RAINFALL INTERCEPTION BY HOLM OAKS IN MEDITERRANEAN OPEN WOODLAND

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ABSTRACT: The role of holm oaks (Quercus rotundifolia) in the redis - tribution of precipitation was studied in the dehesas, a landuse system widespread in the southwestern part of the Iberian Peninsula. It consists of pastureland with an openly spaced tree cover. Measurements of through - flow and stemflow were carried out in the Guadalperalón study catchment, and data of three hydrological years are available on an event basis. The effect of tree pruning on interception was also investigated, an activity carried out in intervals of approximately 10 years. Four trees were selec - ted for monitoring, two non-pruned and two pruned individuals. Throughfall was measured with a total number of 163 raingauges distri - buted in a regular grid below the tree canopies, and meteorological data was registered in intervals of 5 minutes. On average 26.8% of the annual rainfall is intercepted. The pruned trees intercept clearly less rainfall than the unpruned ones, with 23.6% and 29.9%, respectively. Stemflow is of lit - tle importance, representing less than 1% of the annual precipitation. The spatial variation of throughfall is high and is mainly related with morpho - logical characteristics of the tree canopy, though the effect of wind could also be demonstrated. On an event basis, throughfall is mainly controlled by the amount of precipitation and to a minor degree by rainfall intensity, temperature and air humidity. Although individual holm oaks intercept a considerable amount of rainfall, the importance on the water balance of the catchment is small due to the low tree density. With a canopy cover of 8%, the water loss due to interception constitutes only 4% of the annual precipitation.

RESUMEN: El papel de las encinas (Quercus rotundifolia) en la redis - tribución de la precipitación se ha estudiado en las dehesas, un sistema de explotación muy extendido en el suroeste de la península Ibérica. Se han tomado medidas de la trascolación y del flujo a través del tronco en la cuenca de Guadalperalón, disponiéndose de tres años de datos a escala de eventos individuales. Se ha investigado también el efecto de la poda sobre la interceptación, realizándose aquella a intervalos de 10 años. Se selec - cionaron 4 árboles, dos podados y otros dos no podados. La trascolación se midió con 163 pluviómetros distribuidos de forma regular bajo la

cubierta de los árboles, y los datos meteorológicos se registraron cada 5 minutos. En promedio, el 26.8% de la precipitación es interceptada. Los árboles podados interceptan una cantidad de lluvia claramente menor que los no podados (23.6 y 29.9% respectivamente). El flujo por el tronco es de escasa importancia, pues representa menos del 1% de la precipitación anual. La variación espacial de la trascolación es elevada y está relacio - nada con las características morfológicas de la cubierta del árbol, aunque está por demostrar el efecto del viento. A escala de evento, la trascolación está principalmente controlada por la cantidad de lluvia y, en menor medida, por su intensidad, temperatura y humedad del aire. Aunque las encinas interceptan una cantidad considerable de lluvia, su importancia en el balance hídrico de la cuenca es pequeña debido a la baja densidad de arbolado. Con una cubierta del 8%, la pérdida de agua debida a inter - ceptación constituye sólo el 4% de la precipitación anual.

Key words: Interception, Throughfall, Stemflow, Dehesa, Holm oaks, Pruning, Extremadura, Spain.

Palabras clave: Interceptación, Trascolación, Flujo por el tronco, Dehesa, Encina, Poda, Extremadura, España.

1. Introduction

Rainfall interception by vegetation has been demonstrated to constitute an important process of the hydrological cycle which can be considered as a loss in the water balance (Zinke, 1967). A variety of studies were carried out in areas with Mediterranean climate and a vegetation cover consisting of evergreen forests, composed of coniferous or holm oak species (Escarré et al., 1986; Bellot, 1988; Llorens, 1997; Domingo, 1998; Belmonte & Romero, 1999). However very limited information is available about the role of a sparse tree cover in the distribution of surface water (Calabuig *et al.,* 1979). The present work presents the results of an interception study carried out in a *dehesa*, a landuse sys- tem widespread in the southern and western part of the Iberian Peninsula, estimated to occupy more than 3 million ha (Díaz, *et al.,* 1997). It consists of openly spaced evergreen woodland, with holm oaks and cork oaks (*Quercus rotundifolia, Q. suber*) being the dom- inant species. Multiple landuse characterizes this semi-natural ecosystem with extensive livestock breeding, wood production, hunting and cultivation.

