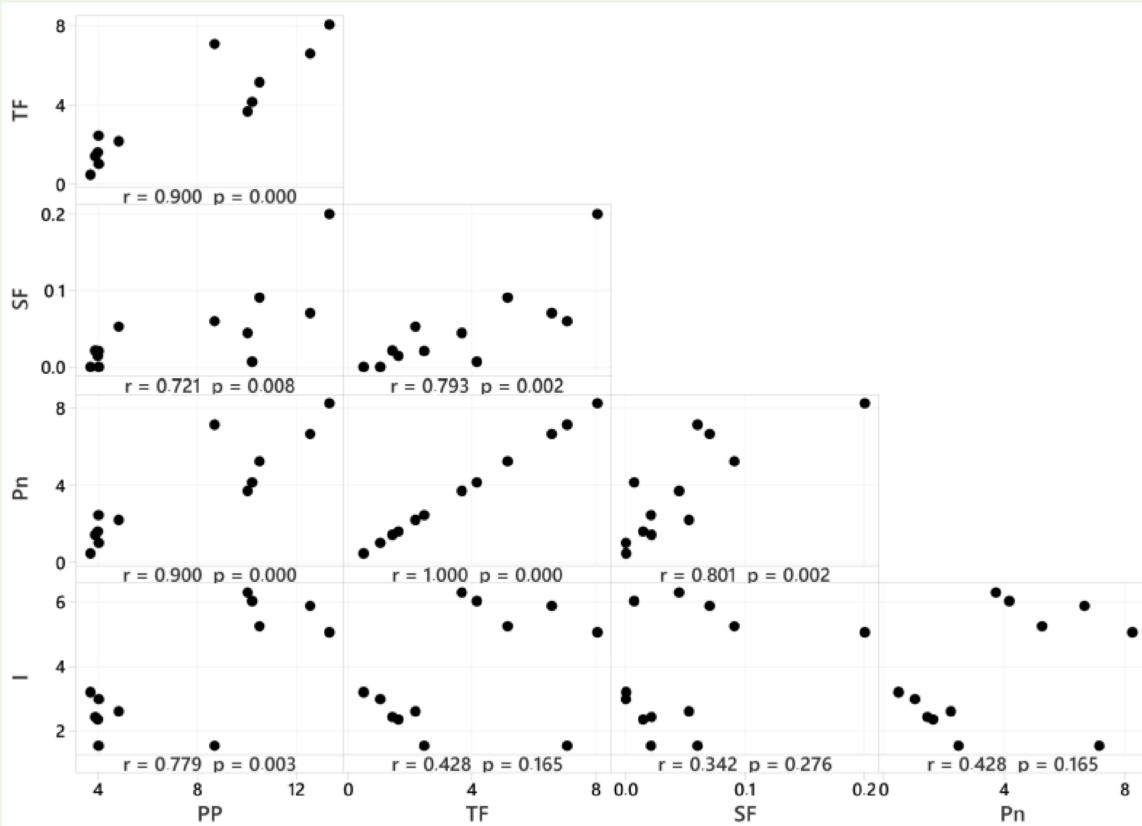


Figure 5. Pearson correlation matrix between the variables total precipitation (PP), net precipitation (Pn), Throughfall (TF), stemflow (SF) and interception (I).

contrast, the larger, waxier leaves of *P. americana* tend to promote water drainage to the soil surface, potentially increasing throughfall generation, consistent with the influence of leaf morphological traits on rainfall redistribution reported by Yan et al. (2021).

Rainfall intensity strongly influenced canopy water storage dynamics and the generation of throughfall and stemflow. Increasing rainfall intensity resulted in greater water transfer to the soil through canopy drainage (Skhosana et al., 2023). Stemflow has been shown to increase with precipitation magnitude, but generally represents a small fraction of total precipitation, particularly in trees (Yuan et al., 2016). Additionally, higher rainfall intensities tend to exceed canopy storage capacity, promoting drainage and reducing the proportional contribution of interception (Pérez-Arellano et al., 2016). Likewise, throughfall has been widely described as the dominant component of rainfall redistribution across vegetation types (Crockford & Richardson, 2000).

Although *V. caven* tended to intercept greater amounts of rainfall than *P. americana*, these differences between species were not statistically significant. Overall, rainfall intensity emerged as the main factor controlling rainfall redistribution components (I, TF, Pn, and SF) with higher intensities increasing throughfall and stemflow while reducing the proportional contribution of interception.

The observed patterns are consistent with the rapid saturation of canopy surfaces, after which additional rainfall is transferred to the soil as throughfall and stemflow. This behavior explains the inverse relationship between rainfall intensity and the proportion of interception losses, as higher intensities exceed the retention capacity of canopy elements (Pérez-Arellano, 2016; Skhosana et al., 2023).

Canopy saturation patterns also differed among individuals. In *P. americana*, tree n°3 reached apparent saturation at approximately 1.5 mm under both rainfall intensities, likely due to its lower foliar density and more open canopy structure. A similar pattern was observed in *V. caven* tree n°3, which showed slightly lower interception and increased stemflow, potentially associated with its reduced canopy area and higher number of stems with lower bark roughness. These patterns likely reflect differences in effective canopy storage capacity, inferred from rainfall redistribution responses rather than direct measurements.

