Interception, throughfall and stemflow of maquis vegetation in Greece

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Abstract: Gross rainfall, throughfall, stemflow and interception losses were determined and studied for seven years (1996 – 2002) in an evergreen schlyrophylous species (maquis) stand of eastern Mediterranean region and specifically of southern – western Greece. The data were collected on a weekly basis and are presented and analysed on annual time scale. The seven years mean annual values of throughfall, stemflow and interception losses were 61.2%, 6.8% and 32% of the corresponding gross rainfall (1134 mm), respectively. The annual values were compared and discussed with those of studies carried out in the western Mediterranean region and partially in southern California.

*Key-Words:*schlyrophylous species, annual scale analysis, hydrological measurements.

1 Introduction

Rain that falls on a forest canopy is distributed in throughfall, stemflow and interception losses as it moves towards the forest floor. Quantification and understanding of the interactions among these three hydrological components, the vegetation and soil of a watershed, are of great importance for the rational management of these natural resourses (Newson, 1992).

Quantification of interception losses is very important due to its significant impact on the watershed's water balance (Ward and Robinson, 2000). Interception losses influence the water yield and the other water components of forested watersheds relative to non-forested watersheds (Calder, 1976; Asdak et al., 1998). Throughfall and stemflow affect the forest biogeochemical cycles (Stökli, 1991; Soulsby, 1997), as they are responsible for the transfer of precipitation and solutes from tree canopies to forest soil. Throughfall and stemflow also influence streamflow generation (Neave and Abrahams, 2002), spatial patterning of soil moisture (Durocher, 1990; Chang and Matzner, 2000; Tobón Marin et al. 2000), soil erosion (Herwitz, 1988), soil solution chemistry (Haworth and McPherson, 1995; Chang and Matzner, 2000) and the distribution of understory vegetation and epiphytes (Crozier and Boerner, 1984; Andersson, 1991).

Measurements and investigation of the referred above hydrological components have been conducted in various types of forests and mostly on temperate broadleaved (Brown and Barker, 1970; Hörmann et al., 1996; Toba and Ohta 2005), coniferous (Gash et al., 1980; Johnson, 1990; Pypker et al., 2005) and tropical forests (Herwitz, 1985; Lloyd and Marques, 1988; Fleischbein et al., 2005) around the world. However, such studies are also very important for the evergreen sclerophylous vegetation (maquis) in the Mediterranean region and according to literature, these hydrological components have been mainly studied in the western parts of it (Roda et al., 1990; Bellot and

Escarre, 1991; Domingo et al., 1998; Avila and Rodrigo, 2004) and partially in eastern regions (Schiller et al., 2002). The hydrological importance of the maquis is associated with the Mediterranean climate itself, which is characterized by seasonality of rainfall, relatively intense and infrequent storms and high temperatures during summer.

Maquis affects the components of the hydrological cycle and so is closely related to major hydrological issues of the Mediterranean region and mainly to soil erosion, flooding, water yield and water quality. Additionally, the effects of maquis on these hydrological issues also depend on its structural and spatial characteristics. Maquis in the Mediterranean region do not grow under undisturbed conditions because it has been severely affected by human activities. Large areas of uniform vegetation cannot be found; thus the research into the relation between the hydrological components and the vegetation conditions and types requires measurements in many representative sites.

These irregularities of vegetation, as well as the wide variety of meteorological conditions in the Mediterranean region, indicate that a rigorous hydrological analysis should take place. In Greece, such work has dealt only with coniferous and deciduous broadleaved species (Papoulias and Nikolaidis, 1979; Nikolaidis and Papoulias, 1981; Michopoulos et al., 2001; Baloutsos et al., 2004) and not with maquis.

The objective of this study was to measure, evaluate and analyze, on an annual scale, the throughfall, stemflow and interception losses of maquis vegetation consisted of many species in south-western Greece and compare the results with those obtained in maquis stands of other Mediterranean countries or other countries with Mediterranean climate. This will help researchers understand the variability of these hydrological components among various Mediterranean regions.