The study was carried out in the Guadalperalón catchment, where surface hydrology and soil erosion is investigated since 1990 (Gómez Amelia & Schnabel, 1992; Schnabel, 1997; Ceballos & Schnabel, 1998; Ceballos, 1999). The main objective of the present work is to evaluate the water losses produced by rainfall interception of the sparse, savan- nah-like, tree cover of this mediterranean ecosystem.

Rainfall interception of holm oaks is determined through the quantification of the dif- ferent water fluxes influenced by the tree cover: throughfall and stemflow. Measurements where carried out during three hydrological years, from September 1995 to August of 1998. Further specific subjects include:

1. Evaluation of the importance of tree pruning on interception. In the dehesas trees are commonly pruned in intervals of 8 to 10 years. The reasons for pruning are manifold, such as an increase of acorn production (for fattening the Iberian black pig), the provision of additional fodder (leaves and branches) for livestock and the production of firewood.

2. The spatial distribution of throughfall below the tree canopy is determined and the possible factors producing this variation are examined.

3. The relationship between meteorological variables and throughfall is established.

4. The importance of rainfall interception in the water balance of the study catchment, and for the dehesa ecosystem, is evaluated.

5. The analytical model to estimate rainfall interception proposed by Gash (1979) with its adaptation for disperse tree cover (Gash et al., 1995) was tested using the Guadalperalón data by Mateos (2001). Only the main results are presented here.

2. The Study Area

The study basin is located 22 km northeast of the city of Cáceres in Extremadura, Spain (Figure 1). It forms part of a peneplain with slope gradients in the order of 10 to 25%. The catchment with a surface area of 35.4 ha and a mean altitude of 378 m a.s.l. belongs to the Tajo drainage system.
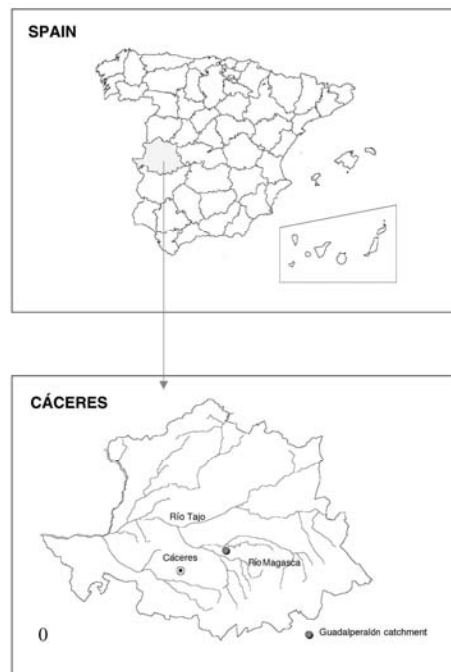

Figure 1. Location of study area

The climate is Mediterranean, with Atlantic and continental influences, giving rise to moderate winters and hot and dry summers. Mean annual temperature is 16.1 ℃. Annual precipitation averages 516.2 mm, distributed over 85 rain days (longterm meteorological data were obtained from the Observatory in Cáceres). The annual distribution shows a dry season lasting from June to September and a wet season from October to April. Annual and interannual variability of rainfall is high (Schnabel, 1998). Using the Unesco aridity index (Unesco, 1979) the climate of the area can be classified as semi-arid.

The soils in Guadalperalón are developed on precambrian schists. They are shallow (10-30 cm), have a silty loam structure and a low organic matter content. In the catchment, areas with a tree cover of *Quercus rotundifolia* alternate with areas lacking oaks. In the treeless zones, where rock outcropping is frequent, shrubs of the species *Lavanduala stoechas* are dominant and the herbacoues cover is very poor. At hillslopes, where trees are growing, herbaceous species dominate. Mean tree density is low with approximately 15 individuals per ha. The tree-covered hillslopes where the interception measurements were carried out have a tree density of 30 to 45 holm oaks per ha. The farm is grazed by sheep and to a minor degree by cattle and pigs.

The physical and environmental characteristics of Guadalperalón (soils, climate, topography, vegetation) are representative of widespread areas of dehesas found in the south-western part of the Iberian Peninsula.

3. Methods

The study was carried out using four trees, which were selected on the basis of a previous analysis of the main characteristics of the holm oaks growing in the study catchment (Mateos & Schnabel, 1998). In order to evaluate the influence of canopy pruning on rainfall interception, two of the selected sample trees were not pruned for more than twenty years, and the other two trees were pruned in 1992, three years before the start of this study.

