J. Agr. Sci. Tech. (2013) Vol. 15: 175-188

Seasonal Variability of Rainfall Interception and Canopy Storage Capacity Measured under Individual Oak (*Quercus brantii*) Trees in Western Iran

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ABSTRACT

While the hydrological balance of forest ecosystems has often been studied, quantitative studies on the seasonal variability of rainfall Interception (*I*) and Canopy Storage Capacity (*S*) by individual trees are less frequently reported. Hence, the effects of the seasonal variation in *I* and *S* by individual Persian oak trees (*Quercus brantii* var. *Persica*) in the Zagros forests of Iran were studied over a 1-year period. Annually, *I* accounted for 84.9 mm (20%) of Gross Rainfall (*GR*) that significantly differed between the in leaf (47.4 mm or 30% of GR) *vs.* leafless (37.7 mm or 14% of GR) periods. Negative logarithmic correlations existed between *I:GR* and *GR* both for in leaf (r^2= 0.808) and leafless (r^2= 0.709) periods. An indirect method, outlined by Pereira *et al.* (2009), estimated *S* to be 1.56 mm in the in Leaf Period (*LP*) and decreased considerably to 0.56 mm in the Leafless Period (*LLP*). The results indicate that while *I* decreased during the *LLP*, it still exerts considerable influence on the hydrology of forests. Hence, measurement of *I* in both the *LP* and *LLP* is essential when assessing the water balance on the catchment scale.

Keywords: In leaf period, Leafless period, Pereira method, Rainfall interception.

INTRODUCTION

In hydrological research, it is critical to understand the mechanisms that control canopy rainfall Interception (*I*) when characterizing the moisture distribution, soil erosion, and concentration as well as distribution of pollutants (Clements 1971; Monokaram 1979; Sanders 1986). In this paper it is assumed that, precipitation entering the top of a forest canopy (Gross Rainfall (*GR*)) is partitioned into Throughfall (*TF*), Stemflow (*SF*) and *I*. Net Rainfall (*NR*) reaches the forest floor *via TF* and *SF* (Manfroi *et al.,* 2004; André *et al.,* 2008). *TF* is the portion of rainfall that reaches the forest floor directly, or through canopy drip following temporary storage in the forest canopy (Wullaert *et al.,* 2009). *SF* is the rainfall that flows to the ground via trunks or stems. The amount of rainfall that remains on the vegetation and evaporated after or during a rainfall is considered as *I*. *I* is estimated as the difference between *GR* and *TF* plus *SF* (Teklehaimanot and Jarvis, 1991; Bouten *et al.,* 1996; Crockford and Richardson, 2000; Staelens *et al.,* 2008). The size of *I* depends on the annual rainfall, such meteorological factors as wind speed, vapor pressure deficits, etc., as well as canopy structure (Rutter *et al.,* 1971; Crockford and Richardson, 1990).

I has been thoroughly studied in closed and in sparse forests, (Rutter, 1975; Ward and Robinson, 2000; David *et al.,* 2005).

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[DOR: 20.1001.1.16807073.2013.15.1.6.3]

However, not much is known regarding *I* from open woodlands, savannah type ecosystems, isolated trees and forest edges (David *et al.,* 2006). An isolated tree canopy may alter the spatial distribution of soil moisture beneath the canopy *via* changes in *TF*, *SF*, and *I* (Joffre and Rambal, 1988; Vetaas, 1992). Haworth and McPherson (1995) demonstrated that *TF* flowing through individual *Quercus emoryi* trees was influenced by tree structure as well by the quantity of rainfall size for rainfall event less than 30 mm. David *et al.* (2006), reported an *I* of 28% of *GR* for an isolated evergreen oak tree (*Quercus ilex*) growing in a Mediterranean climate.

Canopy Storage Capacity (*S*) is an important and useful hydro-meteorological variable (Hancock and Crowther 1979). In this paper *S* is defined as the water remaining on the canopy just after rainfall ceases and when water loss by evaporation is negligible (Gash *et al.,* 1995). Characteristics of the intercepting surface, rainfall and climatic factors influence the size of *S* (Calder *et al.,* 1996; Hörmann *et al.,* 1996; Liu, 1998). The tree phenology alters the surface area of the forest canopy, thereby affecting *S* and *I* (Pypker *et al.,* 2005). For example, rainfall partitioning in deciduous forests is more affected by the time of year, relative to evergreen forests (Augusto *et al.,* 2002), because periods of growth and dormancy will affect both *S* and *I* in deciduous forests (Pypker *et al.,* 2011). During the leaf on period, *TF* and *SF* are generally lower than when the tree is leafless, i.e. dormant period (Levia and Frost, 2003).

Zagros forests cover a vast area of the Zagros mountain ranges stretching from Piranshahr (Western Azerbaijan Province) in northwestern Iran, to the vicinity of Firooz-Abad (Fars Province), occupying an average length and width of 1,300 and 200 km, respectively. The semi-arid Zagros forests cover 5 million hectares, contain 40% of Iran's forests and are mostly dominated by sparse stands of Persian oak (*Quercus brantii* var. *Persica*), i.e. 3.5 million hectares out of 5 million (Sagheb-Talebi *et al.,* 2004). Average annual temperature in the Zagros forests ranges between 9 and 25˚C depending on the latitude and altitude. Seventy percent of the annual 400-800 mm of precipitation falls in winter. *I* and *S* likely constitute major components of the surface water balance in the watersheds. The main goal of this research was to determine the *I* and *S* of individual *Q.brantii* trees.