2 Materials and Methods

2.1 Study Area

The study area is located in south western Greece (38o50΄51΄΄N and 21o18΄20΄΄E), 225 km from Athens (Fig. 1). It lies in the headwaters of one of the small streams of the Acheloos River, which is the main one of western Greece. A plot of 0.27 ha was selected in 1995 for biogeochemical and hydrological studies and being representative of the vegetation (maquis), soil, the parent rock and the topography of the wider area. The altitude of the plot is 360 m a.s.l. and the terain is hilly. The soil is Haplic Luvisol (FAO, 1988) and its parent material is flysch. The mean annual rainfall and the mean annual temperature (1973-2003) at the meteorological station of the area located 400 m from the plot and at an altitude of 350 m, are 1001 mm and 15.2 oC, respectively. The plot and the wider area are covered by evergreen sclerophyllous vegetation (maquis). This is a multi-layer, dense coppice stand with canopy closure 1.2-1.3 (tree canopies overlap) and height varying from 3 to 10 m. The understorey is dominated by Phillyrea latifolia, Arbutus unedo and Erica arborea. Sporadic stems of Cercis siliquastrum and Erica verticilata are also present. In the top storey there is a number of Quercus ilex stems distributed almost uniformly. The characteristics of the tree species are shown in Table 1.

2.2 Gross rainfall measurement

Gross rainfall was measured in a forest clearing located 80 m approximately from the center of the experimental plot and having the same altitude with it. The diameter of the clearing was larger than the double of the height of the surrounding trees to avoid underestimation of the rainfall due to edge effects.

Near the middle of the clearing, two non-recording raingauges (Lambrecht K6, D=16 cm), one with its orifice at the surface of the ground (pit raingauge) and the other at the height of 1.5 m above the ground surface, were installed. Close to them, a recording raingauge (Belfort type) was also installed with its orifice at the height of 1.5 m above the ground surface, for the study of the time distribution of rainfall.

All gauges were checked on a weekly basis, always the same day. In order to correct any underestimation or overestimation of rainfall measured by the above two non-recording raingauges, the arithmetic mean of rainfall of them was estimated and considered as the “true” value of the plot.

2.3 Throughfall measurement

Throughfall was measured in a rectangular subplot (39 X 22 m) located inside the original plot of 0.27 ha. The manual of the ICP-Forests (1994) was used for the determination of the number of throughfall collectors. It recommends using at least 10 to 15 funnels with a diameter of 20 cm and advocates a pre-study of the variation within the plot to determine the required number specifically for the site under study. After taking into account the homogeneity of the forest stand, the subplot area was divided into 858 sampling squares one meter in side. Ten of the above squares were selected randomly and a throughfall collector was installed at the center of each.

The throughfall collectors had a fixed position. This decision was taken because a regular relocation of them, as recommended by Lloyd and Marques (1988) to improve the representativity of the sample, would have resulted in serious disturbance of the forest soil and consequently to the non normal ecological functioning of the plot.

The collector was formed by an 18 cm diameter polyethylene funnel connected through a one-meter long hose to a 5-liter polyethylene bottle. A small plug of tulle was fitted into the neck of the funnel to keep any litter from entering the bottle. The whole assembly was enclosed vertically in a PCV drainage pipe, dug firmly into the ground.

Once a week (always the same day) the volume of water stored in each collecting bottle was first recorded by a polyethylene measuring cylinder and then it was converted in mm of rain taking into account the collecting area of the funnel. The mean value of the ten collectors was considered as the throughfall value of the plot.

2.4 Stemflow measurement

Stemflow was measured on five trees located within the subplot of throughfall measurement (2 stems of Quercus ilex, 2 of Arbutus unedo and 1 of Phillyrea latifolia). The selection of these trees was a compromise among mean basal area of each species at the height of 0.3 m above the ground surface, the number of stems/ha, the basal area in m2/ha and the sufficient dimensions of their trunk to fix and hold the equipment for stemflow measurement.