Rainfall interception was determined by calculating the difference between incident rainfall (P) and the sum of throughfall (Th) and stemflow (St):

I = P – (Th + St)

Throughfall was measured using a total number of 163 simple raingauges distributed in a rectangular grid below the tree canopy. The collecting area of each device was 314 cm^2. The distance between each raingauge was 1.5 m. Incident rainfall was determined by four raingauges. One of these was a tipping bucket device of 0.2 mm resolution and with authomatic recording in 5 minute intervals. The others consisted of raingauges of the same design than those used for throughfall measurement.

Stemflow was monitored by collectors arranged in spiral form around the stem, using an opened rubber tube which was fixed to the stem and sealed with silicone to form a tight junction between the collector and the tree bark. The tube was connected to a 65 l tank. Stemflow and throughfall was monitored on an event basis.

Furthermore, meteorological data in Guadalperalón was registered in intervals of 5 minutes, including air temperature, relative air humidity, global solar radiation, wind velocity and wind direction. Data is downloaded by a portable computer.

During the study period (September 1995 to August 1998) 103 rainfall events were registered and the corresponding amount of stemflow and throughfall were monitored. The total amount of precipitation of these events is slightly lower than the total amount of rainfall of the three corresponding years (table 1). These differences are due to a small number of events which could not be sampled. The data of throughfall, stemflow and interception is presented in relation to the corresponding event rainfall.

Table 1. Total annual precipitation and annual event rainfall (corresponding to the throughfall and stemflow sampling) in Guadalperalón.

Hydrological Year	Total rainfall (mm)	Event rainfall (mm)
1995-96	728.0	708.7
1996-97	692.7	659.7
1997-98	922.8	896.6
Mean	**781.2**	**755.0**

4. Results and Discussion

4.1. Precipitation

Mean annual rainfall of the three years of investigation was 781.2 mm (table 1), exceeding strongly the long-term mean based on a series of data of 91 years from the meteorological station of Cáceres (516.2 mm). The data of this station can be used as a reference for interpreting the data obtained in the study basin due to its proximity and similar altitude (Schnabel, 1997).

The three hydrological years can be classified as very humid (INM, 1994), especially the last one (1997-98), which registered 922.8 mm, an amount which was only exceeded twice at the beginning of the century. Exceptional precipitation was observed during November of 1997, with a total of 355.4 mm, the maximum monthly rainfall of the 91 year record. Large part of this amount was produced during the 5th and 6th of November due to a rainstorm event registering a 24 hour maximum of 135.4 mm. January of 1996 was also exceptionally humid with 246.4 mm of rain. Figure 2 represents monthly rainfall for each of the study years, illustrating that most precipitation was registered from November to January, with December receiving more than 120 mm in each of the years. Most of the months of October, February, March and April, however, registered below average amounts. This contrasts with the month of May, during which in all three cases rainfall exceeded the long-term mean.
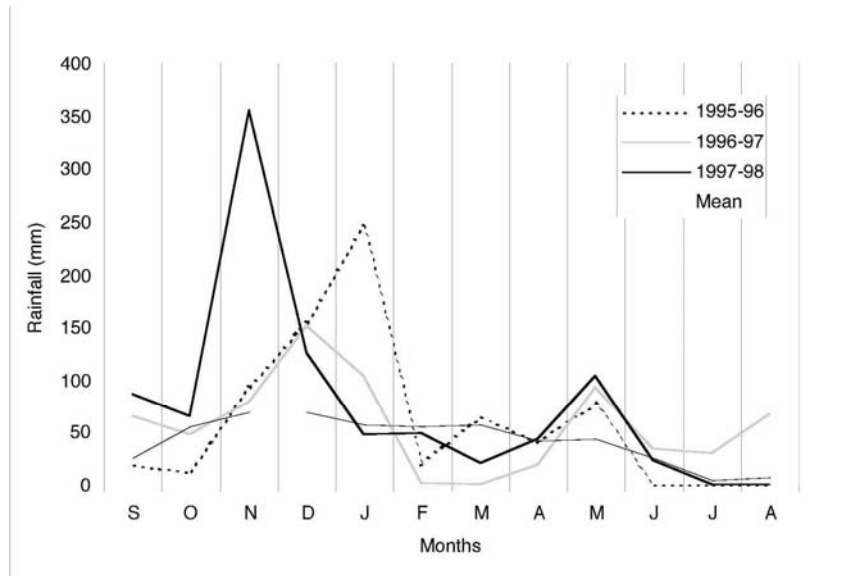
Figure 2. Monthly precipitation during the three years of investigation at Guadalperalón and average amounts from the meteorological station in Cáceres.