MATERIALS AND METHODS

Site Description

The study was conducted in the Zagros forests in the western Iranian state of Ilam (46˚24'E, 33˚37'N, and an elevation of 1,383 m asl) (Figure 1). The study site consists of five sparse and scattered (a tree approximately 30-40 m away from next one) *Q. brantii* trees, originated from seedlings, with average height and diameter of 9.1 m and 66 cm, respectively, and with an understory that is currently exploited for agroforestry activities. Typical tree density in the area is approximately 50 trees per hectare, including coppiced ones.

Ilam Meteorological Station (46˚26'E, 33˚38'N, 1363 m asl) is located 500 m from the study site. Records from this synoptic station indicate that long-term (1986-2009) average annual rainfall is 587.2 mm (SD: ±152.5 mm) and that January is the most rainy month (111.5 mm; SD: ±53.5 mm) while August the driest (0.13 mm; SD: ±0.28 mm). The dry period begins in May ending in October. The wet period extends from November to April, and historically accounts for 92% of the total annual precipitation. The meteorological records also indicate annual open water evaporation to be 1,974 mm (SD: ±149.5 mm) and mean annual air temperature 16.9˚C (SD: ±0.77˚C), ranging from 4.5 ˚C (SD: ±1.97˚C) in January to 29.3˚C (SD: ±1.12˚C) in July.

[DOR: 20.1001.1.16807073.2013.15.1.6.3]

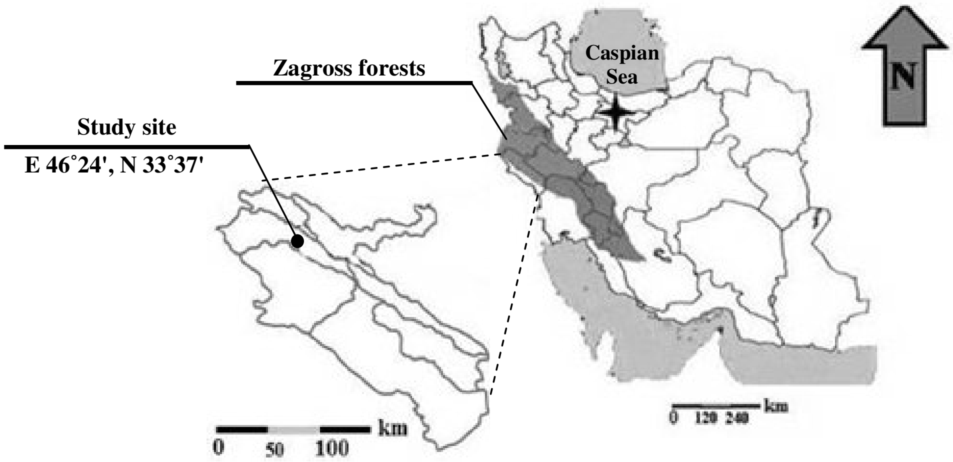

Figure 1. Study site location in the Zagros forests (dark circle) in the western Iranian state of Ilam.

Field Measurements

Five isolated and mature *Q.brantii* trees with similar morphologies (tree height, Diameter at Breast Height (DBH), and Crown Projected Area (CPA) were randomly selected among the trees of similar size located in a 2.5-ha tract (Table 1). The canopies of these trees did not overlap with those of the adjacent trees.

GR was collected through 6 cylindrical plastic rain gauges, 9 cm in diameter, placed in a neighboring open area that was 20 m from the oak trees (with no interaction of the crowns), measured manually using a graduated cylinder with an accuracy of 1 mL. Rainfall in each collector was quantified either 2 hours after rainfall ceased or at sunrise if the event occurred at night (Carlyle-Moses *et al.,* 2004). The average of the six rainfall collectors was used to estimate *GR*. Individual rainfall events were defined as those separated by a period of at least 4 hours of no rainfall. More than 4 hours, in this climate, is long enough to allow the canopy to dry out completely (Ahmadi *et al.,* 2011; Carlyle-Moses *et al.,* 2004).

TF was collected using the same type of manual gauges used for measuring *GR* during the study period. The experimental network consisted of 16 rain gauges for each tree, in total 80 gauges for the five study trees, randomly placed in a radial layout centered on the tree trunk, at eight geographical orientations (Figure 2).

Table 1. Height (m), Diameter at Breast Height (DBH, cm) and Crown Projected Area (CPA, m^2) of the five trees selected in the study site.

Tree	Height (m)	DBH (cm)	CPA (m^2)*
A	10	58	52.8
B	5.5	66	58.1
C	11	67	78.5
D	10.7	75	45.3
E	8.4	63	66.4
Mean	9.1	66	60.2

*CPA was calculated by assuming the tree canopy was a circle and the radius calculated by averaging the distance to the edge of the crown in the cardinal directions.