Interception constitutes a relevant component of evapotranspiration (ET), as it represents the fraction of rainfall temporarily retained by the canopy and subsequently returned to the atmosphere by evaporation (Belmonte-Serrato, 1997; Calder, 1990; Huber & Oyarzun, 1990). In forest ecosystems, interception has been reported to range between 13% and 49% of total precipitation, depending on canopy structure, rainfall intensity, and meteorological conditions (Llorens et al., 1997). In Mediterranean climates such as central Chile, characterized by strong rainfall seasonality and prolonged dry periods, interception may play a particularly relevant role in regulating water inputs to the soil.

In this study, interception values in *Persea americana* and *Vachellia caven* suggest that this process may represent a substantial fraction of water losses. However, similar interception values between species do not necessarily imply equivalent ecohydrological responses. *P. americana* is an irrigated evergreen crop with relatively stable water availability, whereas *V. caven* is a native species adapted to water-limited conditions, with functional strategies linked to seasonal water regulation. These differences may lead to contrasting ecohydrological dynamics, particularly considering that intercepted water is largely evaporated from the canopy and contributes to evapotranspiration (Calder, 1990; Monteith & Unsworth, 2013), although transpiration typically represents the dominant component of ET in Mediterranean ecosystems (Paço et al., 2009).

These results have relevant implications for the water balance of semi-arid ecosystems in central Chile. A substantial proportion of rainfall may be intercepted before reaching the soil surface—up to nearly 90% in *V. caven* under low-intensity events—potentially reducing immediate soil water inputs and influencing groundwater recharge, understory moisture availability, and erosion processes.

***Limitations and sources of uncertainty.*** This study presents several sources of uncertainty and methodological limitations that should be considered when interpreting the results. Uncertainties arise from the measurement of rainfall partitioning components. Throughfall (TF) estimation may be affected by spatial variability beneath the canopy and collector distribution (Staelens et al., 2006). According to Rodrigo & Ávila (2001), the error in mean throughfall estimation is approximately 10% when using 9–11 collectors and decreases to around 5% when using 22–23 collectors of 200 $cm^2$. In this study, however, TF was measured using gutter systems with a total collection surface equivalent to approximately 68 collectors of 200 $cm^2$, substantially exceeding this threshold. Therefore, the sampling design employed in this study is expected to yield a TF estimation error well below 5%.

Stemflow is known to exhibit high variability among individual trees, driven by differences in stem architecture, bark characteristics, and canopy structure (Calder, 2001; Levia & Germer, 2015). This variability can introduce uncertainty in its estimation, particularly when sample sizes are limited. In heterogeneous vegetation systems, such variability may be amplified, potentially requiring a larger number of sampled individuals to adequately characterize stemflow responses. Similar considerations regarding spatial variability in rainfall partitioning have been reported in previous studies (Crockford & Richardson, 2000).

Interception (I), being indirectly estimated as the difference between total precipitation (PP) and the sum of TF and SF, propagates the errors associated with these measurements (Crockford and Richardson, 2000).

Additionally, experimental design constraints may influence the observed patterns. The relatively small number of sampled trees may limit the representativeness of the results, particularly given inter-individual variability. Rainfall simulations were conducted under controlled conditions using a fixed duration (30 min) and a limited number of rainfall intensities, which may not fully capture the variability of natural rainfall events. Furthermore, factors such as wind conditions during simulations (Hudson, 1993), rainfall intensity and duration (Iroumé & Huber, 2002), and simulated drop size (Calder, 2001) may affect canopy water retention and redistribution processes.

The temporal distribution of simulations across several months may have introduced variability in environmental conditions, which should be considered when interpreting the results, despite efforts to conduct experiments under stable weather conditions. In addition, the lack of direct measurements of canopy water storage introduces uncertainty, as interpretations are based on indirect indicators derived from rainfall partitioning. Therefore, the reported values should be interpreted as representative of the specific experimental conditions and should be interpreted with caution when extrapolating to natural field conditions.

***Future research.*** Future studies should incorporate additional vegetation parameters, such as leaf area index, increase the number of sampled trees, and explore a wider range of rainfall durations and intensities to better characterize canopy dynamics and rainfall redistribution processes. Although the 30-minute simulations allowed the observation of key processes, fixed-duration events may not fully capture variability among individuals.

## Conclusions

Rainfall intensity was the primary factor controlling rainfall redistribution, whereas species differences were not statistically significant. Throughfall dominated net precipitation due to the minimal contribution of stemflow. These results highlight the importance of rainfall intensity in regulating water partitioning in semi-arid Mediterranean ecosystems.

## Author contributions

Thalia Guardia designed the study and experimental approach, conducted field data collection, performed data analysis, and contributed to data interpretation and manuscript preparation. Cristian Youlton participated in field data collection and contributed to data interpretation and discussion. Carlos Oyarzún supervised the research and provided critical manuscript revisions. All authors contributed to the final version of the manuscript and approved the submitted version.

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