During the study period a total of 103 events were sampled. The frequency distribution of the event rainfall, represented in figure 3, shows two dominant groups: events with an amount of 5 to 10 mm (24.3%) and those with an amount of 10 to 20 mm (23.3%). Rainfall of less than 10 mm represents 36.9% of the total number of events. In contrast, the least frequent rainstorms were those with 40 to 50 mm of precipitation (1.9%) followed by those of 30 to 40 mm (8.7%). However, rainstorms which registered amounts in excess of 50 mm were quite frequent (10.7%).

With respect to rainfall intensity, most of the events were characterized by low intensities: 51.5% registered maximum 10-minute intensities (I-10) below 10 mm h^{-1}. However, moderate (20-40 mm h^{-1}) and high intensity storms (> 40 mm h^{-1}) represented a fairly large number of the events, with 14.5% and 10.7%, respectively. The third study year (1997-98) registered the largest number of high intensity storms. Since the start of the investigation in Guadalperalón in 1990 six events were observed with I-10 either in excess of 60 mm h^{-1} or with a daily maximum amount greater than 55 mm (Schnabel, 1999). Four of these events were observed during the period of the interception study.

4.2. Throughfall

Throughfall for each sample tree was calculated as the average height of water collected in the raingauges situated below the tree canopy. On average 550,1 mm of throughfall were registered, which represents almost 73% of the total precipitation
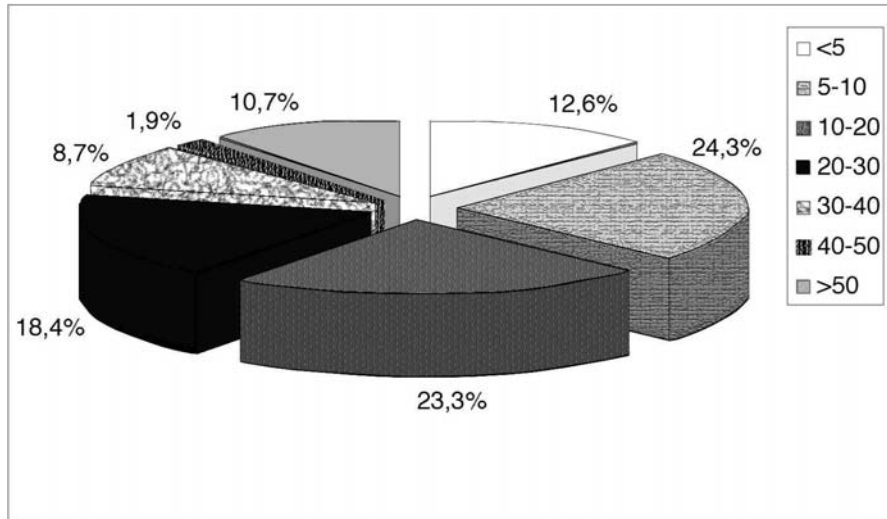
Figure 3. Frequency distribution of the event rainfall amounts (1995-1998).

(table 1). Throughfall varied between 491.5 mm and 654.8 mm, though as a percentage of rainfall, it varied only between 71.1 and 74.5% (table 2).

On average throughfall of the pruned and unpruned trees was 75.9 and 69.9%, respectively, which represents a difference of 6% with respect to the annual rainfall (table 2). This can be explained by the lower density of the canopy and a lower amount of biomass of the pruned trees. The volume and distribution of throughfall depends, amongst other factors, on the storage capacity of the tree canopy, which is determined by its morphology (amount of biomass, structure and angle of the branches), the characteristics of the rainfall event (amount, intensity, duration), as well as the prevailing atmospheric conditions. In order to determine the role of the meteorological factors in controlling throughfall, factor analysis was carried out (see for more detail Mateos, 2001). It was considered that the morphological characteristics of the tree canopy did not change during the study period. The analysis, based on the event scale, was carried out using the average values of throughfall of the four trees. Further variables considered are: total amount of rainfall,

Table 2. The annual amount of throughfall as a percentage of incident rainfall of each of the sampling trees (A1 – A4) and mean values.