In each of the five trees a polyethylene tube 12 mm of internal diameter was split into half and wound firmly one spiral around the stem. Stemflow was collected into 75 to 200 liters polyethylene containers. Measurements were made on a weekly basis and always the same day with the throughfall measurements. Total stemflow was converted to water depth by multiplying the weekly collected volume of water with the ratio of total subplot basal area over the basal area of the five stems employed and dividing the product by the subplot area (858 m2). No attempt was made in this study to estimate stemflow separately from each tree species because they all together constitute the maquis vegetation which is investigated in this work.

3 Results

Based on the weekly-collected water samples, annual values of gross rainfall, throughfall and stemflow were calculated. The annual values of gross rainfall, throughfall, stemflow and interception losses from January 1996 to December 2002, are summarized in Table 2. During this period gross rainfall was measured for 225 weeks and throughfall and stemflow for 208 and 143 weeks respectively.

The seven years study period was actually wetter than the 30 year (1973-2003) average conditions of the area, as the mean gross rainfall of it was 1,134. 5 mm. This value was higher than the 31 years average value of the area by 133.5 mm (13.3%). It ranged from 747.7 to 1.457.5 mm and the coefficient of variation was 20.6%. The seven years included one very dry (2000) and one very wet (1996) year.

The mean values of throughfall, stemflow and interception losses were 61.2%, 6.8% and 32% of gross rainfall respectively and ranged from 56.7% to 66.1%, 6.1%-7.4% and 27.8%-36.5%. The coefficients of variation calculated from Table 2 were 21.1%, 32.9%, and 15.8% respectively. The maximum and minimum percentages of these hydrological components did not coincide with the corresponding values of gross rainfall. This “irregularity” could be attributed mainly to different characteristics of rainfall events during the study period. For example, the maximum value of throughfall (66.1%) was generated from 1.264 mm of annual rainfall depth (year 2002) and not from 1.457,6 mm (year 1996). Similarly, the minimum value of throughfall (56.7%) resulted from 930 mm (year 2001) and not from 747.7 mm (year 2002), as it would be expected.

4 Discussion

The mean seven years values of throughfall, stemflow and interception losses of our study are also presented in Table 3 for comparison and discussion with those of other studies carried out in the Mediterranean region. From this Table it is clear that the references to this vegetation type are limited in Mediterranean region, because a number of other studies in this region refer only to pure coniferous stands (Rapp and Ibrahim, 1978; Loustau et al., 1992; Viville et al., 1993) or to deciduous broadleaved species (Giacomin and Trucchi, 1992). The reasons for the small number of studies carried out on maquis vegetation may be the difficulties of hydrological measurements due to its morphological characteristics.

Two of the studies of Table 3 refer to mixed maquis stands (No 1,2), three to pure holm oak stands (No 3,4,5), one (No 6) to open grown shrubs and one (No 7) to chaparral vegetation of southern California. Among these experiments and taken into account that some pieces of information were not available to fill completely the mentioned Table, there are definitely some differences with regard to tree and shrub species of the experimental plots, their density, the duration of the measurements, the topography and the amount of gross rainfall. These differences were expected because this is the "nature" of rainfall and the maquis vegetation grown in the Mediterranean region during the last decades.

More analytically, the data of Table 3 are compared and discussed separately as throughfall, stemflow and interception losses.

Regarding throughfall, Table 3 shows that the mean seven years throughfall value (61.2%) of the present study is out of the range (66.0% to 76.5%) of similar studies carried out in the study area. More specifically, this difference is 4.8% smaller than the low range and could be attributed to the higher canopy density of the maquis vegetation in the present study. This is supported by the larger number of stems (8,020/ha) and the higher basal area (41.4 m^2/ha).

Concerning the tree and shrub species of the six (1-6) experimental plots, it could be argued that plots 1 and 2 are practically more similar to the species of the study in Greece. However, despite this similarity, their throughfall values (74.8% and 76.5%) are among the largest and the corresponding gross rainfall among the smallest (570 and 650 mm, respectively). This could be attributed probably to high intensities of the rain events or to small density of the tree's canopy.