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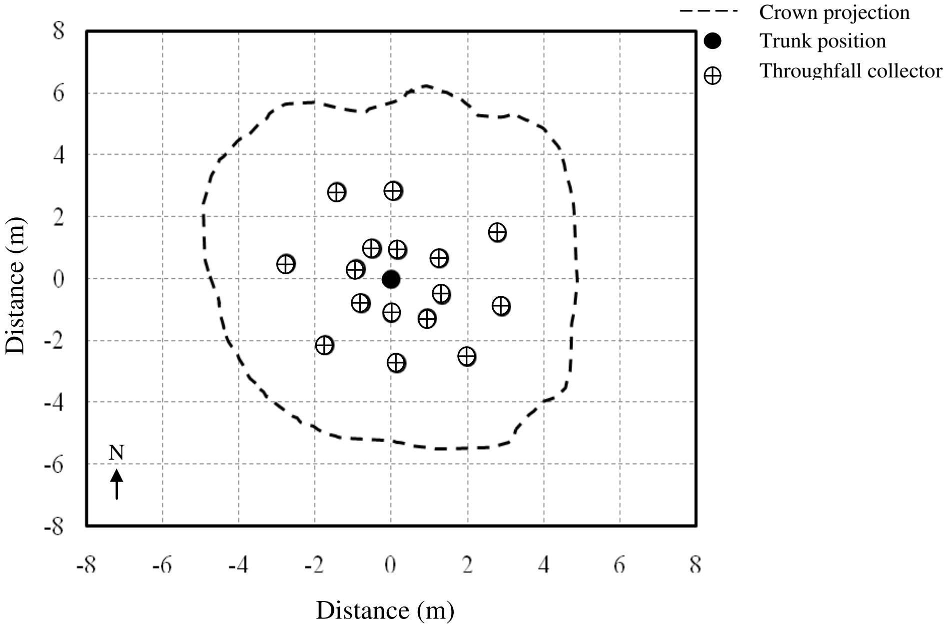

Figure 2. Location of the Throughfall (*TF*) rain gauges for tree C.

I was calculated as the difference between *GR* and *TF*. No attempt was made to measure *SF*. *SF* was assumed to be very small because such rough-barked species like *Q. brantii* typically have low *SF* values (Helvey and Patric, 1965; Geiger, 1965). A Duncan test was employed to compare the *I* for each individual tree.

Canopy Storage Capacity (*S*)

S is commonly estimated by the so-called Leyton method by fitting a regression line to data from rainfall events that saturate the canopy when evaporation rates are low (Leyton *et al.,* 1967). However, this method is somewhat subjective in the selection of the storms used to derive *S*. The correct selection of storms may be particularly critical under isolated trees (David *et al.,* 2006) where *TF* is highly varied in space (Lloyd *et al.,* 1988). Here, a method was employed to estimate *S* outlined by Pereira *et al.* (2009), that was built upon a previous work by Lloyd *et al.* (1988) and corresponding to the "*mean method*" referred to by Klaassen *et al.* (1998). The method proposed by Pereira *et al.* (2009) also accounts for evaporation during the canopy wetting phase (Pereira *et al.,* 2009). This procedure uses information from a larger number of rainfall events and is less sensitive to *TF* spatial variability (Pereira *et al.,* 2009). Based on this method, a linear relationship between *TF* and *GR* for rainfall events that are large enough to saturate the canopy was created (*TF*= *aGR*+*b*). Hence, *S* was calculated as:

$$S = -\frac{b}{\left(\left(\overline{E}/\overline{R}\right)-1\right)}\frac{\overline{E}}{\overline{R}}\frac{1}{\ln\left(1-\left(\overline{E}/\overline{R}\right)\right)} \quad (1)$$

where, $\overline{E}/\overline{R}$ is the ratio between evaporation rate and rainfall intensity and is estimated as one minus the slope of the aforementioned regression line (Leyton *et al.,* 1967; Klaassen *et al.,* 1998; Pypker *et al.,* 2005). The crown cover fraction was assumed to be 1 at the individual crown level, because the gaps in the crown are few and of small dimension (Pereira *et al.,* 2009). To ensure the complete saturation of the canopy, only rainfall events with GR≥ 3.1 mm in the in leaf period of the tree (*LP*) and GR≥ 1.6 mm in the leafless period (*LLP*) were considered.

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Data Analysis

Throughout the study, the rainfall events were initially divided into four canopy development stages: Leaf Burst Period (*LBP)* (March 23-April 20); Full-Leaf Period (*FLP*) (April 21-October 15); Leaf Senescence Period (*LSP*) (October 16-December 20); and Leafless Period (*LLP*) (December 21-March 22). The distinction was regularly made (at least weekly) by inspecting the phenology of the trees in study.

The last week of *LSP* and the first week of *LBP* were included into the *LLP* because very few leaves were present then. Few rainfall events occurred within all the above-mentioned periods excluding the *LLP*. Therefore, investigations were based on two periods of: *LP* (*LBP*, *LSP*, and *FLP*) and *LLP*.

RESULTS

Long-term Average and Observed Meteorology

From March 2010 to March 2011, cumulative *GR* totaled 474.2 mm, which is 19% lower than the long-term average of 587.2 mm. Annual distribution of precipitation during the study period mirrored the long-term average, with 86% of the rainfall occurring from November to April. The wettest and the driest months in the long-term records were January (111.5 mm) and August (0.1 mm), respectively (Figure 3). During the study period, the most rainy month was January (140.2 mm) and the driest months June, July and September (0 mm). Compared to the 23-year mean monthly precipitation record (1986-2009), the study period showed significant deviations from the climate average, especially in the autumn months. In October and November 2010, there was 1.9 mm of rainfall, nearly 98% lower than the long-term period of 112.4 mm.