Hydrological Year	Rainfall (mm)	A1 (%)	A2 (%)	A3 (%)	A4 (%)	Mean (%)
1995-96	708.7	75.8	74.6	69.4	64.7	71.1
1996-97	659.7	78.6	77.4	74.1	68.0	74.5
1997-98	896.6	74.8	73.9	73.8	69.6	73.0
Mean	**755.0**	**76.4**	**75.3**	**72.4**	**67.4**	**72.9**

maximum 10-minute rainfall intensity, duration of precipitation, mean air temperature, relative air humidity, solar radiation, wind velocity. The results of the factor analysis show that the rainfall characteristics (amount, intensity, duration) are the dominant group of factors, representing the highest weight for explaining the amount of throughfall, with high positive correlations (r = 0.99; r = 0.90 y r = 0.83, respectively). The importance of the amtmospheric conditions could also be demonstrated (humidity, temperature, global radiation), though the influence of wind velocity could not be proven. The influence of the latter factors on throughfall can be explained by the role they play in the evaporation process. Increased evaporation of intercepted water increases further interception and hence reduces throughfall.

The spatial variation of throughfall, whose importance was described by several authors (Eschner, 1967; Ford and Deans, 1978; Durocher, 1990; Belmonte y Romero, 1999), was also investigated in this research. In order to determine the distribution of throughfall at the soil surface isoline maps were produced, based on linear krigging. This was done for each of the trees using mean throughfall of each collector. Throughfall below the tree canopy was highly variable. However, similar patterns could be observed. Distribution was concentric around the stem, with lowest values close to the stem, and increased throughfall with increasing distance to the stem. Highest values, occasionally higher than incident rainfall, were registered below the end of main branches, which seem to canalize part of the intercepted water. Large amounts of throughfall were also registered below the border of the canopy, at the site exposed to the main wind direction (southeast to southwest).

4.3. Stemflow

Stemflow is expressed in millimeters, which is calculated in relation to the surface area of the canopy of the sample trees. The average amount of annual stemflow represents only 0.3% of total rainfall (table 3). No significant differences were observed between the pruned and un-pruned trees, and neither between different years. These low values of stemflow can be attributed to the morphological characteristics of the holm oaks, i.e. the rugosity of the bark, and its effect as a sponge. Probably the horizontal alignment of the main branches also influences, favouring either drainage by dripping of water from the branches or retention of water, and hence reduces the flow towards the

Table 3. Annual incident rainfall and interception, as well as throughfall, interception and stemflow expressed as a percentage of rainfall, during the study period from 1995 until 1998.

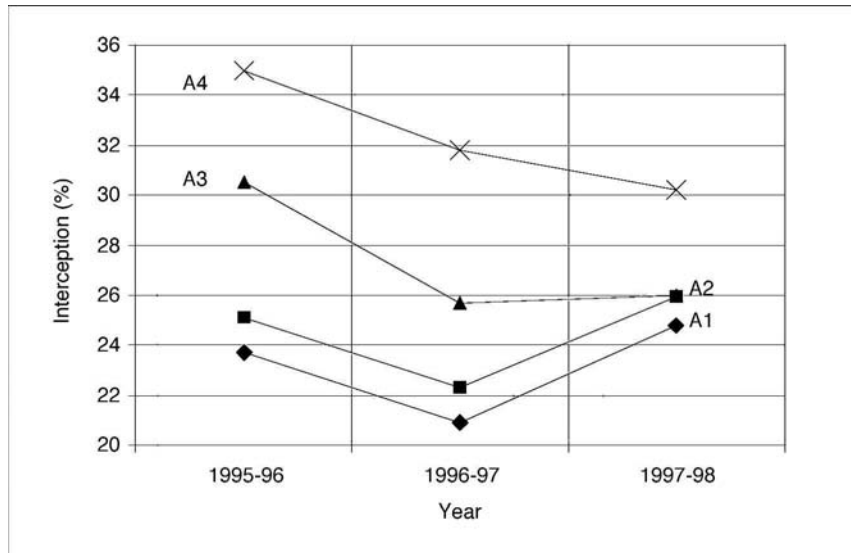| Hydrological Year	Rainfall (mm)	Throughfall (%)	Stemflow (%)	Interception (%)	Interception (mm)
1995-96	708.7	71.12	0.33	28.55	202.3
1996-97	659.7	74.50	0.33	25.17	166.0
1997-98	896.6	73.03	0.25	26.72	239.6
Mean	**755.0**	**72.88**	**0.30**	**26.81**	**202.4**

Figure 4. Development of rainfall interception for each of the sample trees between the hydrological years 1995-96 and 1997-98.

stem. The low value of stemflow indicates that its influence on the hydrological balance of the catchment is very small.