With regard to throughfall values of plots 3, 4 and 5, they ranged from 66% to 75.5%, despite the fact they were all covered by the same tree species (holm oak). Plot 3 (66%) is closer to the Greek plot. At this point, it is also emphasized that the throughfall value of experiment 6 was similar to the previous ones despite the fact that the shrubs studied, were open grown. The good agreement of this value could be attributed to large dimensions of the studied shrub, as its height and canopy diameter can reach 4 and 6 m, respectively (Domingo et al., 1998).

Finally, the throughfall value of the chaparral vegetation in southern California (81%) is 20% higher than the corresponding value of our study and 4.5% to 15% higher than the values of the western Mediterranean region. This difference could probably be attributed to different rainfall and vegetative characteristics in southern California from those in the Mediterranean region.

From the data comparison, it is evident that the annual amount of throughfall of the maquis vegetation in the Mediterranean region ranges roughly from 60% to 75% of the corresponding gross rainfall. This is a large percentage and so an important component of the water balance of an area. Furthermore, the forest canopy moderates the intensities of throughfall in comparison with those of gross rainfall during the storm period (Lee, 1980). More specifically, the canopy causes more uniform intensities of throughfall by reducing the peaks. This is of great importance for the infiltration of water and so the protection of soil from erosion in the Mediterranean region where rain mostly falls in the form of heavy storms.

Regarding stemflow, the mean seven year value of stemflow of the present study (6.8% of gross rainfall) is within the ranges (2.7% to 14.2%) of the values of other studies carried out in the western Mediterranean region (Table 3). However, further consideration reveals that the low and high values of this range may have been due to specific characteristics of the studied trees or of the rain events. In fact, the low value (2.7%) of the experiment 4 may be attributed to the rough bark of holm oaks as they were of a re-sprout origin after coppicing during the decades 1950 and 1960. So the age of them ranged from 35 to 45 years (Rodrigo et al., 2003). On the other hand, the high value of experiment 1 could be attributed to heavy rain events.

Without these "outliers", stemflow of maquis vegetation in the western Mediterranean region would range from 5.3% to 8.5% of gross rainfall and the value of the present study is much closer to this range. The stemflow value of the chaparral of southern California also lies in this range despite the fact that their throughfall value was much higher than the values of the Mediterranean region.

Considering the previous stemflow values and with some reservations due to the limited number of such studies carried out on maquis vegetation of the Mediterranean regions, it could be argued that this is an appreciable hydrologic component for these areas which receive a relatively small amount of annual rainfall. The mentioned stemflow values of maquis take the second order after that of beech in a ranked list of broadleaved deciduous and coniferous species published by Lee (1980). Furthermore, the quick infiltration and deep percolation of a large quantity of stemflow into the soil at the primary rooting zone at the base of the trees, reduces losses by evaporation and so increases the availability of water to streamflow and to the plants in dry Mediterranean regions.

Concerning the interception losses, the values of the experiments 0 to 7 of Table 3 were calculated from the difference of the sum of throughfall and stemflow from gross rainfall. With regard to the experiment 3, stemflow was not estimated at all and so its interception losses of 34% are overestimated by the percentage of stemflow. A reasonable value of this percentage could be 4% if the stemflow values of holm oaks of experiments 4 and 5 would be considered. With this compromise, the interception losses of experiments 1 to 7 range from 11 to 30% of gross rainfall and the generally wide range of them could be mainly the result of different degrees of human impact to this type of vegetation. The 32% value of this component estimated for the eastern Mediterranean region was higher than the upper limit by 2%. This high value could be attributed to the dense canopy of the vegetation.

The above range of interception losses of the Mediterranean maquis almost coincide with that of the European broadleaved deciduous species (10-30%) (Institute of Hydrology 1998) despite the fact that they have a leafless period. This “irregularity” may show different degrees of human activities on the Mediterranean maquis.

It is also emphasized that the high percentage of interception losses by maquis and the limited availability of water resources in eastern Greece and in other Mediterranean countries (Pinol et al., 1991; Vouzaras, 1999), bring up the crucial issue of the need for increase of streamflow in watersheds covered by maquis by the appropriate manipulation of vegetation. Such activities are however very risky for the disturbance of the beneficial relationships between rainfall and maquis in the dry Mediterranean regions and should be decided with consideration.