Mean annual air temperature was 17.4˚C during the study period, slightly more than the long-term average temperature of 16.8˚C. The difference in air temperature occurred because of warmer than average temperatures from September to December. As with the long-term record, July was the warmest month (29.9˚C), and January the coldest month (4.6˚C).

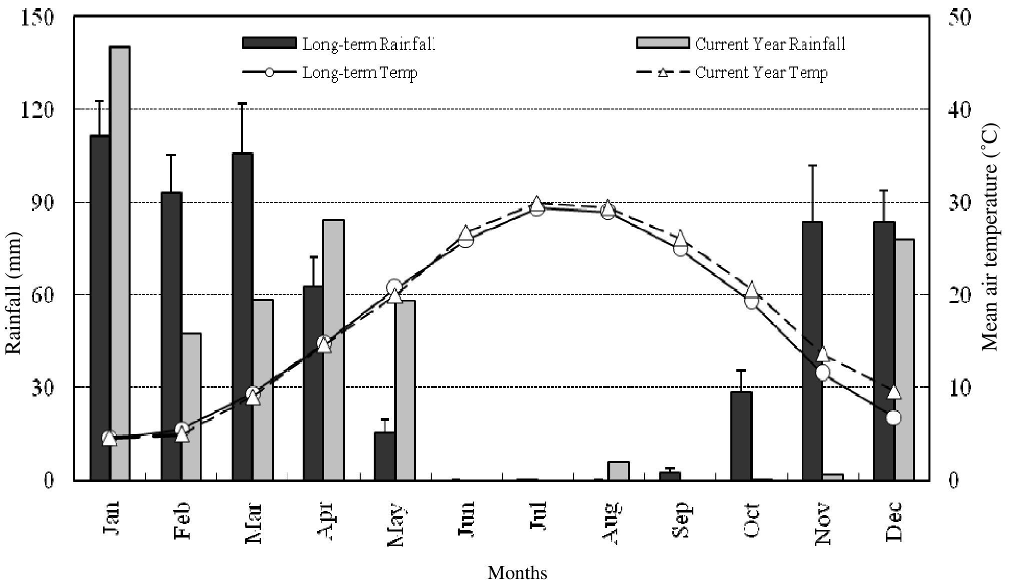

Figure 3. Monthly mean rainfall and air temperature for the study period (2010-2011) and the past 23 years (1986-2009), as recorded by a nearby synoptic meteorological station (approximately 500 m away). Error bars show the standard error (SE) of monthly rainfall for the long-term period.

Rainfall Partitioning

During the study period, 30 rainfall events were recorded, with 9 events during the *LP* (total = 157.3 mm) and 21 events during the *LLP* (total= 268.3 mm). Rainfall ranged from 3.2 to 57.3 mm during the *LP* and from 0.66 to 47.3 mm during the *LLP*. Furthermore, *GR* averaged (±standard error) 17.5 mm (±5.9) during the *LP* and 12.8 mm (±3) during the *LLP*.

Rainfall events were grouped into three classes (*GR*≤ 6 mm, 6 mm≤ *GR*≤ 17 mm and *GR*≥ 17 mm), both for *LP* and *LLP*, to allow for a better understanding of the relationship between *GR* and *TF* (Table 2). The mean *TF*: *GR* values in classes of the *LP* and *LLP* were 55.7%, 67.3%, 69.4% *vs.* 65.4%, 82.2% and 90.0%, respectively (Table 2).

Average cumulative *TF* (±SE) was recorded 109.9 mm (±3.6), or 70% of cumulative *GR*, *vs.* 230.8 mm (±3.7), or 86% of cumulative *GR,* during the *LP vs. LLP*, respectively. For individual rainfall events, *TF* averaged (±SE) 12.2 mm (±4.6) or 64.1% of *GR* in the *LP* and 11 mm (±2.7) *viz.* 75.6% of *GR* in the *LLP*. *TF* ranged from 50 to 78% and from 46 to 96% for *GR* events ranging from 3.2 to 57.3 mm *vs.* 0.8 to 24.9 mm in the *LP* and *LLP*, respectively.

Over the study period, *I* was 84.9 mm or 20% of cumulative *GR*. When distributed between the *LP* and *LLP*, *I* was 47.4 mm (SE: ±3.6 mm) and 37.5 mm (SE: ±1.8 mm), or 30% *vs.* 14% of total *GR*, respectively. The mean annual event based *I:GR* value was 27.8% (SE: 2.5%), with *I* being equal to 35.8% (SE: ±2.8%) during *LP vs.* 24.6% (SE: ±2.5%) during *LLP* (Table 3). *I:GR* ranged from 22% (SE: ±2.2%) of *GR* (57.3 mm) for larger rainfall events to 50% (SE: ±3.5%) of *GR* (3.2 mm) for smaller rainfall events during the *LP*. During the *LLP, I:GR* ranged from 4% (SE: ±0.6%) of *GR* (24.9 mm) to 54% (SE: ±6%) of *GR* (0.8 mm) for

Table 2. Cumulative Gross Rainfall (*GR*) depth, the percent of average relative Throughfall (*TF:GR*), Standard Deviation (SD), divided into 3 *GR* classes for rainfall events during in Leaf Period (*LP*) and Leafless Period (*LLP*).