4.4. Interception

The average annual water loss produced by interception for the study period amounted to 202.4 mm, which represents 26.8% of the total rainfall. The annual amounts of throughfall as an average of the four sample trees varied between 166.0 mm and 239.6 mm, though interception expressed as a percentage of rainfall varied only between 25.2% and 28.6% (table 3).

Mean annual interception of the pruned and unpruned trees was 23.6% and 29.9%, respectively, representing a difference of approximately 6%. However, the annual values for the individual trees varied throughout the study period (Figure 4). Interception of the unpruned trees was highest during the first year and was lower during the second and the third year. This variation can be explained by the characteristics of the rainfall events, with higher interception related with lower amounts and/or lower intensities of precipitation. The first year registered a smaller number of intensive rainstorms. Interception of the pruned trees showed a contrasting behaviour. Although the second year produced less throughfall than the first one, the difference is less pronounced than in the case of the unpruned holm oaks. The values of the third year are even higher than the first one (Figure 4). As a result, the difference of interception between the two groups was 8.7% during 1995-96 and only 2.7% in 1997-98. This decreasing difference is probably related with a

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change of the canopy of the pruned trees. It is assumed that the biomass of these trees increased during the three year period. Although extrapolation of this data is limited due to the reduced number of sample trees and sample years, it may be argued that 6 years after having practiced pruning (carried out during 1992 in our case) its effect on throughfall is rather small.

Water loss through interception by holm oaks represents a fairly high percentage of annual rainfall (26.8%), which are of importance especially in the Mediterranean areas, with its semi-arid climate conditions and highly variable rainfall. However, this value is based on the individual tree, neglecting the open spaces. In the Guadalperalón catchment with a mean tree density of 15 individuals per hectare and a canopy cover of 8%, water loss produced by interception is estimated to be only 4%. Tree density of dehesas varies strongly in Spain and Portugal. In order to obtain some idea about the interception losses produced by holm oaks in a drainage basin a simple estimation was carried out. Assuming an average canopy cover of 45.1 m^2 for each tree (equivalent to the mean value of the sample trees used in this study) and taking into account the amount of interception recorded in the sample grid with an average size of 99 m^2, the water loss by interception is estimated to be approximately 5% with a tree density of 20 individuals/ha and 13% with a density of 50 trees/ha. These values can only be considered as very crude estimates.

The analytical model of Gash for disperse tree cover (Gash et al., 1995), which is based on morphological and climatological parameters, was tested with the data obtained in Guadalperalón. The result was not satisfactory because the predicted values presented less than 50% of the observed values of interception (Mateos, 2001).

5. Conclusions

The sampled holm oaks in Guadalperalón intercepted important amounts of rainfall, with approximately 27%. However, due to their disperse cover water loss produced by interception in Guadalperalón was estimated to be only 4% with an average tree density of 15 individuals per hectare. Tree density in the wooded pasturelands of the southwestern part of the Iberian Peninsula varies strongly, and as a consequence, interception losses will vary too.

Of the different flows related with interception, throughfall is of major importance, accounting for 73% of the incident rainfall, whereas stemflow represents only 0.3%.

Spatial variation of throughfall at the ground surface is high, and is primarily related with the morphological characteristics of the tree and to a minor degree with wind direction. Throughfall is lowest in the area around the tree stem, where values represent less than 50% of total rainfall. Maximum values, even higher than incident rainfall, where recorded below the main branches and at the border of the canopy cover.

On an event basis, throughfall is mainly controlled by the amount of precipitation and to a minor degree by rainfall intensity, temperature and air humidity. The latter two factors indicate the importance of evaporation in the interception process.

Pruning of the canopy of holm oaks reduced interception by approximately 6% with respect to annual rainfall during the three years of observation and covering a period of 3 to 6 years after pruning was carried out.

Acknowledgments

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