5 Conclusions

This study showed that the seven years mean values of throughfall, stemflow and interception losses of a maquis stand in southern – western Greece were 61.2%, 6.8% and 32% respectively of the corresponding mean annual rainfall. Additionally, comparison and discussion of these values with others found in western Mediterranean region, showed that the throughfall and stemflow values of this type of vegetation on the wider Mediterranean area, ranged from 60% to 75% and from 5.5% to 8.5% respectively, of the annual gross rainfall. Especially the stemflow values of maquis were the largest, after beech, among a number of selected broadleaved and coniferous tree species, reported in literature. The range of interception losses ranged from 11% to 32% of gross rainfall. This wide range can be attributed to different degrees of canopy density of this vegetation type in the Mediterranean region.

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Table 1. Characteristics of the tree species

Serial number	Tree species	No of stems per ha *	Percentage of stems	Basal area / ha	
				m^2	%
1	*Phillyrea latifolia*	3,803	47.4	10.3	24.9
2	*Arbutus unedo*	3,447	43.0	21.6	52.2
3	*Quercus ilex*	343	4.3	8.3	20.0
4	*Erica arborea*	367	4.6	0.6	1.5
5	Other species	60	0.7	0.6	1.4
	Total	8,020	100.0	41.4	100.0

- $D_{0.3m} \geq 2.5$ cm: Only stems having a diameter (D) larger than 2.5 cm at the height of 0.3 m were measured

Table 2. Partitioning of annual gross rainfall into throughfall, stemflow and interception losses

Year	Number of weeks with rainfall	Total gross rainfall (mm)	Throughfall		Stemflow		Interception losses	
			mm	%	mm	%	mm	**%**
1996	33	1,457.5	928.3	63.7	108.5	7.4	420.7	28.9
1997	28	1,156.0	723.2	62.6	83.0	7.2	349.8	30.3
1998	32	1,132.2	689.7	60.9	79.0	7.0	363.5	32.1
1999	34	1,253.5	728.8	58.1	82.8	6.6	441.9	35.3
2000	31	747.7	449.3	60.1	48.3	6.5	250.1	33.4
2001	29	930.6	527.4	56.7	63.7	6.9	339.4	36.5
2002	38	1,264.0	835.4	66.1	76.6	6.1	352.0	27.8
Mean values	32 (Σ=225)	1,134.5	697.4	61.2	77.4	6.8	359.6	**32.0**
Std Dev.		233.4	147.1	3.2	25.5	0.5	56.8	**3.2**

Table 3. Comparison of throughfall (T), stemflow (S) and interception losses (I) of reference 0 (eastern Mediterannean) with those selected from western Mediterranean region and southern California (1-7)