	In Leaf Period (*LP*)				Leafless Period (*LLP*)			
GR class (mm)	Frequency	*GR* (mm)	*TF:GR*** (%)	SD (%)	Frequency	*GR* (mm)	*TF:GR* [b] (%)	SD (%)
< 6	3	13.1	55.7	6	11	26.4	65.4	10.4
6 - 17	3	36.1	67.3	1.4	4	52.1	82.2	8.8
> 17	3	108.1	69.4	7.5	6	189.8	90.0	7.2
Cumulative	9	157.3			21	268.3		
Average (±SD)		17.5*	64.1 (±7.4)			12.8 [a]	79.2 (± 12.6)	

[a] Event based average , [b] Event based for each class.

Table 3. Summary of the Duncan tests comparing the relative Interception loss (*I:GR*) for individual oak trees during the in Leaf Period (*LP*) and Leafless Period (*LLP*). There is no significant difference (P> 0.05) observed between trees denoted by same letter. n denotes the number of rainfall events and SE refers to the standard error.

Tree	$(I:GR)_{LP}$ (%)	SE_{LP} (%)	Sign $_{LP}$	$(I:GR)_{LLP}$ (%)	SE_{LLP} (%)	Sign $_{LLP}$
	(n= 9)		α= 0.05	(n=21)		α= 0.05
A	33	2.8	b	18	2.8	b
B	30	2.5	b	23	3.1	b
C	45	3.3	a	33	4.1	a
D	32	2.7	b	22	2.9	b
E	39	2.6	ab	27	3.5	ab
			0.006			0.031
Mean (±SE)	35.8 (±2.8)			24.6 (±2.5)		

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larger *vs.* smaller events, respectively. Moreover, for *LP* and *LLP* both, the relative *I* decreased as *GR* increased (Figure 4). Significant negative logarithmic relationships were found out between *I:GR* and *GR* both for *LP* (*I:GR*= -0.0759 Ln (*GR*)+0.545, r^2= 0.808) and *LLP* (*I:GR*= -0.0912 *Ln (GR)+0.411*, r^2=0.709). Duncan tests indicated that there were no significant differences between the measured parameters at the different individual oak trees, except for tree C in the *LP* ((*I:GR*) ±SE: (45%) ±3.3%) *vs. LLP* ((*I:GR*) ±SE: (33%) ±4.1%) (Table 3).

Canopy Storage Capacity (*S*)

The linear regressions established between *TF* and *GR* for all rainfall events sufficient to saturate the canopy (*GR*≥ 3.1 mm in the *LP* and *GR*≥ 1.6 mm in the *LLP*) are presented in Figure 5 for five individual oak trees. The intercept of the regression lines were employed in Equation (1) to obtain an estimate of *S*. Using the Pereira method, *S* averaged (±SD) 1.56 mm (±0.44 mm) during the *LP* and decreased to 0.56 mm (±0.22 mm) during the *LLP* (Table 4).

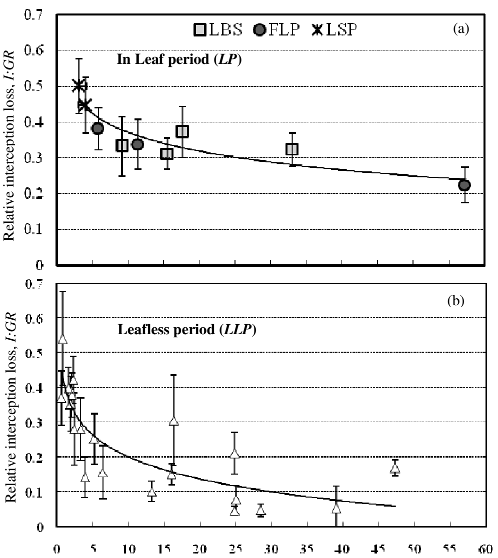

Figure 4. Regression analyses between relative interception loss (*I:GR*) and Gross Rainfall (*GR*) for individual oak trees in: (a) In Leaf Period (*LP*) and (b) Leafless Period (*LLP*). Data of *LP* were divided into Leaf Burst Period *(LBP*); Full-Leaf Period *(FLP)*, and Leaf Senescence Period *(LSP).* The regression equation for (a) and (b) are *I:GR= -0.0759LN (GR)+0.545* and *I:GR= -0.0912LN (GR)+0.411*, respectively. Error bars represent the standard deviations (SD).

DISCUSSION

Interception (I)

Annual and seasonal average values of *TF:GR* and *I:GR* measured in the present study are in agreement with the values reported by other researchers (Table 5). A review of the literature on rainfall partitioning for the various tree-based *vs.* stand–based studies indicates that the values for *TF:GR* and *I:GR* measured throughout the present study are comparable with those from other similar oak forests. For example, David *et al.* (2006), in a tree-based study on an evergreen oak (*Q. ilex*) tree in Portugal, estimated annual *TF:GR* and *I:GR* of 78% and 21.7% per unit of the crown-projected areas, respectively. Furthermore, Mateos and Schnable (2001), reported the portions of *TF* and *I* to be 73 and 26.8% of annual *GR*, respectively, in individual evergreen oak (*Q. rotundifolia*) trees in Spain. Xiao *et al.* (2000), reported mean annual *TF:GR* and *I:GR* of 58% and 27%, respectively, with an *SF* of 15% of *GR,* under an 8-year-old evergreen cork oak (*Q.suber*) tree in California. In Maryland, *I:GR* was equal to 5.8% in a mixed deciduous forest during the *LLP* (Klingaman *et al.,* 2007). All the tree-based research on oak trees reported in Table 5 occurred when foliage was still on the trees.

In the present study, relative *I:GR* is significantly higher in *LP* relative to *LLP*. These results are consistent with findings for other tree-based and stand-based research in deciduous forests (Dolman, 1987; Augusto *et al.,* 2002; Levia and Frost, 2003; Herbst *et al.,* 2008; Staelens *et al.,* 2008). For example, *I:GR* was 31% in the *LP* and 10% in the *LLP*, for an individual beech tree located in

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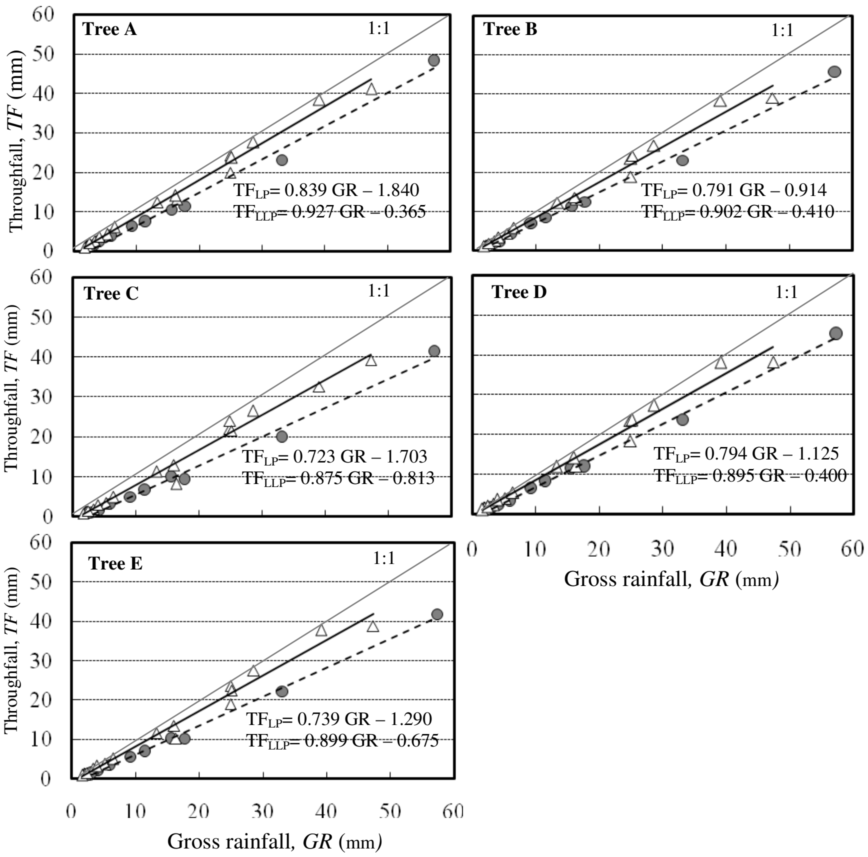

Figure 5. The relationship between Gross Rainfall (*GR*) and Throughfall (*TF*) for all rainfall events with *GR*≥ 3.1 mm in the in Leaf Period (*LP*) and *GR*≥ 1.6 mm in the Leafless Period (*LLP*) for individual oak trees. Canopy Storage Capacity (*S*) was derived from the intercept of the regression lines between these two variables. Triangles (Δ) and filled circles (●) denote rainfall events in the *LLP* and *LP*, respectively.

Belgium (Staelens *et al.,* 2008). Dolman (1987), in a study on an oak forest in the Netherlands, reported an *I:GR* of 30% and 20% in the *LP* and *LLP*, respectively. In a deciduous mixed oak-birch forest in the U.K, Herbst *et al.* (2008) reported an *I:GR* of 29 and 20% in the *LP* and *LLP*, respectively. Lastly, Neal *et al.* (1993), in a lowland beech plantation in southern England, also found that the lowest *I* occurred during winter, but the effect of foliation on *TF* could not be determined because water inputs from dew, frost, and fog condensation during the winter months complicated the results.

Therefore, it is difficult to draw general conclusions about *I* for particular forest types because of *I* typically depending on climatic factors (quantity, intensity, and duration of rainfall, air temperature, relative humidity, wind speeds and directions, rain angle, temporal distribution of rainfall events) (Jackson, 1975; Crockford and Richardson, 2000; Marin *et al.,* 2000; Xiao *et al.,* 2000; Huber and Iroumé, 2001; Iroumé and Huber, 2002; Link *et al.,* 2004), forest type, location and structure (crown size, leaf shape, branch angle, composition, stand age, basal area, stand density, flow path obstructions, bark type, canopy gaps, canopy storage capacity, Leaf Area Index (*LAI*), hydrophobicity (water repellency of leaf and wood) (Forgeard *et al.,* 1980; Crockford and Richardson, 2000; Xiao *et al.,* 2000; Iroumé and Huber 2002; Carlyle-Moses et al. 2004;

Table 4. Canopy Storage Capacity (*S*) as calculated by method of Pereira (2009) during the in Leaf Period (*LP*) and Leafless Period (*LLP*) for five selected oak trees. n denotes the number of events and SD the standard deviation.