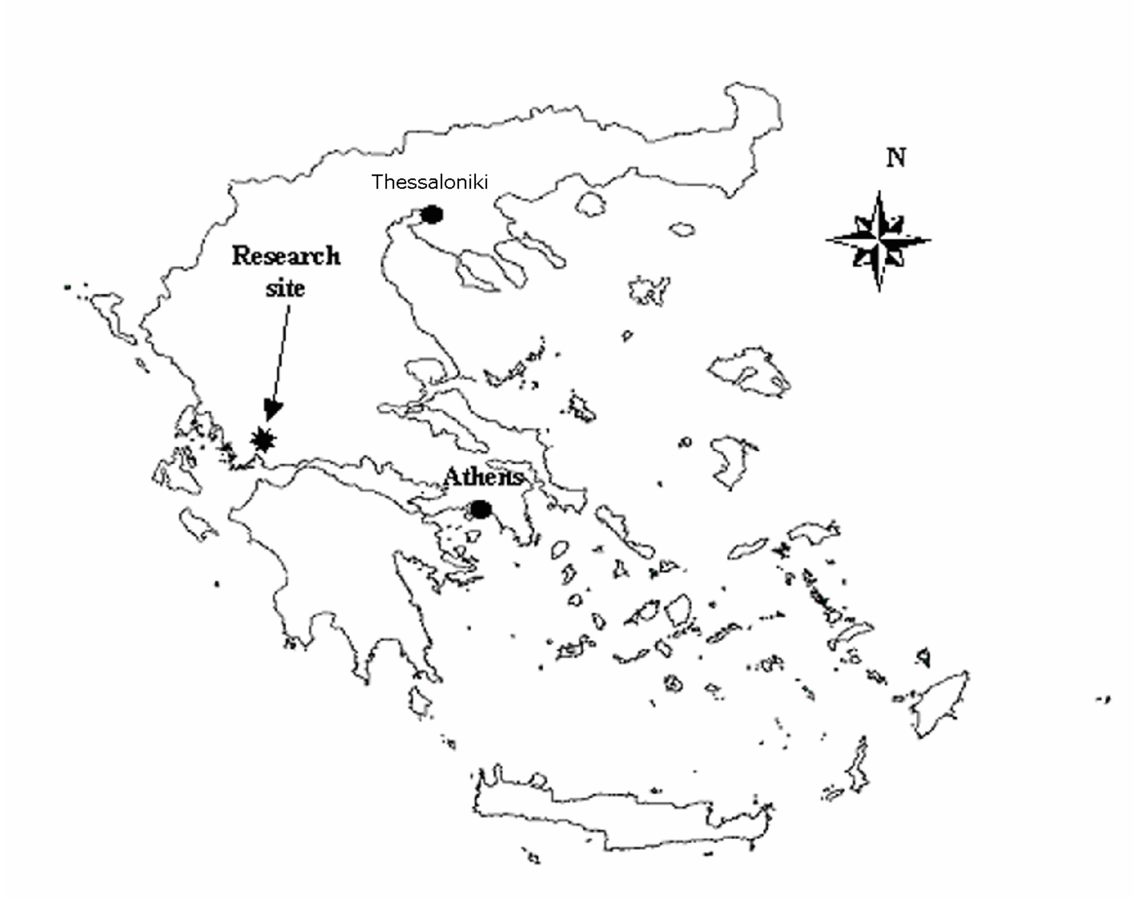
Experiment no.	Reference	Country	Location: Longitude Latitude	Altitude (m)	Main plant species	Stand density (trees/ha)	Basal area (m2/ha)	Study period (months)	Gross rainfall (mm)	T (%)	S (%)	I (%)
0	Baloutsos and Bourletsikas 2006	Greece	SW Greece 38^0 51' N 21^0 18' E	360	Phillyrea latifolia Arbutus unedo Quercus ilex Erica arburea	8,020	41.4	84	1,135	61.2	6.8	32
1	Bellot and Escarre 1991	Spain	SE Spain	680 to 1,007	Quercus ilex Arbutus unedo Phillyrea latifolia	4,576	38.45	36	570	74.8	14.2	11
2	Domingo et al., 1994	Spain	S. Spain	1,560 to 1,740	Pinus pinaster Pinus nigra Adenocaprus sp. Cistus laurifolius	–	–	12	650	76.5	8.5	15.0
3	Roda et al., 1990	Spain	410 46' N 020 21' E	731	Querqus ilex	2,010	26.6	24.5	857	66	_	34 – S
4 *	1. Rodrigo et al., 2003	Spain	Site 1 : 410 46' N 020 21' E	731	Querqus ilex	2,127	26.5	17 (only Gross+T)	1,275	75.5	2.7	21.8
5 *	2. Avila and Rodrigo, 2004	Spain	Site 2 : 410 43' N 020 23' E	535	Querqus ilex	1,753	22.3	12 (only S)	1,048	72.1	5.3	22.6
6	Domingo et al., 1998	Spain	370 08' N 020 22' W	630	Retana spherocarpa	Open grown shrub		5.5	85.3 **	72	7	21
7	Hamilton and Rowe 1949	South California	San Dimas area		Quercus dumosa Ceanothus sp. Cercocarpus beruloides	16,000 (Diameter 1.3-8.9 cm)	Crown density 75%	36	953	81	8	11

* Both authors used the hydrological components of Sites 1 and 2.

** Total rainfall of seven events.

Figure Captions

Figure 1. Location of the research site in Greece.



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