		Tree						
	n	A	B	C	D	E	Mean	SD
S_{LP} (mm)	9	2.01	1.03	2.01	1.27	1.50	1.57	0.44
S_{LLP} (mm)	19	0.38	0.43	0.87	0.42	0.71	0.56	0.22

Table 5. Review of Canopy Storage Capacity (*S*) and measured values of rainfall being partition into Throughfall (*TF*) and Interception loss (*I*) from various research studies for different broad leaved forest types. *All the values for tree-based studies are expressed per unit crown projected area while stand based studies presented on a total area basis.

Tree species	Study type*	Study period	*TF*:*GR* (%)	*I*:*GR* (%)	*S* (mm)	location	Reference
Oak (*Quercus brantii*)	Tree-based	In leaf Leafless	70 86	30 14	1.4- 1.8 0.5-0.6	Iran	This study
Oak (*Q. ilex*)	Tree-based	Annual	-	23-30	1.16	Portugal	Pereira et *al.* (2009)
Evergreen oak (*Q. suber*)	Tree-based	Annual	58	27	2	California	Xiao *et al*. (2000)
Evergreen oak (*Q. ilex*)	Tree-based	Annual	78	21.7	0.26	Portugal	David *et al*. (2006)
Evergreen oak (*Q. emoryi*)	Tree-based	Annual	27-100	-	-	Arizona	Haworth and McPherson (1995)
Evergreen oak (*Q. rotundifolia*)	Tree-based	Annual	73	26.8	-	Spain	Mateos and Schnabel (2001)
Beech (*Fagus sylvatica*)	Tree-based	Leafed Leafless	59.8 79.4	31 10	1.1 0.4	Belgium	Staelens *et al.* (2008)
Olive	Tree-based	Annual	-	21.7	2.7	Spain	Gomez *et al.* (2001)
Eucalyptus melanophloia	Tree-based	Annual	88.4	11	2	Australia	Prebble and Stirk (1980)
Pear (*Pyrus calleryana*)	Tree-based	Annual	77	15	1	California	Xiao *et al*. (2000)
Mixed (Oak, hornbeam, ash, maple)	Stand-based	Annual	67-72	25-29	0.9	Slovenia	Sraj *et al.* (2008)
European beech (*Fagus sylvatica*)	Stand-based	Leafed Leafless	82-83 68-80	16 14	- -	Southern England	Neal *et al.* (1993)
Mixed (Oak, maple, hornbeam)	Stand-based	Annual	76.4	19.3	1	Canada	Carlyle- Moses and Price (1999)
Mixed (Oak, birch)	Stand-based	Leafed Leafless	69.8 76.6	29 20	1.2 0.6	U.K	Herbst *et al.* (2008)
Mixed (Beech, Poplar, Black oak, maple)	Stand-based	Leafless	-	5.8	1.48	Maryland	Klingaman *et al.* (2007)
Konara oak (*Q. serrata*)	Stand-based	Annual	72	18.6	0.62	Japan	Cantú Silva and Okumura (1996)
Oak	Stand-based	Leafed Leafless	57-77 80-87	30 20	0.8 0.3	Netherland	Dolman (1987)
Mixed (Oak, beech)	Stand-based	Leafed Leafless	- -	- -	2.3 1.5	France	Halldin *et al.* (1984)
Mixed (multi-species)	Stand-based	Leafed Leafless	76.3 80	17.6 14.3	1.26 0.97	Japan	Deguchi *et al.* (2006)

[DOR: 20.1001.1.16807073.2013.15.1.6.3]

Fleischbein et al. 2005; Deguchi et al. 2006; Staelens *et al.,* 2008; Muzylo *et al.,* 2009) and other factors during the study period. Hence, differences in rainfall partitioning reported by other researchers are presumably due to differences in the aforementioned factors.

As with past research (e.g. Staelens *et al.,* 2008), the logarithmic fit obtained between *GR* and *I:GR* (Figure 4) differed significantly between the *LP vs. LLP*. The difference between the two periods of the year (seasonal effect) is clearly illustrated when *TF* is expressed as a percentage of *GR*. During the *LP*, the *TF* fraction of *GR* increased from an average of 55.7% for ≤ 6 mm rain events, to over to 69.4% for events ≥ 17 mm (Table 2). The increase in *TF:GR* was found for *LLP* as well. *TF:GR* in the *LLP* was greater than in the *LP* for all the rainfall classes (Table 2). The present study confirms that the largest percentage of *I* for individual storms occurs during small rain events (Llorens, 1997; Price and Carlyle-Moses, 2003). This occurs because most of the rainfall is stored in the canopy during the small rainfall events. On the contrary, during large rainfall events, the canopy saturates and a considerable portion of the rainfall will drip through the canopy as *TF* (Gash, 1979; Sraj *et al.,* 2008; Staelens *et al.,* 2008). The remaining rainfall is either stored in the canopy or lost as evaporation during the rainfall event (Gash, 1979).

During the *LP*, 67% of the rainfall events were greater than 6 mm (large events), whilst for the *LLP*, the percentage of small events (52% for ≤ 6 mm rain events) and large events (48% for ≥ 6 mm rain events) were equal. Hence, the higher frequency of large events in the *LP* likely reduced *I*. *I:GR* varied widely when *GR* values were low and this was more evident for *LLP* than for *LP* (Figure 4). This suggests that in addition to tree phenology and size of *GR*, other climatic factors played a very important role in determining the size of *I*. For example past research demonstrates that evaporation rates during the storm can be similar between *LP* and *LLP* (Staelens *et al.,* 2011). This may occur because changes in canopy structure result in a lower aerodynamic resistance to latent heat exchange during the *LLP* (e.g. Krämer and Hölscher, 2009). Hence, a portion of the differences between *LP* and *LLP* periods may result from the leaves, increasing *S* and a portion resulting from differences in micrometeorological variables.

Canopy Storage Capacity (*S*)

The Pereira method, provided estimates of *S*, ranging from 1.56 mm in the *LP* to 0.56 mm in the *LLP* (Table 4). Consequently, the lower *S* allowed for more *TF* in the *LLP* than in the *LP* for individual oak trees (Figure 5). A summary of 18 studies of *I* in broad-leaved forests that report estimates of *S* is presented in Table 5. The results from the current study are in agreement with those from other research in other broad-leaved forests. For example, Deguchi *et al.* (2006) reported that *S* for broad-leaved deciduous forests was generally less than 1.8 mm. Xiao *et al.* (2000) estimated *S* to be 2 mm using an indirect, regression based, method for an isolated evergreen oak (*Q.suber*) tree in California. Staelens *et al.* (2008) determined *S* to be 1.1 and 0.4 mm in the *LP vs. LLP*, respectively, for an individual deciduous beech tree.

In our study, *S* was greater in the *LP* than in the *LLP*. The magnitude of the seasonal change in *S* is difficult to quantify because *S* varies with changes in rainfall intensity, wind speed, the nature of the intercepting surface (type of species, leaf shape, dimension and orientation) and such other factors as water viscosity (Leonard, 1967; Jackson, 1975; Calder *et al.,* 1996; Hörmann *et al.,* 1996; Liu, 1998; Llorens and Gallart, 2000; Fleischbein *et al.,* 2005).

CONCLUSIONS

The present study is indicative of the fact that *TF* and *I* are of major importance, accounting for 80% and 20% of annual gross precipitation, respectively. In deciduous forests, tree phenology alters the surface area

[DOR: 20.1001.1.16807073.2013.15.1.6.3]

of the forest canopy, thus influencing *S* and *I*. On an event basis, *TF* is mainly controlled by the amount of rainfall. *S* for individual oak trees was estimated to range from 1.56 mm in the *LP* to 0.56 mm for the *LLP*. This study is the first to document rainfall partitioning in the individual *Q.brantii* trees in the Zagros forests of western Iran. The effect of other climatic conditions, as well as vegetative factors in canopy hydrology, should be considered in the future research.

In this region, *I* must be considered when constructing a watershed scale water balance because *I* was considerable and *Q.brantii* covers a vast area of broad-leaved forests of the Zagros forests in Iran. Furthermore, *I* should be more prominently considered in the future hydrological studies in the Zagros forests in western Iran.

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تغییرات فصلی باران‌ربایی و ظرفیت نگهداری تاج پوشش تک درختان بلوط (*Quercus brantii*) غرب ایران

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چکیده

اگرچه تراز هیدرولوژیکی اکوسیستم‌های جنگل اغلب مورد مطالعه قرار گرفته است، مطالعات کمی تغییرات فصلی باران‌ربایی و ظرفیت ذخیره‌ی تاج پوشش تک درختان، بسیار کمتر گزارش شده است. بنابراین هدف از مطالعه حاضر، بررسی اثر تغییرات فصلی بر باران‌ربایی و ظرفیت ذخیره‌ی تاج پوشش تک درختان بلوط ایرانی (*Quercus brantii* var. *Persica*) در جنگل‌های زاگرس ایران در طی یک دوره‌ی یکساله بود. به صورت سالانه، باران ربایی ۸۴/۹ میلی‌متر(۲۰ درصد) از بارندگی محاسبه شد که به صورت معنی‌داری بین دوره‌ی برگدار (۴۷/۴ میلی‌متر یا ۳۰ درصد از بارندگی) و دوره‌ی بی‌برگی (۳۷/۷ میلی‌متر یا ۱۴ درصد از بارندگی) سال، متفاوت بود. برای هر دو دوره‌ی برگدار (r^2= 0.808) و بی‌برگی (r^2= 0.709) بین نسبت باران ربایی به بارندگی و بارندگی، همبستگی منفی و لگاریتمی مشاهده شد. ظرفیت ذخیره‌ی تاج پوشش با استفاده از روشی جدید توسط Pereira و همکاران (۲۰۰۹) در فصل برگدار ۱/۵۶ میلی‌متر تخمین زده شد که این مقدار در فصل بی‌برگی ۰/۵۶ میلی‌متر محاسبه گردید و به صورت قابل توجهی نسبت به فصل برگدار کاهش نشان داد. نتایج نشان می‌دهد که اگرچه باران ربایی در طی دوره‌ی بی-برگی کاهش یافته است، باز هم اثر قابل توجهی را بر روی هیدرولوژی جنگل‌ها می‌تواند داشته باشد. بنابراین اندازه‌گیری باران ربایی در هر دو دوره‌ی برگدار و بی‌برگی در هنگام ارزیابی تراز آب حوضه‌ی آبخیز ضروری است.

[DOR: 20.1001.1.16807073.2013.15.1.6.3]